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PREFACE

Dear participants,

On behalf of the Organizing Committee, we would like to welcome each of you to the 13th Annual Industrial Simulation Conference (ISC 2015), hosted by the Universitat Politècnica de Valencia, in Valencia (Spain) from June 1st -3rd 2015.

During two and a half days, we offer a very high-level scientific program, spanning a wide array of topics in simulation, from theory to applications, over a large spectrum of industrial and service domains. Three keynote speakers, from academia and industry, will be sharing their professional expertise.

To encourage the exchange of techniques and ideas, which is the basic premise at the heart of the Industrial Simulation Conference, the timetable is organized to allow for ample opportunity to meet and discuss. We are convinced that this will permit you to elaborate on some issues and go home with a collection of bright new ideas for your future research.

We are indebted to a number of people without the support of whom, the conference would not be possible. First of all, thanks go to all reviewers for critically evaluating the papers and keeping an eye on the scientific quality of the conference.

Moreover, we are grateful to the keynote and tutorial speakers for accepting our invitation and for presenting their latest contemplations on significant simulation themes.

Furthermore, we would like to express our thanks to Mr. Philippe Geril, Secretary General of EUROSIS, who has taken the responsibility for most of the organizational matters. The Industrial Simulation Conference is only possible thanks to his hard work and never-ending enthusiasm.

Finally, our warm thanks go to all of you for submitting your research results, attending sessions and actively participating and discussing. We wish you all a stimulating and productive meeting.

General Conference Chair
Carlos E.Palau

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SCIENTIFIC PROGRAMME

KNOWLEDGE MANAGEMENT SIMULATION

Value Innovation: Opposite of Porter's 'Stuck in the Middle' characteristic

An Agent Based Modeling

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KEYWORDS
Firm positioning, NK Modeling, Value Innovation, Agent Based Modeling

ABSTRACT

Porter's strategic positioning school has its' root in neoclassical economics and industrial organization. *Differentiation* and *Cost Leadership* are *general strategies* of this school which -as Porter claims- one firm could not select both of them simultaneously. But there are many critics and also solutions to simultaneously pursuit these strategies which one of them is value innovation. There are some formal methods to realize or qualify the Porter's claim, but there isn't any model to realize the claim about value innovation. This paper proposes a new agent based model to show the effect of value innovation on firms' market share.

INTRODUCTION

There is no doubt that the dominant discourse on the strategic management –at least in last two decades- is Porter's strategic positioning. Porter (1980) argues that this school is based on neoclassical economics and industrial organization view. By the spread of criticisms on neoclassical economics, and the evolution of innovation economy, gradually appeared new insights and approaches

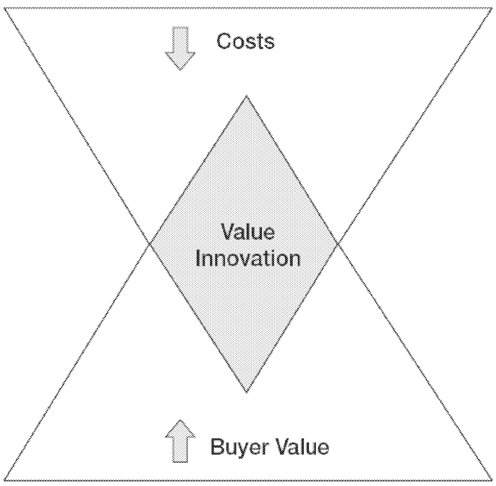

Figure 1. The Simultaneous Pursuit of Differentiation and Low Cost (adopted from Kim & Mauborgne, 2005)

in strategic management. Some these approaches are Business Ecosystem (Moor, 1996), Blue Ocean Strategy (Kim & Mauborgne, 2005) and Innovation Strategy (Davenport & et al. 2006). The main idea behind these new strategies is simultaneously pursuing the cost leadership and differentiation strategies *-value innovation (Fig.1)-* which is against the porter's view on the existence of tradeoff between these strategies and the *'Stuck in the middle'* characteristic. (Porter 1980, 1996)
Fig. 2 shows the *'Stuck in the middle'* characteristic. In the figure, a firm that pursues a low-cost strategy gets a high market share (M1). With this high market share, the low cost leader is likely to have a high level of profitability

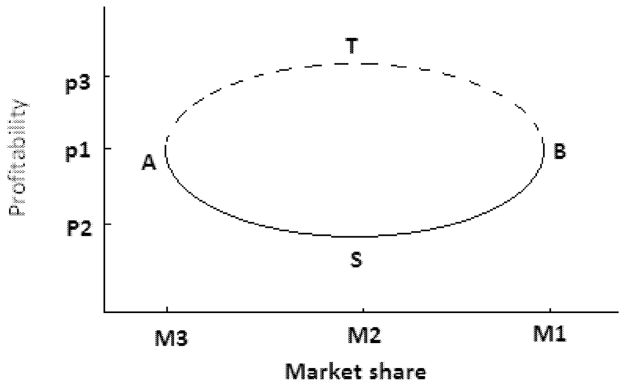

Figure 2. Relation between general strategies (adopted from Afuah, 2004)

(P1). If a firm pursues a differentiation strategy, it has a smaller market share (M3). However, it can still have a high level of profitability (P1). So according to Porter, firms that try to be both low-cost and differentiation providers may be stuck in the middle (point S) with low market share (M2) and low profitability (P2). (Afuah, 2004)

Kim & Mauborgne (2005) argue that firms which follow *value innovation*, instead of focusing on beating the competition, focus on making the competition irrelevant by creating a leap in value for buyers and themselves and thereby opening up new and uncontested market space.
Value innovation places equal emphasis on value and innovation. Also Davenport & et al (2006) argue that, the shift to new value innovation, i.e. innovative customer value propositions (products and services), and/or how they are innovatively newly created and provided, breaks

decisively with the old industrial economy, in which information scarcity encouraged value capture through knowledge hoarding and physical assets. Successful companies today are those that transform purposefully-shared and networked knowledge into new value-creating innovations, and aggressively use this to capture new opportunities and additional profit.

On the other hand there are a few studies on modeling and simulation of strategic positioning and doing experiments on the views of Porter and innovation strategy scientists. Ander & et al. (2010) propose a simulation model to analyze Porter's view about the existence of tradeoff between two general strategies. But there isn't any formal or simulation model to analyze the effect of value innovation strategy on firms' market share.

This paper at first renders an agent-based model of Ander & et al.'s (2010) work (Positioning on Multi-Attribute Landscape -PMAL) and compares the results of two works, and then extends this model to add value innovation strategy and compares the results in different scenarios.

For the sake of simplicity we use PMAL abbreviation for the Ander & et al.'s (2010) original work and AB-PMAL1 for the agent-based version of this work and AB-PMAL2 for the extended version of its which includes value innovation strategy.

A REVIEW ON PMAL

Ander & et al. (2010) propose a simulation model to qualify Porter's view on the *'Stuck in the middle'* characteristic.

NK Model of Attributes

They used Kauffman's NK modeling (Kauffman, 1993) to model Porter's Productivity Frontiers concept (Porter 1996). They used a two dimensional landscape which cost and quality are its' dimensions. Then they use NK modeling to calculate the value of each attribute as follows:

Attributes are determined by numerous underlying organizational and product design choices. They represent these decisions by a vector s of N binary design choices, i.e., $s = (s_1, . . . , s_N)$ where $s_j \in \{0, 1\}$. The design choices could relate to organizational design or to product design. For example, in the context of the automobile industry, the product design choices could be whether or not a car has anti-lock brakes, and whether or not it has four-wheel drive. Every distinct design gives rise to a different possible positioning in the industry, and hence there are 2^N possible positions.

Tradeoffs between Attributes

In many settings the value of the attributes may exhibit trade-offs where increasing the level of one attribute necessitates decreasing the other. For example, the size of a car is usually negatively correlated to its fuel efficiency. Although they argue that, it is possible to capture strong tradeoffs between attribute levels by imposing that the contribution functions for the second attribute are perfectly negatively correlated with the contribution functions for the first attribute: $a_2(s) = 1 - a_1(s)$.
So they show this correlation by ρ; which varies from -1 (negative full correlation) to 1 (positive full correlation).

Value Creation

In this section they used Brandenburger and Stuart (1996) and Chatain and Zemsky (2007)'s concept of value-base strategy to calculate value created and value captured by each firm and customer in the industry.
Value creation is increasing in both Attribute 1 and Attribute 2 and depends on consumer preferences. In particular, buyer served by firm j at position $s_j \in S$ leads to a value creation of (Eq. 1)

$$v(\alpha, \mathbf{s}_j) = \alpha \log(a_1(\mathbf{s}_j)) + (1-\alpha)\log(a_2(\mathbf{s}_j)) \quad (1)$$

Results

Fig. 3 depicts the final result of their work, in which market share of Extremes (firms which are in positions of differentiation or cost-leadership) when tradeoff is low (ρ near to zero) is in the minimum level. This result is very similar to Fig. 2 and the Porter's *'Stuck in the middle'* characteristic. Although they argue that their finding on viability qualifies Porter's claims that in the face of tradeoffs firms must locate at the extreme points of the frontier (i.e., on his landscape in which cost and quality were the two dimensions, the only viable positions were 'cost leader' or 'differentiator'). Furthermore, they argue that as tradeoffs become more stark (i.e., ρ decreases), there is an increase in the number of niches in which a firm can sustainably locate in the face of rivals.
Base on Fig. 3they do find support for the warning against being 'stuck in the middle.' Firms at the extremes capture a

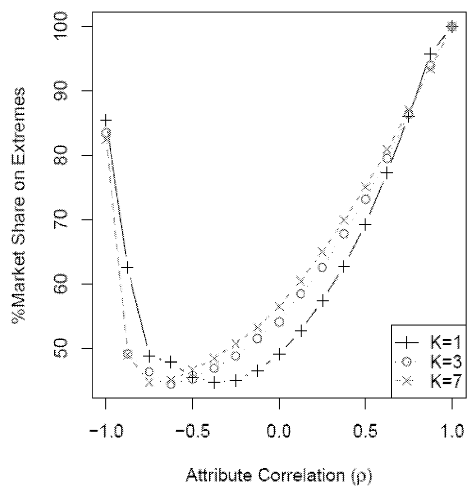

Figure 3. Market share of Extremes (adopted from Ander & et al., 2010)

disproportionate share of both sales and profits. However, the driver of these results is the firm's position relative to the location of rivals (due to the fact that the firms at the extremes can command monopolistic power over the corner of the market), rather than negative spillovers on 'corporate policy and culture' or the lack of internal fit.
In other words, they propose an explanation of the 'stuck in the middle' hypothesis that relies only on external fit arguments, rather than internal fit ones. Moreover, they qualify the stuck in the middle hypothesis, as they point out that its effect size should depend on attribute correlation (ρ) and consumer heterogeneity (the distribution of α).

AB-PMAl1 AND COMPARISON OF ITS RESULTS WITH PMAL

According to preceding sections, this paper at first stage, proposes an agent based version of PMAL (AB-PMAL1) in NetLogo. Fig. 4 depicts the results of model which are very similar to PMAL.

The parameters of model are N in NK model which is no. of firms' policy, no. of customers and total no. of iterations

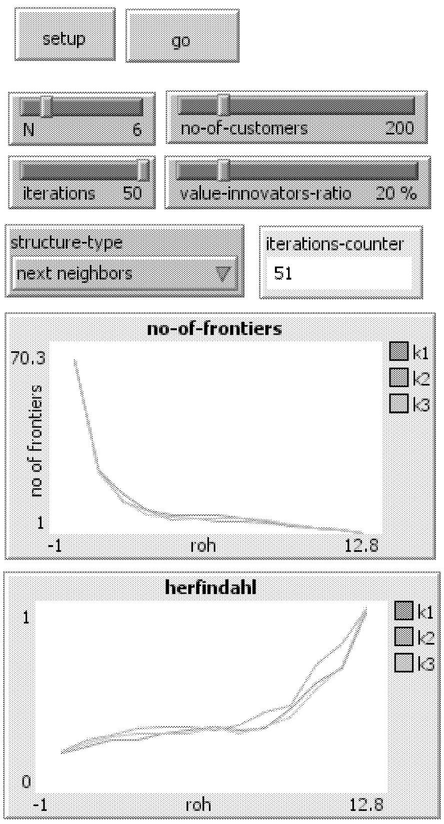

Figure 4. AB-PMAL1: Agent based implementation of Ander & et al.'s (2010) work in NetLogo.

of simulation. Also the parameter structure-type shows how each element of N are connected to each other based on the K value. The first diagram –no. of frontiers- show no. of efficient firms in industry and the second diagram shows the market concentration (less or high competition) via Herfindahl index. Also for N =6 the different values of K are 1, 3, 5. (K1, K2, K3)

Also Fig. 5 depicts the market share of Extremes which comparable with Fig. 3.

After validating AB-PMAL1 -by comparing its' results with PMAL- the next step is extending this model to add value innovation strategy to it.

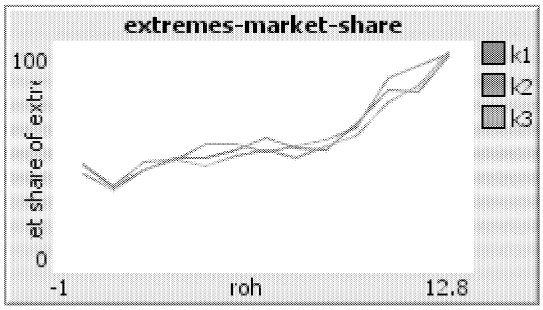

Figure 5. Market share of Extremes (AB-PMAL1)

EXTENDING AB-PMAL1: ADDING VALUE INNOVATION STRATEGY (AB-PMAL2)

Davenport & et al. (2006) argue that value innovation is no longer achieved by finding and protecting a defensible position in a single, traditional industry. Furthermore, Kim & Mauborgne (2005) argue that value without innovation tends to focus on value creation on an incremental scale; something that improves value but is not sufficient to make a firm stands out in the marketplace**.** Also they use the strategy canvas as a diagnostic and an action framework for building a value innovation strategy. Strategy Canvas

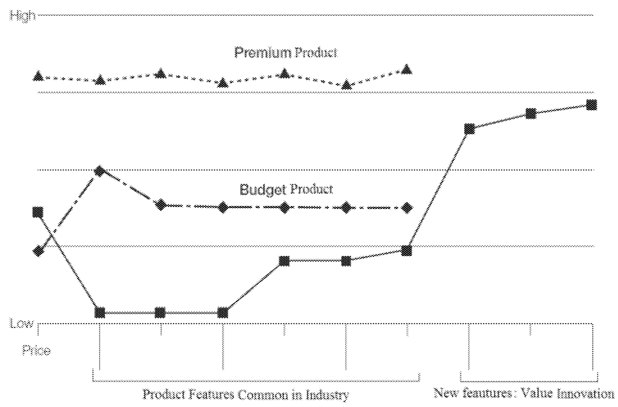

Figure 6. Strategy Canvas

shows, the factors that industry currently competes on in products, service, and delivery, and also it shows new factors which are beyond the current industry structure. (Fig. 6)

We have used this concept to add some new positions to strategy landscape. Fig. 7 shows 4 positions in the landscape, point A, B and C are computed via NK modeling and are industry frontiers. (Based on Ander & et al. (2010)) We have added point D to the middle of these positions which based on strategy canvas it has following properties:

- It is in the middle of positions.
- It is beyond current industry structure.

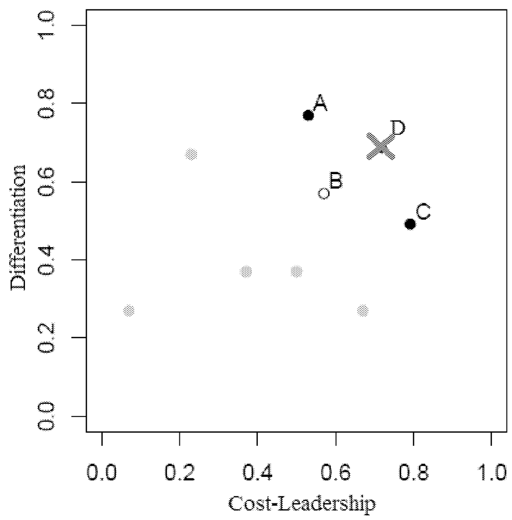

Figure 7. Position of frontiers and value innovators (AB-PMAL2)

Fig. 8 depicts the value of these points and it shows that for some values of customer preferences the D has value greater than points A and B.

As Fig. 4 depicts the no. of value innovations positions are a percent of total no. of positions which is determined in the model by the parameter value innovators ratio. Now the model is ready to calculate the market share of some firms in value innovation

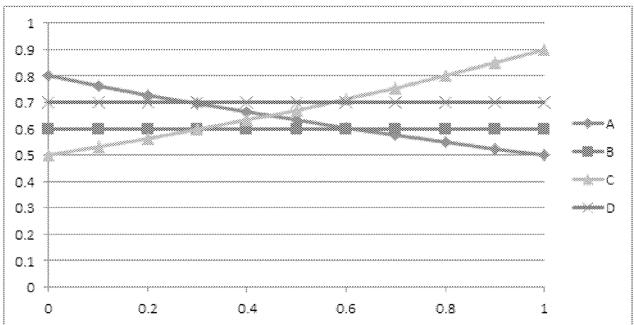

Figure 8. Value creation of frontiers and value innovators (AB-PMAL2)

positions. Fig. 9 depicts this plot and it shows a convex plot which is comparable with point T in Fig. 2. So the new model shows high market share for firms which adopt value innovation strategy, although they are in the middle.

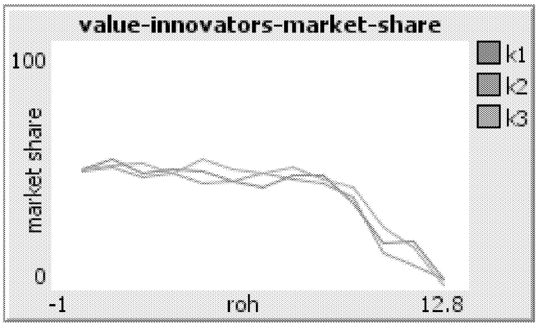

Figure 9. Market share of value innovators (AB-PMAL2)

CONCLUSION

This paper proposes a simulation model to show the effect of value innovation strategy on firms' market share. The model which has been proposed here is an extension of Ander & et al.'s (2010) work on realizing and qualifying Porter's 'Stuck in the middle' characteristic. The main contribution of this paper is adding value innovation strategy to the original model and implementing it as an agent-based model by NetLogo. The results show that value innovation -despite it's in the middle of positions- creates more value than other positions. But there are some difficulties in adopting this strategy, because positioning in a place beyond the current industry frontiers means that firms should adopt continuously, radical research instead of incremental research policy which is the cornerstone innovation economy.

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THE OTHER APPLICATION AREA OF SURVEY SAMPLING

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KEYWORDS

Survey sampling, multivariate nonlinear optimization, feasible solution space, geometry, statistics, systems of equations.

ABSTRACT

The law of large numbers and the central limit theorem (in its various forms) lead to a number of useful formulas (statistics) that can be rearranged for confidence intervals and then solved for the attendant sample size formulas as desired. These formulas are useful in surveying large populations (by market researchers, scientists and engineers, etc.) because one does not need a significant percentage sample of a large population to obtain useful information about the large population being studied. Many times samples of a few thousand (even if the population size is a hundred million or even infinite) will be adequate. An example or two of this type of survey sampling will be presented.

INTRODUCTION

Then the point will be made that any nonlinear multivariate optimization problem can be approached by viewing its feasible solution space as the large target population. Then a several stage survey sampling approach can be efficiently carried out to locate the optimal solution region and close in on the true optimal or a useful approximate solution. Let us look at a few preliminary examples and then a multivariate nonlinear minimization of eight variables followed by a maximization problem with fifteen variables, where the goal is to find the optimal solution rather than estimate probabilities (as is done in regular survey sampling).

SURVEY SAMPLING FOR PROBABILITY ESTIMATION

One form of the central limit theorem (Hayter 2002) and (Black 2014) is that sample proportions p□ pile up in a normal distribution (bell shaped curve) (Anderson, Sweeney, Williams 1999) with mean p (the true population proportion) and standard deviation $\sqrt{\frac{p(1-p)}{n}}$ where n is the sample size. Therefore, subtracting the mean and dividing by the standard deviation gives one the standard normal formula (or statistic)

Z=$(\hat{\text{p}} - \text{p})/\sqrt{\frac{p(1-p)}{n}}$ for large n (usually n>30 will suffice).

Given this information, if a market researcher (Black 2014) (or pollster) wanted to estimate the percentage of voters that favor candidate A in an upcoming election to within 2% with 95% confidence, she could proceed as follows:
P(1.96 < Z < -1.96) = .95 because ± 1.96 are the upper and lower .025 points on a standard normal distribution. Therefore

$$P\left(-1.96 < (\hat{p} - p)/\sqrt{\frac{p(1-p)}{n}} < 1.96\right) = .95$$

and $P\left(-1.96\sqrt{\frac{p(1-p)}{n}} < \hat{\text{p}} - \text{p} < 1.96\sqrt{\frac{p(1-p)}{n}}\right) = .95$

so $P\left(-\hat{\text{p}} - 1.96\sqrt{\frac{p(1-p)}{n}} < -\text{p} < -\hat{\text{p}} + 1.96\sqrt{\frac{p(1-p)}{n}}\right)$
=.95

so $P\left(\hat{\text{p}} + 1.96\sqrt{\frac{p(1-p)}{n}} \geq \text{p} \geq \hat{\text{p}}\ 1.96\sqrt{\frac{p(1-p)}{n}}\right) = .95$

Therefore the true proportion p is bounded by $\pm 1.96\sqrt{\frac{p(1-p)}{n}}$
with 95% confidence around the sample proportion p.
Therefore

$$B = 1.96\sqrt{\frac{p(1-p)}{n}}$$

$$B^2 = 1.96^2\left(\frac{p(1-p)}{n}\right)$$

So $n = 1.96^2\left(\frac{p(1-p)}{B^2}\right)$
Now the maximum of f(p) = p(1-p) obviously is .25 when p= .5 (this covers all possible population proportions).

Therefore:

$$n = 1.96^2\left(\frac{.5\,x\,.5}{B^2}\right)$$

so $$n = 1.96^2\left(\frac{.5^2}{B^2}\right)$$

and $$n = \left(\frac{1.96x.5}{B}\right)^2$$

or $$n = \left(\frac{1.96}{2B}\right)^2$$

Therefore solving for the sample size needed for the polling study she knows that a sample of $n = \left(\frac{1.96}{2x.02}\right)^2 =$ 2401 people who are old enough to vote (and qualified to vote) will be sufficient.

Therefore, if her survey of 2401 people (selected at random) reveals a sample proportion of $\hat{p}$ = .53 for candidate A (.53 ± .02) or .51 to .55 with 95% confidence yields pretty overwhelming evidence that candidate A will be elected (if 50% + is needed to win).

Now that formula can be generalized to $n = \left(\frac{Z}{2B}\right)^2$ where B is the bound.

Therefore, to be 90% sure use ± 1.645
and to be 95% sure use ± 1.96
and to be 99% sure use ± 2.575

Also popular bounds used are:
B=.05 or B=.04 or B=.03 or B=.02
or B = .01 or B=.005.

The classic text (Cochran 1977) provided an overview of sampling. Note that with higher confidence levels and lower (more accurate) bounds sample sizes do increase. However, they do not depend on the overall size of the population.

Now this type of survey sampling reasoning can be easily applied (in our computer age) to solve optimization problems by surveying the feasible solution space (the overall population of potential answers) to find out where the best answers are. Note that we are looking for the optimal not a proportion but the survey sampling will still be effective with a little geometry included (please see Figures 1, 2 and 3) to preserve the integrity of the process.

SURVEY SAMPLING FOR MINIMIZING

Consider the eight variable twelve equation system below where the x_i's are all $0 \le x_i \le 99$ and whole numbers for i = 1, 2, 3, …. 8. Therefore, $100^8 = 1.0x10^{16}$ (or ten thousand trillion feasible solutions). We cannot survey all of the feasible solutions or even a significant percentage of them. So using our sample size formula $n = \left(\frac{Z}{2B}\right)^2$ let us set Z=2.575 and B=.005 then $n = \left(\frac{Z}{2B}\right)^2 = n = \left(\frac{2.575}{2x.005}\right)^2 = 66{,}306$.

Therefore, let us have a seven stage survey of the feasible solution space (drawing 66,306 feasible solutions at each stage) controlled by seven eight dimensional rectangles of decreasing size to look for and close in on the optimal solution region and find the true optimal or a useful approximation.

The system is:

$x_1x_1x_3 + x_4x_5 = 182{,}066$ (1)
$x_3x_3x_4 + x_6x_7 = 392{,}596$ (2)
$x_5x_5x_6 + x_6x_8 = 29{,}481$ (3)
$x_1x_2x_2 + x_5x_6 = 12{,}063$ (4)
$x_4x_4x_5 + x_7x_7 = 54{,}608$ (5)
$x_2x_3x_4 + x_3x_7 = 73{,}636$ (6)
$x_1x_1x_5 + x_5x_8 = 36{,}320$ (7)
$x_6x_6x_7 + x_6x_8 = 247{,}845$ (8)
$x_1x_1x_2 + x_3x_4 = 37{,}891$ (9)
$x_2x_2x_3 + x_6x_8 = 24{,}123$ (10)
$x_7x_7x_2 + x_4x_5 = 12{,}688$ (11)
$x_8x_8x_8 + x_7x_7 = 227{,}765$ (12)

subject to $0 \le x_i \le 99$ and all whole numbers for i=1,2,3 …. 8. We first transform this system to minimize $g(x_1,x_2,x_3 \ldots x_8) =$

$\sum_{j=1}^{12} |L_j - R_j|$ subject to $0 \le x_i \le 99$ for 1, 2, 3, …. 8 and L_j and R_j are the left and right hand sizes of equation j for j = 1, 2, 3, ….12.

We decided to have a seven stage MSMCO simulation drawing 66,306 feasible solutions at each stage. Therefore, if we use a focusing factor of F=2 (in other words reducing the width of the search region by a factor of two at subsequent stages (in each dimension)) that should yield a relatively small search region in the seventh stage as 2^7 = 128 and 100/128 is less than one (the width for each dimension).

Note that the solution produced is x_1 = 47, x_2 = 15, x_3 = 82, x_4 = 58, x_5 = 16, x_6 = 93, x_7 = 28 and x_8 = 61 which checks in all 12 equations so the total error is zero. Classic multivariate statistical analysis (Anderson 2003) is concerned with decision making. However, here one can apply it to optimization and solving systems of equations.

MAXIMIZING WITH SURVEY SAMPLING

Fifteen products are made by passing them from department 1 to 2 to 3 to 4 to department 5 where the product is finished and boxed for shipment. The x_i's for i = 1, 2, 3, …. 15 are the number of units that the company will make of each product each time period. The 1.3 hours. .1i + 1.5 hours, .1i + 1.9 hours, .2 + 2.4 hours, and .3i + 2.7 hours are the average time spent in each of the departments 1 through 5 for each unit of the 15 products being made. However, there are volume returns to scale and inefficiencies to scale for the various products.

There are currently 8700, 19900, 20000, 38000, and 105000 hours available in departments 1, 2, 3, 4 and 5 respectively. This yields the system of equations

$$\sum_{i=1}^{15} 1.3\, x_i^{(.87+.01i)} = 8700 \text{ worker hours } (1)$$

$$\sum_{i=1}^{15} (.i+1.5)x_i^{(.90+.01i)} = 19900 \text{ machine \& worker hours } (2)$$

$$\sum_{i=1}^{15} (.1i+1.9)x_i^{(.77+.02i)} = 20000 \text{ machine \& worker hours } (3)$$

$$\sum_{i=1}^{15} (.2i+2.4)x_i^{(1.1-.01i)} = 38000 \text{ machine \& worker hours } (4)$$

$$\sum_{i=1}^{15} (.3i+2.7)x_i^{(13-.02i)} = 105000 \text{ worker hours } (5)$$

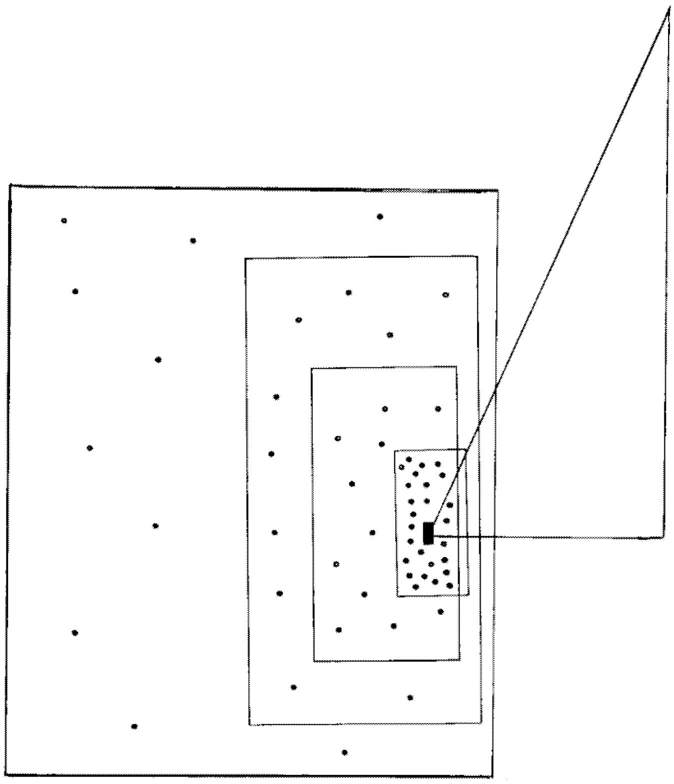

Figure 1: Closing in on the Minimum with Multi Stage Monte Carlo Optimization or MSMCO

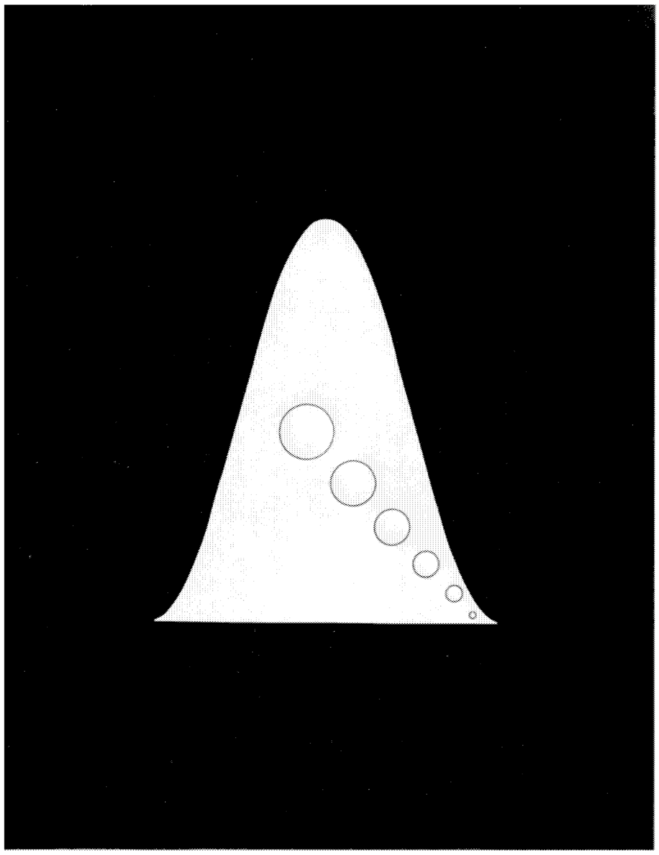

Figure 2: Pursuing the Maximum Solution Region with Multi Stage Monte Carlo Optimization (MSMCO)

Note that the range for each variable is 0 to 1000, because the company does not want to make more than one thousand of any product per time period. Therefore we select a 21 stage MSMCO simulation because we are reducing the width of the search region at each subsequent stage by 1.4 and 1000 divided by 1.4^{21} is a little less than one which should give the multi stage Monte Carlo optimization (MSMC0) simulation a pretty good chance of finding a useful solution if we draw enough samples at each stage. Using our sample size formula we select B=.001and Z=1.96 and get $n = \left(\frac{Z}{2B}\right)^2 = \left(\frac{1.96}{.002}\right)^2 = 960400$ sample answers for each stage subject to $0 \le x_i \le 1000$ and whole numbers for i = 1, 2, 3, …. 15.

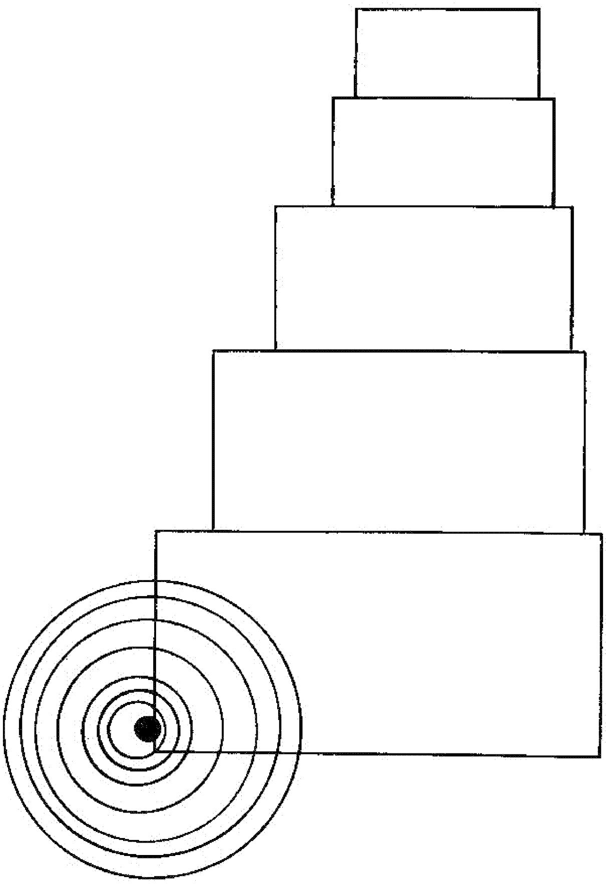

Figure 3: Multi Stage Monte Carlo Optimization (MSMCO) Closing in on the Minimum Solution with N Dimensional Spheres

First we define $g = \sum_{j=1}^{5} |L_j - R_j|$ where L_j and R_j are the left and right hand sides of equations j = 1, 2, 3, 4, and 5. Then we do a 21 stage MSMCO computer simulation to maximize $f(x_1, x_2, x_3, \ldots x_{15}) = 1/g$ drawing 960400 feasible solutions at each of the stages. Four runs of the program on a desk top computer yielded the following solutions which should help to guide production and use all of the five departments' worker and machine hours.

Answer 1:

x_1=519 x_2=338 x_3=373 x_4=820 x_5=426
x_6=847 x_7=233 x_8=754 x_9=910 x_{10}=267
x_{11}=259 x_{12}=861 x_{13}=697 x_{14}=590 x_{15}=726

Max=.01495
E(1)=6.4268 hours
E(2)=52.8008 hours
E(3)=5.9316 hours
E(4)=1.1875 hours
E(5)=.5625 hours

Answer 2:

x_1=484 x_2=138 x_3=778 x_4=588 x_5=462
x_6=437 x_7=787 x_8=855 x_9=719 x_{10}=531
x_{11}=349 x_{12}=443 x_{13}=561 x_{14}=528 x_{15}=947

Max=.03787
E(1)=20.2061 hours
E(2)=3.4902 hours
E(3)=1.2598 hours
E(4)=.6875 hours
E(5)=.7656 hours

Answer 3:

x_1=663 x_2=475 x_3=348 x_4=599 x_5=487
x_6=303 x_7=654 x_8=572 x_9=999 x_{10}=688
x_{11}=235 x_{12}=659 x_{13}=779 x_{14}=245 x_{15}=929

Max=.02111
E(1)=2.9082 hours
E(2)=39.8047 hours
E(3)=2.4531 hours
E(4)=1.9844 hours
E(5)=.2109 hours

Answer 4:

x_1=736 x_2=353 x_3=392 x_4=324 x_5=783
x_6=421 x_7=398 x_8=867 x_9=556 x_{10}=837
x_{11}=716 x_{12}=464 x_{13}=324 x_{14}=515 x_{15}=939

Max=.02661
E(1)=6.8857 hours
E(2)=27.7031 hours
E(3)=.0898 hours
E(4)=1.8438 hours
E(5)=1.0547 hours

Please note that Max is the Maximum of $f(x_1, x_2, x_3 \ldots x_{15})=1./g$ which should minimize the equation errors (the E(i)'s in the printouts) of worker and machine hours in the five production departments for the four different solution runs. Note also that the equation errors are relatively small. Therefore, the production managers have four different useful production plans to choose from in the coming time periods.

This should help to guide production of the 15 products more smoothly and use all of the available resources in the five production departments.

LOCAL OPTIMALS AND OTHER CHALLENGES

Depending on the number of variables and the degree of nonlinearity in the function to be optimized or the system of equations to be solved, local optimals can present a problem to be overcome.

One point to be made is that in the "real world" of big business and economics where "time is money" a so called local optimal solution that is arrived at quickly with

MSMCO or other evolutionary computing strategies may be so much cheaper that it is actually the true optimal (or close to it) from a cost of solution point of view.

However, local optimals or just approximate solutions arrived at using multistage Monte Carlo optimization (MSMCO) or evolutionary computing tend to, in many cases, pile up near the true optimal solution. Therefore, given the ever increasing amount of computer speed in today's computers, one can average these approximate solutions (coordinate wise) to locate the optimal solution region more accurately for subsequent future simulations.

The famous test problems 30 and 32 worked on in (Conley 1991) produced the true optimals to these 150 and 200 variable problems by repeatedly "averaging" the preliminary MSMCO solution attempts until the true optimal was located and printed. This was done in one complete MSMCO program that kept averaging the subsequent solution attempts.

There is clearly enough computing power now (and certainly in the future also) to take this approach with even a small desk top computer.

Additionally, in science and business sometimes the researchers and practitioners want to identify some of the local optimals to better understand the problem at hand and its "solution" possibilities.

GEOMETRY AND STATISTICS

Figures 1, 2, and 3 give a partial statistical and geometric representation of the multi stage Monte Carlo optimization (MSMO) solution approach crossing the feasible solution space of an optimization problem to look for and find the true optimal or a useful approximate solution.

CONCLUSION

Presented here was the classical approach to survey sampling (with an example) as a lead in to two examples (of systems of equations) of optimization problems that were solved using a new application area of survey sampling. The idea is to sample the feasible solution space of the optimization problem to not estimate a probability, but to locate and find the optimal solution. "Random sampling" can be very effective in both application areas of survey sampling.

The two subsequent examples presented were an eight variable twelve equation nonlinear system and a fifteen variable five equation nonlinear system involving a production problem in a factory.

The computer age and evolutionary computing are really providing business people, scientists, and researchers with a very viable new application for survey sampling.

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BIOGRAPHY

WILLIAM CONLEY received a B.A. in mathematics (with honors) from Albion College in 1970, an M.A. in mathematics from Western Michigan University in 1971, an M.Sc. in statistics in 1973 and a Ph.D. in mathematics - computer statistics from the University of Windsor in 1976. He has taught mathematics, statistics, and computer programming in universities for over 30 years. He is currently a professor emeritus of Business Administration and Statistics at the University of Wisconsin at Green Bay. The developer of multi stage Monte Carlo optimization and the CTSP multivariate correlation statistics, he is the author of five books and more than 200 publications world- wide. He is a member of the American Chemical Society, a fellow in the Institution of Electronic and Telecommunication Engineers and a senior member of the Society for Computer Simulation. Career highlights include presentation of two papers at National Aeronautics and Space Administration (NASA) conferences in Houston, Texas and Washington, D.C.

Evaluating Efficiency of Collective Learning in Innovation Networks: Simulation based Experiments in SKIN

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KEYWORDS
Collective Learning, Innovation Networks, Complexity Catastrophe, SKIN Framework.

ABSTRACT

Innovation networks aim to increase collective learning and are a means of creating innovation. Different policies are made to increase the efficiency of these networks. These policies have several financial consequences for policy-makers. One of the most low-cost policies is a policy to increase collaborations and communications among network members, which leads to the improvement of collective learning and network efficiency. The present paper aimed to study the effect of increased network collaboration and communication on network efficiency through experiments based on simulations in the SKIN framework. In addition, the effect of density, as the notion of network complexity, is also examined in this regard. The analysis performed on simulated data using the structural equations method revealed that density is a variable with mediating and moderating effect on the relationship between support for collaboration and network efficiency.

1. INTRODUCTION

Study of the emergence and dispersion of innovation was for the first time discussed by Joseph Schumpeter in 1912, in economic discussions. He emphasized on the prominent role which an entrepreneur plays in economy (Pyka, 2002). About 30 years later, in 1942, Schumpeter introduced the growth of the American industry as the result of changes made to the structure of the research and development process through establishment of specialized laboratories by big companies. About 40 years later, another change was made in the structure of research and development structure of big companies. The change led to establishment of an interaction between research and development laboratories and other actors such as universities and public research institutions within the framework of innovation networks (Pyka, 2002). However, analysis of these networks and their effect on economy has been theoretically studied since 1990s. Pyka and Fagiolo (2007)believe that one of the reasons for the delay in theoretical analysis of innovation networks is problems caused by the Firm Theory (in the form of neoclassical economics and industrial organization) to the economics.

The recent approach to innovation networks –which supposes networks as a means of innovation- realizes that, the main advantage of networks is creation of innovation opportunities for different firms. It also introduces networks as a social process including interactions, coalitions and collaborations among various actors. That is to say, the firms use inter-organization networks as safe platforms which protect them against unreliability and unfavorable business conditions. Since interactions among network members (network density) and collaborations among them are considered as a means of innovation, apparently with an increase in the number of interactions among members, collective learning and network efficiency are enhanced. Hence, the present paper aimed to answer the following questions: What is the effect of a support for collaboration aimed at creating a chance for collective learning on network efficiency? What is the effect of complexity catastrophe (increased network density) on the relationship between support for collaboration and efficiency?

2. LITERATURE REVIEW

Networks were considered as a means of innovation more than before with the emergence of Nelson and Winter's evolutionary economics (1982). Moreover, more studies were conducted on these networks in the form of dynamic systems and especially complex adaptive systems (Ahrweiler, Pyka, & Gilbert, 2004), (Ahrweiler, Pyka, Schilperoord, & Gilbert, 2012), (Dawid, 2005), (Morone & Taylor, 2010). The complex adaptive systems were formed following the criticisms on system thinking about self-organization and co-evolution and have the following characteristics (Anderson, P., 1999), (Yuan & McKelvey, 2002):

- They are formed of a set of components with numerous communications among them.
- Instead of modeling complex and nonlinear systems, they study the interactions among components (agents) using a set of variables and causal relationships.

2.1 Learning in Complex Adaptive Systems

Most learning theories refer to the existence of a relationship between agents and the outer environment that influence their knowledge acquisition capabilities. However, these theories have never explored this relationship seriously. These theories only emphasize on single-agent

learning and do not address interactive learning. Researchers of collective learning believe that the act of learning not only takes place in the person's mind, but also can take place at the social level where individuals connect (Yuan & McKelvey, 2002).
Lave and Wagner (1996) introduced this type of learning as situated learning. In this type of learning, focus is moved from people's mentalities to the relationships among their mentalities and also the focus on individuals' characteristics or their environments is replaced by the focus on inter-person interactions or interactions among people and the environment. According to them, situated learning has the following two major characteristics:

- Individual learning is not separable from collective learning
- Learning is modeled in the form of organizational communications forming a learning network

2.2 Collective Learning and Kauffman's Complexity Catastrophe

Yuan and McKelvey (2002) used the NK modeling concept, which was proposed by Kauffman (1993) to simulate the efficiency of complex systems, to test the efficiency of collective learning. Kauffman (1993) believed that an increase in the number of communications among interacting agents leaves a nonlinear effect on their relationships and finally leads to complexity catastrophe (Fig. 1). His use of the phrase "complexity catastrophe" was aimed at showing the fact that an increase in social interactions first facilitates learning. Yuan and McKelvey (2002) used the NK modeling method to test different hypotheses on the rate of collective learning as well as the degree of collective learning. They showed the number of group members with N and the number of communication with K. The most important hypotheses tested by these researchers through simulation are as follows:

- For small values of K the rate of collective learning is a positive function of communications among members (K).
- For high levels of network density accelerates learning, but it easily is entrapped by low-level learning.
- As K reaches N-1 value (and for very large values of N), adaptive learning is lost. (the Complexity Catastrophe)

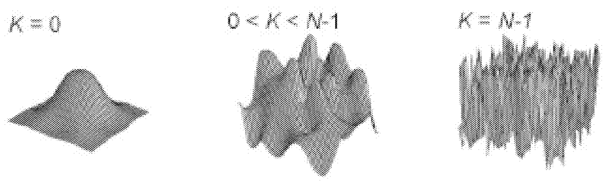

Figure 1. . Increasing Complexity of system by increasing K

On the other hand, McKelvey (1999) believes that collective learning is an integral part of today's competitive world while complexity of communications may balance the success of firms or the network competitive advantage. He also believes that there is a very small difference between Kauffman's complexity concept and network density. Therefore, he explored answers to the following three questions:

- Does the existence of many co-evolution relationships among competencies of the value chain of a firm hinder competitive advantage?
- Does the existence of many co-evolution relationships among one firm and another hinder competitive advantage?
- Do strategists need to be worried about the complexity catastrophe?

2.3 Analyzing the Dynamics of Complex Adaptive Systems

Anderson (1999), Yuan & McKelvey (2002) ,Stacey et al. (2000), and Mahmoudzadeh and Jassbi (2011) stated that the best method of modeling complex adaptive systems is the agent-based modeling method. In the agent-based modeling method a whole system is modeled in the form of a set of independent decision-making components known as an agent. This method is used to model individuals' behavior and their relationships. Moreover, unlike the previous methods it can also model the heterogeneity among components. The three main characteristics introduced for this method are as follows (Gilbert, 2008):

- The ability to analyze the emergent phenomenon in systems
- Providing a more natural system model compared to other methods
- High flexibility

2.4 Simulation of Knowledge Dynamics in Innovation Networks

Various studies have been conducted on modeling the dynamics of innovation networks using the agent-based modeling method. However, one of the most commonly used studies (Blom & Hildrum, 2012), (Gilbert, Ahrweiler, & Pyka, 2007), (Pyka, Gilbert, & Ahrweiler, 2009) and (Korber, 2011) is the framework proposed by Ahrweiler et.al (2004) in a study titled "Simulation of Knowledge Dynamics in Innovation Networks" (SKIN). This framework is an agent-based computer simulation which studies dynamic processes associated with innovation in knowledge-based industries.
The SKIN model is an agent-based model composed of heterogeneous agents interacting in a variable and complex environment. Agents of innovative firms try to sell their innovations to other agents and the end users. Each firm tries to enhance its efficiency with regard to innovativeness by improving its knowledge base through one of the three following methods: adapting to the needs of the end user; incremental or radical research; and collaborating with other firms (or creating a collaborative network). In the SKIN model a Kene is used to show the total knowledge of

an organization. The knowledge base of an agent in the SKIN model includes a set of knowledge units. Each unit of knowledge is expressed as a (C, A, E) triple, which C denotes the scientific or technical Capability of a firm in a business area (e.g. biochemical engineering), which is shown by an integer. A is the Ability of a firm to perform a task in the field of concern and is show by a real number. Examples of this ability include a mixing or filtering method. Finally, E stands for the Expertise level achieved by the firm in doing the aforementioned ability. E is shown by an integer. The Kene for each firm is a set of knowledge units' triple whose count depends on the firm size (Fig. 2).

$$\begin{Bmatrix}C\\A\\E\end{Bmatrix}, \begin{Bmatrix}C\\A\\E\end{Bmatrix}, \begin{Bmatrix}C\\A\\E\end{Bmatrix}, \begin{Bmatrix}C\\A\\E\end{Bmatrix}, \begin{Bmatrix}C\\A\\E\end{Bmatrix}, \ldots$$

Figure 2. Kene of a firm

Innovation Hypothesis (IH) is the concentration of firms on a specific field and innovation in that field. In other words, it is the potential innovativeness of the firms. The innovation hypothesis is, in fact, a set of Kene triple of a firm (Fig. 3).
Transformation of IH to a product is a process that multiplies the capabilities and abilities of the IH to calculate an index for the product. (Eq.1)

$$P = \left(\textstyle\sum_{IH} C_i \cdot A_i\right) mod\ N \qquad \text{(Eq.1)}$$

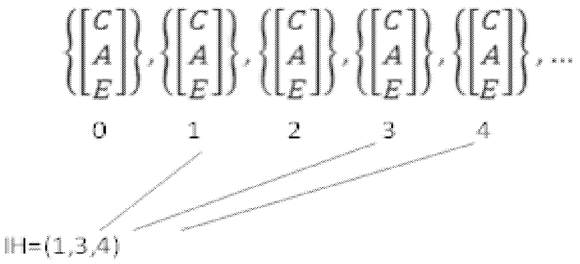

Figure 3. Innovation Hypothesis

3. RESEARCH MODEL

Figure 4 shows the research model in the form of path analysis diagram, which by Partial Least Squares Structural Equation Modeling (PLS-ESM) techniques (using SmartPLS) will be tested. In this model the effect of different levels of "support of collaboration policy" (independent variable) on efficiency of network (dependent variable) will be tested. Also in this model the effect of complexity of network as a moderator/mediator variable on this relation will be tested.

The data needed to test this model have been produced by the SKIN framework which is simulation of artificial innovation networks. Table 1 shows the relationship between SKIN framework's parameters and outputs by the variables of research model. (See figure 4)

Efficiency: is a latent variable which has been defined by the following variables:

Table 1: Relationship between SKIN framework and research model variables

Variable Type	Variables in Research Model	Equivalent parameter/output variable in SKIN	
Dependent / Latent	Efficiency of Network	Herfindahl Index	
		Avg. Innovation Hypothesis	
		Speed of Innovation	
Moderator / Mediator	Complexity	Network Density	
Independent	Support of collaboration policy	Attractiveness-threshold	0.7
			0.3
			0.1

Herfindahl Index: This index is used to measure firm size (the firm capital and the size of its IH) in relation to the whole industry. It is also an index that shows the competition between the firm and the industry (whether monopolized or competitive). This index can also be compared to a set of specific values and monitor its variations over time. In this research, the second approach was used.

Avg. Innovation Hypothesis (IH): The length of the IH of each firm shows the ability of the firm to produce diverse products. In other words, as the number of abilities in a network increases, the possibility to produce more products grows as well. This variable reflects the level of technological development in the network and was used to measure the technology index of the problem.

Speed of Innovation: The shorter the interval between productions of two successful products, the higher is the innovation speed. This index is a criterion for measuring the gap between science and product productions. Hence, this variable is used to measure market index.

Complexity: Complexity is a research variable which has been showed by the network density in simulation.

Support of collaboration policy: The policy to support member collaboration is, in fact, an incentive to increase collaborations among firms or to reinforce their mutual trusts. The policy to support collaboration is independent variable which is a categorical variable with three values: more support, relative support, lack of support which is controlled in SKIN by the Attractiveness-threshold parameter at three levels: 0.1, 0.3 and 0.7 respectively.

4. RESULTS

After running the SKIN program for three levels of the Attractiveness-threshold parameter, variations of network

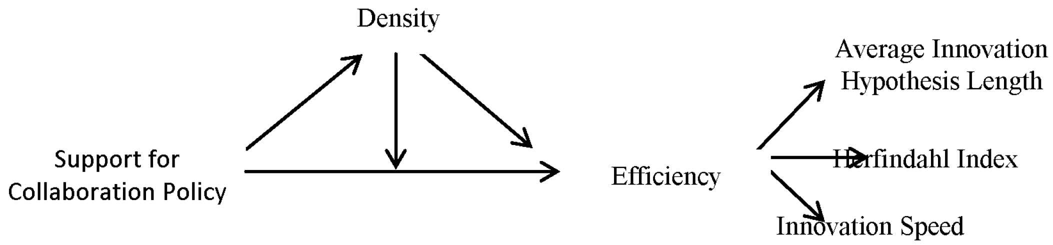

Figure 4. Research Model

density were obtained as seen in figure 5. According to this figure, with an increase in the support for collaboration (or a reduction in attractiveness-threshold), network density increases.

In order to test the model using the structural equations method smartPLS software has been used. Based on Kwong and Wong (2013) the results of model analysis are as follows:

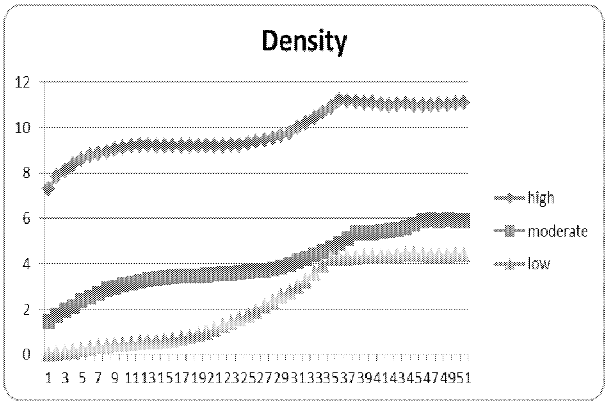

Figure 5. Network density for different levels of collaboration

4.1. Explanation of target endogenous variable variance

Figure 6 shows the path modeling in smart PLS. Numbers in the circle show how much the variance of latent variables is explained by the other (coefficient of determination, R^2) latent variables which in this case R^2 is 0.694 for the efficiency endogenous latent variable, which means that the three variables (Policy, Density and Policy*Density) moderately explain 69.4% of the variance in efficiency. Also Policy explains 66.3% of the variance of Density.

4.2. Inner-model path coefficient sizes and significance

In Figure 6 numbers on the arrows are called the path coefficients. They explain how strong the effect of one variable is on another variable. The weights of different path coefficients enable us to rank relative statistical importance. So figure 6 shows that density has the strongest effect on efficiency (-0.917) followed by policy (-0.779) and policy*density (-0.406). The hypothesized path relationships between policy, density and policy*density on efficiency are statistically significant because all of the absolute values (0.779, 0.406, 0.917) are greater than 0.1 (Figure 6) and all of the T-statistics (6.663, 7.203, 6.492) are larger than 1.96 (Figure 7).

4.3. Outer model loading

Outer model loadings show the correlation between latent variable and the indicators in its outer model. Figure 6 shows these indicators (Innovation Hypothesis, Herfindahl Index, Speed of Innovation) for efficiency latent variable, which their loadings are 0.869, 0.894 and -0.893.
For these values the absolute value of 0.7 or higher is preferred, but in exploratory researches 0.4 or higher is acceptable.

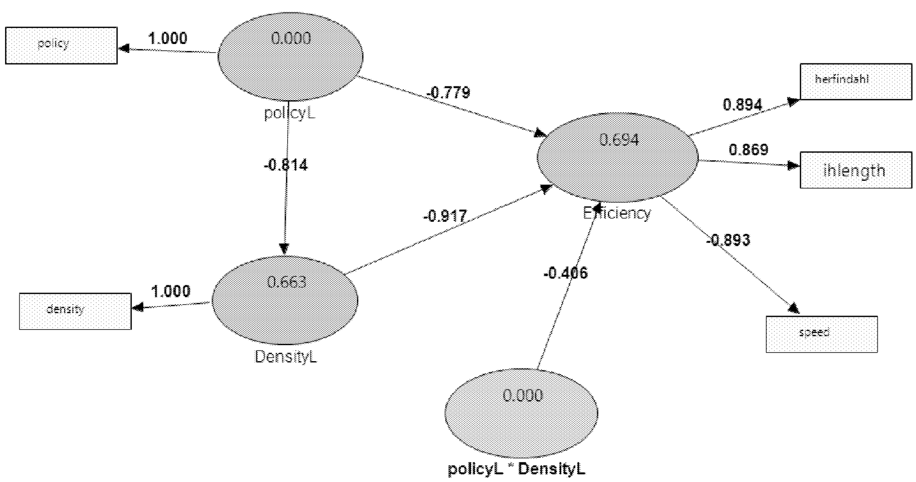

Figure 6. Moderating and mediating effect of density on network efficiency

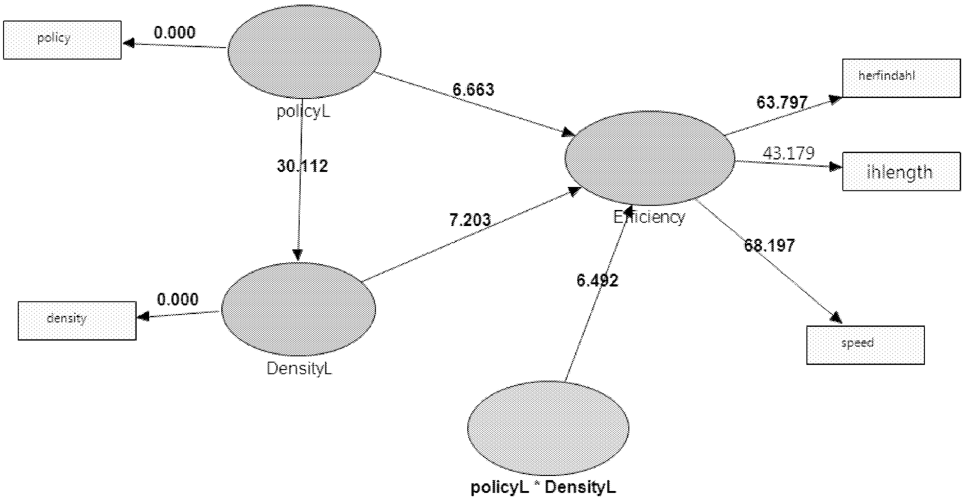

Figure 7. Model significance

5. CONCLUSION

Results of the experiments based on simulation using the SKIN framework indicate that with an increase in communications within innovation networks, network efficiency, which is caused by collective learning, increases. However, increase in density has a negative effect on efficiency. This complies with findings of Kauffman (1993) and McKelvey (1999) that reflected the moderating effect of complexity (density) on efficiency. Moreover, the results of this paper show that density also influences the relationship as the mediating variable. Policy makers in the field of innovation networks should note that although support for collaboration among members increases efficiency, but this policy should be used together with other supportive policies such support of startups, … since using only this policy and increasing support of collaboration will be caused to reduction in efficiency.

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SEVERE BRAIN INJURED PATIENTS: MODEL AND SIMULATION TO IMPROVE ASSISTANCE MANAGEMENT

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KEYWORDS
Health care, system analysis, forecasting, discrete simulation

ABSTRACT

The organization of health care systems represents an essential service for the community. In this paper we analyze the care pathways for severe brain injured patients, which have heterogeneous needs and characteristics throughout each phase of the healthcare assistance, with the scope of a correct dimensioning of resources at disposition, in order to satisfy patients needs, both in present and future situation, consequent to population growth in time. First an accurate description of acquired brain injury and of consequent disorders of consciousness is presented; related required health care, developed in successive phases according to the disease development, is accurately examined; acquired brain injury epidemiology is reported from the literature. We develop a simulation model written in language Arena® that represents the health care assistance and rehabilitation, able to provide the behaviour of system demand, the patient queues statistics, the resource utilization and availability. Such a model was applied to the assistance offered by the Veneto Region Healthcare System; the simulation results showed the assistance deficiencies that will take place the next years in long term assistance; we propose a solution (increase of some resources at disposition) to improve the assistance for patients in vegetative state and minimally conscious state.

INTRODUCTION

Acquired brain injury (ABI) is a term that embraces traumatic brain injury (TBI) or concussion, caused by motor vehicle accidents, sports accidents, falls, assaults, etc., and non traumatic brain injury, consequent to cerebral vascular accident (CVA) or stroke, aneurysm, brain tumor, drowning or postsurgical complications resulting in anoxia or hypoxia, etc. (see for instance Alted Lòpez et al. 2009, Azienda Sanitaria Regionale dell'Umbria 2003, Brain Trauma Foundation 2007, Castellanos-Pinedo et al. 2012, Feigin et al. 2010, Haddad and Arabi 2012, Harrison 1992, Jennet 1996, Tawil et al. 2007).

The acquired brain injury varies in severity that leads from good recovery, through moderate or severe disability, vegetative state or death. To consider an acquired brain injury as severe, the patient must pass by coma state for more than 24 hours and, consequently, the patient will present motor, sensorial, cognitive and behavioral impairments, frequently generating permanent disability of different levels (see for instance Jannet and Bond 1975, Hukkelhoven et al. 2003).

The health care for patients who have suffered an ABI can be described as follows:

1) Critical phase: hospital recovery through reanimation and neurosurgery in emergency (see Conferenza Nazionale di Consenso 2000, Haddad and Arabi 2012);
2) Acute and sub-acute phase: period of variable duration from several days to several weeks and sometimes months, dedicated to the management of septic respiratory, neurological (status epilepticus), surgical, neurosurgical, orthopedic complications in order to stabilize the patient and provide early rehabilitation (see Azienda Sanitaria Regionale dell'Umbria 2003, Brain Trauma Foundation 2007);
3) Post Acute phase: medical assistance and rehabilitation of specific intensive type; this phase is also in hospital settings, which can last from several weeks to several months (see Azienda Sanitaria Regionale dell'Umbria 2003, Brain Trauma Foundation 2007);
4) Outcome phase (after hospitalization): in most cases sequels remain; therefore, health and long-term social assistance are necessary, aiming to address persistent impairments and disabilities, as well as the difficulty of returning to family, social, school and work environments (see Gazzetta Ufficiale della Repubblica Italiana 2011, Giacino and Kalmar 2005).

The residual disability of a patient with ABI depends of the primary damage (not reversible) and from the secondary damage (preventable) in a chain of events that may occur while the patient is in acute phase; the secondary damages have higher probability to become permanent as time passes (see Boldrini et al. 2001, Fins 2007, Giacino and Kalmar 2005, Gigli et al. 2009, Lammi et al. 2005, The Multisociety Task Force on PVS 1994, von Wild et al. 2012).

The assistance planning for severe brain injured patients is acquiring interest nowadays due to the increasing number of present cases with vegetative state and minimally conscious state as a consequence of critical care improvement and innovation in medical procedures which lead to a greater survival rate through the years and consequently bigger resource consumption to the health care systems that take care of patients in these conditions (see Beis et al. 2009, Bernat 2012, Boldrini et al. 2001, Bnrusselman et al. 2004, Donis and Kraftner 2011, Gigli et al. 2009, lavirjsen et al. 2005, Taub 2012, The Royal College of Physicians 2003).
The healthcare planning for vegetative state and minimally conscious state does not begin when they are deemed as being at that states: there is an entire system in every community focused on planning the resources to meet the demand from the critical phase through rehabilitation and long term care facilities. The problems here concern a precise forecast of assistance needs, connected to the number of patients, and a correct dimensioning of resources at disposition (see Marucco 2012, Leonardi 2012).
The literature covering issues about brain injury assistance is complex due to the emergence of new concepts such as the minimally conscious state, which generates doubts about how the patients were diagnosed before the existence of this state (see Castellanos-Pinedo et al. 2012, Fins 2007, Giacino and Kalmar 2005, von Wild et al. 2012, Zeman 1997 and 2002); articles mainly cover acquired brain injury as traumatic, while non traumatic brain injuries are not covered in the same way resulting in an elusive epidemiology that is not possible to apply widely due to specific considerations (see Baguley et al. 2008, Brusselmans et al. 2004, Feigin et al. 2009 and 2010, Harrison 1992, Jennet 1996, Lammi et al. 2005, Lavirjsen 2005, Saout 2010, Stephan et al. 2004, Tawil et al. 2007, Zampolini 2003 .
Another factor that contributes for the literature complexity is that in the majority cases papers cover primarily clinical details and specific parts of the whole health care problem, while neither organizational nor forecasting issues are considered; as a result, there is a lack of long term management information that could help hospitals and healthcare systems to improve services planning.
Here is presented a widespread approach of healthcare assistance that considers the two main etiologies for severe brain injuries (traumatic and non traumatic injuries), covers the care pathways from resuscitation and intensive care unit through rehabilitation and long term care and focuses on resources utilization as well as the population dynamics to propose changes in the resources allocation of assistance for patients brain injured patients in vegetative state and minimally conscious state; a simulation model (Lowery 1998, Robinson 2004) in Arena® has been built up, validated and employed as an instrument to obtain future system behavior both in present and in different situations, related to different amount of resources at disposition; a specific application to Veneto Region in Italy is considered and discussed in detail (data obtained from Rare diseases coordinating centre of Veneto Region 2012).

ABI ASSISTANCE ORGANIZATION IN VENETO REGION

Veneto Region has a population of about 5,000,000 inhabitants; the population age is currently distributed in 17% persons with 0-17 years old, 27% with18-39 years old, 36% with 40-64 years old, and a 20% people with 65 years old and over; the population increases approximately at a rate of 34,000 inhabitants per year.
The Veneto Health Care System focused on the integration between the hospital phase and the homecare phase as well as the integration between the health care and the social care. It has built a network system that covers the assistance paths through all phases (emergency, acute, post-acute phase and long term care).
Each year, about 1932 persons suffer a severe brain injury in the Veneto Region, of this number, 1294 patients have a cerebral vascular accident, and 638 sustain a severe traumatic brain injury.
According to data in hospital discharge records, 341 persons in vegetative state and minimally conscious state are currently followed in the structures of the Veneto Region; from these 341 patients, 302 are Veneto residents, there are no residents followed outside the Region. Therefore, the Region is self-sufficient; and also offers healthcare to residents of other Italian regions.
These 341 cases are the total of new cases and the prevalent cases; there are approximately 90 new cases every year; the number of prevalent cases tends to increase with time, due to the increase of survival rate and also the rate of new cases.
These numbers indicated us an incidence of VS and MCS of 2 persons every 100 000 inhabitants, and a prevalence of 7 persons in VS and MCS every 100 000 inhabitants. The age distribution is 6% of people under 18 years, 44% between 18 and 65 years, and 50% over 65 years. In the age group of 18-65 years, there are three frequency peaks:

1) Around 20 years old: this age group is affected especially for traumatic etiology
2) Between 40-50 years old: these patients are followed for hypoxia, particularly myocardial infarction.
3) The group of 55 years old and over is followed for acute brain insults, such as cerebral hemorrhage, stroke.

21% of those patients in VS and MCS (60 cases) are followed by home health care (Integrated Home Assistance, where multiple figures, specific hospital doctor, general practitioner, nurses, social assistants and family care givers cooperate), 70% are admitted to a residential non-hospital dedicated, small, often within healthcare assisted residences, but with spaces and dedicated staff, 9% (20 cases) housed temporarily in acute hospital wards awaiting to be transferred to intermediate structures dedicated.
The Health Care System of Veneto Region must be organized and coordinated to receive and host this number of patients annually, from the Accident and Emergency department, through Intensive Care unit, to rehabilitation and long term care structures.

There were activated through the entire Region specific sections dedicated to persistent or permanent vegetative states, hosting a small number of people (up to 10, with very few exceptions), according to the pre-defined structural requirements, personnel and equipment.
In 2001, the Veneto Region approved the "Guidelines for the definition of regional care to patients in a vegetative state", since year 2001 the Veneto Region has in disposition 120 skilled nursing home beds and this budget increased with time until the recent 250 beds in 2010.
For the vegetative states of recent onset (persistent vegetative states) sudden after the resuscitation phase, and if there were certain signals of non-recovery, it is considered to transfer the patients to intensive neuro-rehabilitative structures in hospital settings.
The admission to nuclei for minimally conscious state or permanent vegetative states is always subject to a multi-dimensional evaluation unit attended by the district specialists who assess the socio-economical conditions of patients prior to take a decision for long term care.

MODEL

On the basis of the above information a simulation model was built for the dimensioning and foreseeing of the Veneto Region Health Care System. Such a model can be easily adjusted to be used in similar situation in any other region, in Italy or outside Italy.
Data were obtained from Regional Healthcare System statistics office.
Patients with severe acquired brain injuries arrive to the Accident & Emergency department according to an exponential distribution; since every patient arrives with a severe brain injury a FIFO prioritizing queue discipline was adopted due to the urgency presence in all arriving patients.
The patients' arrivals were subdivided in the two relevant types of severe brain injuries classified as traumatic and non traumatic brain injury.
In Veneto there are approximately 1932 severe brain injuries in a year, the proportion of injuries are 67% to the non traumatic brain injury and 33% for the traumatic brain injury; we have the following details for the inter arrival time of both etiologies described by the following probability density functions:

a) Traumatic Brain Injuries Patients' Arrivals
   Inter arrival time: Exponential, mean =0.57 days
b) Non Traumatic Brain Injuries Patients' Arrivals
   Inter arrival time: Exponential, mean = 0.282 days

According to data provided by the Veneto Healthcare System patients remain in Resuscitation and Intensive Care Unit (ICU) for an average of 15 days, but this length of stay varies from 1 day to 4 months. This numbers are consistent with literature data found for TBI patients.
The patients' time duration in Resuscitation and Intensive Care Unit is described by a gamma distribution, which was thought to be the most apt to describe the phoenomenon.
The data and parameters are the following: Average: 15 days, Standard Deviation: 35 days, Range: [1, 120]. Gamma Distribution parameters in Arena: α= 0.1837, β= 81.67.

After the intensive care unit phase it is expected to have a 30-day mortality probability of thirty three percent for patients who have suffered a traumatic brain injury, while for non traumatic patients it is twenty three percent; the model needs to take into account this data to continue processing the patients' passage through the model.
The data provided from Veneto Healthcare System for intensive rehabilitation were processed to calculate the following data and parameters: Average: 32.26 days, Standard Deviation: 23.91 days, Range: [10,104] days, Gamma Distribution parameters in Arena: α= 1.82, β= 17.73.
The intensive rehabilitation facilities have a capacity of 1199 beds that are the sum of intensive rehabilitation and high specialty intensive rehabilitation.
After the intensive rehabilitation it is expected to have a mortality of 5% for both types of patients so the system must consider this mortality to process the next phases in the model.
For the Extensive Rehabilitation: Average: 25.4 days, Standard Deviation: 6.2 days, Range: [15, 44] days, Gamma Distribution parameters in Arena: α= 16.78, β= 1.51.
The extensive rehabilitation has a capacity of 976 places to meet the rehabilitation demand within outpatients' clinic.
Long term includes the outcomes of permanent vegetative and minimally conscious states that are followed either in skilled nursing homes or at home through home health care program; the capacity for skilled nursing homes is currently at 250 beds available; Average: 5 years, Standard Deviation: 10 years, Range: [2 months- 35 years], Gamma Distribution parameters in Arena: α = 0.25, β = 20.
The simulation model covers from the patients' hospital arrivals, passing through intensive care unit, intensive rehabilitation, and discharges to home, extensive rehabilitation or skilled nursing home and home health care.
The resources capacity will be the same stated before and for the purpose of obtaining a simple model that represents reality, ICU beds and Home health care resources will be considered infinite due to the nature of these resources. The intensive care unit is not allowed to have queues; on the other hand, Home Health Care program receives more resources if the demand requires them due to the policies of the health care system.

MODEL IMPLEMENTATION

The model is implemented in tool Arena and uses 45 modules. The model performed 9 runs after 10 years warm up; each run increases the length of one year, so that it is possible to follow changes in model behaviour, after a first run with current data. After the simulation run it has been encountered that resuscitation, intensive care unit, extensive rehabilitation and intensive rehabilitation do not present queues and are ready to meet a larger demand; the reason for this fact is that resuscitation and intensive care units will never allow queues due to the urgency of arriving patients in severe conditions, another aspect is that some departments have beds shared to receive patients with other urgent conditions. On the other hand there is a queue of patients waiting for a place in long term care specifically in skilled nursing home, due to the period of survival time of patients and the new arriving patients' rate. Then the following points will concentrate on resources demand and the findings in long term care.

After simulation runs it can be observed in the analysis of resources that demand showed a low utilization on extensive rehabilitation and intensive rehabilitation.

The following data are the details for the demand of resources with 1932 brain injuries a year in the Veneto Region in terms of busy resources assigned to severe brain injured patients.

The current average utilization of the system is the following:

- 79 beds busy in Intensive care unit
- 124 beds busy for Intensive rehabilitation
- 74 beds busy for extensive rehabilitation
- resources needed to follow 74 patients in home healthcare program (Home Integrated Assistance, where hospital specialists, general practitioner, nurses, social assistants and home care givers cooperate
- 250 places busy in skilled nursing home with a queue of patients in vegetative state and minimally conscious state waiting for healthcare.

In long term care for VS and MCS there are two paths to follow depending of multidimensional analysis made by Health Care system specialists; the first is to arrive in a skilled nursing home and the other is to receive home health care assistance. The healthcare system adds more resources to home health care while time passes and the demand increases since the number of patients followed at home is lower than patients followed in skilled nursing homes.

By the other hand in long term care within skilled nursing home was observed that the number of waiting patients increases with time due to the recurrence of arriving patients and the length of stay of current patients in skilled nursing home leading to state that the demand from patients is greater than the available resources.

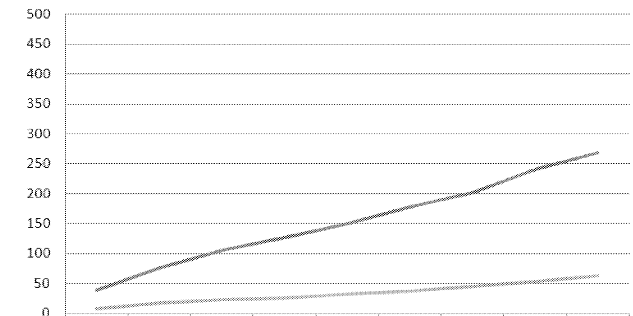
As can be seen in the simulation results reported in Fig. 1 the waiting time and the queue length increase with time, becoming about 6 times larger in 9 years, in the situation with the current number of inhabitants. A solution to improve the level of service is to increase the capacity in the resources from 250 to 315 beds, which makes the Veneto Region skilled nursing homes work without queues at least for 9 more years. The utilization percentage with the new solution varies from 80 to 90% in 9 years.

Taking into account that the population increases through the years, if there takes place an increment of 300,000 people, this increment leads to increase the waiting time and the queue length for patients in VS or MCS, as seen in Fig. 2.

The average utilization of the system is the following:

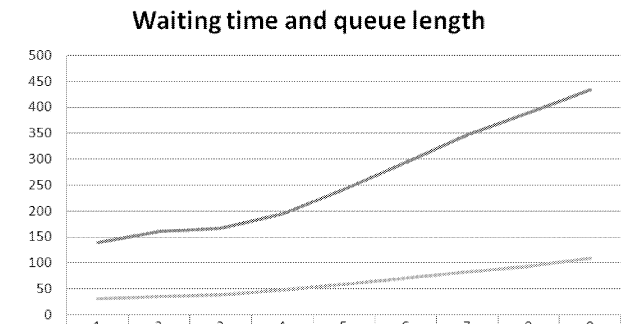
- 85 beds busy in Intensive care unit
- 136 Beds busy for Intensive rehabilitation
- 81 Beds busy for extensive rehabilitation
- resources need to follow 75 patients in home healthcare program
- 250 places busy in skilled nursing home with a queue of patients in vegetative state and minimally conscious state waiting for healthcare.

One of the limitations of this study, due to missing epidemiological data, is that it does not consider age to calculate how many non traumatic patients will arrive in the following years; epidemiological studies state that stroke will be the fourth most common cause of disability in western countries by 2030, and the age groups of populations is the most important factor to consider in this issue. In fact according to the demographical statistics in Veneto Region in 2011 there was a population proportion of people older than 50 years old of 39%; however, by 2031 the population of persons with 50 years old and over will be 48%; this statistic shows the current trend of the population aging, which leads to increase the incidence of non traumatic brain injuries and surely a redesign of resources available will need to take place. traumatic brain injuries in order to make a correct planning for the availability of resources.



	1	2	3	4	5	6	7	8	9
Wt	39	76	106	128	150	178	202	240	269
Lq	9	17	22	26	32	38	45	53	63

Fig.1 Average waiting time (Wt: days) and patients queue length (Lq) in skilled nursing home in next years from current situation



	1	2	3	4	5	6	7	8	9
Wt	140	160	167	195	241	293	347	390	434
Lq	32	36	39	49	59	71	83	95	109

Fig.2 Average waiting time (Wt: days) and patients queue length (Lq) in skilled nursing home in next years after population increase.

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MANUFACTURING OPTIMIZATION

An Improved Genetic Algorithm for Optimising a Manufacturing Production Process

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KEYWORDS
Genetic algorithm, Mathematical model, Optimisation, Production process, Scheduling

ABSTRACT
This paper presents an approach to improve the performance of a manufacturing production process to minimise the total production time via an improved genetic algorithm (GA) for optimising the job-shop scheduling problem (JSP). Orders of each product are placed randomly to form a queue to be produced in differing vessels. The problem is how to schedule the orders to produce in each vessel to obtain the optimal time based on the constraints and conditions as given. The improved GA integrates different strategies for generating the initial population, selecting the individuals for reproducing new individuals, and adaptive adjustment of crossover and mutation probability. The result shows that the algorithm is efficient and effective for reducing the total production time; it has saved approximately 5% more when contrasted with a traditional GA.

INTRODUCTION

It is well-known that the job-shop scheduling problem (JSP) is one of the most difficult combinatorial problems which is classified as a non-deterministic polynomial-time (NP) hard problem. It is a decision process to allocate resource optimally to tasks over a given period time. The GA is one optimisation method of that could be used efficiently for solving the JSP as described in (Yamada 2003; Zhang, Gao and Shi 2011; Huang, Zhao and MA, 2014). However, it may generate an error or miss the optimal results in the crossover procedure due to slow simulation speed, local optimisation, premature phenomenon, etc. In order to avoid these problems, many authors have suggested to improve the GA based on differing methods in encoding representation, generating the initial population, and selecting the individuals for reproducing new individuals, and offspring generation strategy. For example, (Pezzella, Morganti and Ciaschetti 2008) have applied a GA for a flexible JSP; it integrates different strategies for generating the initial population, selecting the individuals for reproduction and reproducing new individuals. (Chen *at el.* 2012) have also implemented a GA to solve flexible JSP based on two major modules: machine selection module and operation scheduling module. In addition, some authors have improved the GA to solve the JSP in various domains. (De Giovanni and Pezzella 2010) proposed an improved GA to solve the distributed and flexible JSP; it improved a new local search based operator to refine the most promising individuals of each generation. (Huang, Zhao and Ma 2014) also proposed an improved GA for JSP with process sequence flexibility; it redesigned the chromosome encoding schema, crossover operator and mutation operator to minimise the makespan. (Zhang, Gao and Shi 2011) designed the global selection and local selection to generate high-quality initial population in the initialisation stage; improved the chromosome representation and adopted different strategies for the crossover and mutation operator. (Qing-dao-er-ji and Wang 2012) proposed a new hybrid GA for JSP. It designed some genetic operators, such as a mixed selection based on the fitness value and the concentration value for increasing the diversity of the population, and local a search operator is improved for local search-ability of GA. (Asadzadeh 2015) has been proposed an agent-based local search GA for JSP. Two local search procedures are developed and applied to enhance the efficiency of the GA.

This paper considers the optimization task for a micro-brewery production system as defined previously by the authors (Shen *et al.* 2014). The Matlab/Simulink software is used to simulate the scenarios presented in a brewery production system and to identify bottlenecks that include uncertainty and non-linearity due to the production process constraints. The optimisation problem for the scenario of a brewery production system has been formulated using a mathematical model. Further work is concerned with a heuristic algorithm to optimise the production system. Subsequently, a traditional GA is implemented to optimise the JSP problem (Shen, Burnham and Smalov 2015). In this work an advanced GA is used to improve the previous work to apply the real number encoding representation to improve the computational accuracy and efficiency. It also adopts a method of adaptive adjustment of crossover and mutation probability, which is implemented to improve the diversity of the population, and to speed up the convergence towards a global optimal solution. The improved GA produces is shown to the better performance than the previous work.

ASSUMPTIONS

It is assumed that a formulation of the problem may be presented using an example of three beer types, namely Type 1, 2 and 3, and denoted p_1 , p_2 and p_3 respectively, and three parallel fermentation vessels of differing capacity. They also operate simultaneously within the same process, and are termed Vessel 1, 2 and 3, and denoted v_1 , v_2 and v_3 respectively. The maximum capacities of v_1 , and are expressed in terms of barrels (b) and denoted 20b, 30b and 50b, respectively. The assumed production process can be represented as shown in Fig 1 as follows:

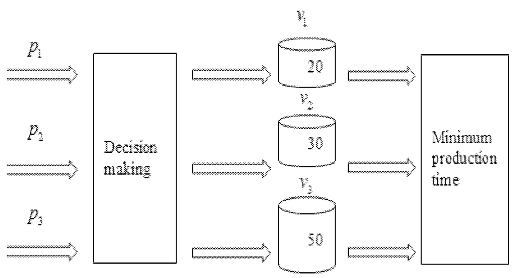

Fig 1: Schematic model of a brewery production process

The production process is determined by the fermentation time denoted T_{p_i} , cleaning time, setting up time and changeover time. The cleaning times for each vessel will depend on vessel capacity and it is increased by a nominal period when changing over from one type of product to another, so that when no changeover takes place the cleaning time is a minimum.

The saccharification process (expressed here the set up time prior to fermentation) varies for different types, denoted S_{p_i} . The cleaning times for the three vessels v_1 , and are denoted, c_{v_1} , c_{v_2} and c_{v_3} and these are taken to be 2, 3 and 5 hours, respectively. If a changeover of product type in a given vessel is necessary, an additional 12 hours is set for cleaning, denoted $C_{p_i v_j}$. Each beer order has a delivery date specification. It can be assumed that each order can be accumulated (for the same type of beer) up to a maximum capacity of the vessel. The due date denoted D_{p_i} for each product is also considered based on the customer demand and satisfaction. The parameters of such a brewery production system are presented in Table 1.

Table 1: Parameters of brewery production

		P_1	P_2	P_3
(days)		15	20	30
(hours)		24	48	72
(days)		20	30	40
(hours)	v_1	0	12	12
		12	0	12
		12	12	0

MODEL BUILDING

Several main conditions need to be taken into account as follows:

- Three different products working in three parallel vessels with limited capacity
- A set of fixed processing times and setting up time for each product as well as cleaning time for each vessel and changeover time. They are considered deterministic and known in advance
- Each vessel must process one batch of production only, once a vessel starts to process a batch of orders, no interruption is allowed, and then it needs to be cleaned when finished
- The arriving orders will be within accumulated batches in the same order to meet the required capacity of the vessels
- Priority of order is allowed based on due date
- The production time cannot exceed the due date

Mathematical Model

The following notation is used:

Table 2: List of notation

Abbreviation	Definition
p_i	Number of different products type i, $i = \{1,2,3\}$
v_j	Number of vessels j, $j = \{1,2,3\}$
$X_{p_i v_j}$	Number of occurrences of made in vessel v_j
$M_{p_i v_j}$	Decision making: if coefficient is 1, working in the same vessel, if coefficient is 0, working in different vessel
T_{p_i}	The fermentation time of
N_{p_i}	Number of orders n to be scheduled for , $n = \{1,2,3 \cdots n\}$
D_{p_i}	Due date for
S_{p_i}	Setting up for
$C_{p_i v_j}$	Changeover time for and v_j
c_{v_j}	Cleaning time for v_j
V_j	Capacity of v_j

Objective Function Formulation

It is assumed that three different types of beer are to be produced in three vessels separately, and no vessel changes at all, then the equation can be derived as follows:

$$T = \sum_{i=1}^{n} \sum_{j=1}^{n} X_{p_i v_j} M_{p_i v_j} \tag{1}$$

However, constraints are considered based on the real-life brewery production system, e.g. a due date of a product handover, a production delay, level of order priority. Therefore the following constraints are introduced to include the cleaning time, changeover time and setting up time. The objective function can be presented as follows:

$$\begin{aligned} T = {} & T_{p_i} \sum_{i=1}^{n} \sum_{j=1}^{n} X_{p_i v_j} M_{p_i v_j} \\ & + \sum_{j=1}^{m_1} \left(\sum_{i=1}^{n_1} S_{p_i} + \sum_{i=1}^{n_1} c_{v_j} \right) \\ & + \sum_{j=1}^{m_2} \left(S_{p_i} + \sum_{i=1}^{n_2} c_{v_j} + \sum_{i=1}^{n_2} C_{p_i v_j} \right) \end{aligned} \tag{2}$$

Constraints

In the real-life brewery production process, one batch of orders of each product can be produced in each vessel during a production process. This situation can be represented as follows:

$$\sum_{i=1}^{n} M_{p_i v_j} = 1 \tag{3}$$

$$\sum_{j=1}^{n} M_{p_i v_j} = 1 \tag{4}$$

where

$M_{P_i V_j} \in \{0,1\}, \forall\, i \in \{1,2,3,\ldots,m\}, \forall\, j \in \{1,2,3,\ldots,n\}$

The capacity of vessels cannot be exceeded when the accumulated orders of the same type of beer are to be scheduled to be processed. This can be represented as

$$0 \le N_{p_i} \le V_j \tag{5}$$

The due date of orders is also considered here, and production needs to be completed before or on the due date (the lateness will have a negative impact on the customers' satisfaction and may lead to loss of profit):

$$T_{p_i} + \left(\sum_{i=1}^{n_1} S_{p_i} + \sum_{i=1}^{n_1} c_{v_j} \right) \le D_{p_i} \tag{6}$$

$$T_{p_i} + \left(\sum_{i=1}^{n_2} S_{p_i} + \sum_{i=1}^{n_2} c_{v_j} + \sum_{i=1}^{n_2} C_{p_i v_j} \right) \le D_{p_i} \tag{7}$$

IMPROVED GENETIC ALGORITHM

According the drawbacks of traditional GAs several main aspects are improved as follows:

- Selection operator

In the GA, the main function of the selection operator is to obtain an excellent individual from a genetic population. The selected individual from the population will have a better chance to reproduce the next generation. Here we implemented a selection method of fitness value proportion, also as known as roulette wheel selection. The selection probability of each individual is obtained by the sum of each individual fitness and population fitness to generate a new population. The probability of an individual being selected can be denoted:

$$P_{mi} = \frac{f_i}{\sum_{j=1}^{m} f_j} \tag{8}$$

where P_{mi} is the selection probability of the i th individual; f_i is the fitness of the individual in the population; $\sum_{j=1}^{m} f_j$ is the cumulative fitness of the population.

- Encoding representation

Traditional GAs employ binary strings for the gene encoding. An important issue of the binary representation implementation has been identified by (Beasley and Chu 1996); the resulting solutions are no longer guaranteed to be feasible. Also it has been stated that real number encoding is best employed and gives better performance than binary or Gray encoding for function optimisation problems. In order to obtain a larger search space, here we applied real number encoding for gene encoding in the GA, so it is beneficial to retrieve the special heuristic information and to improve the computational efficiency and accuracy.

- Adaptive adjustment of crossover probability and mutation probability

The diversity of population is one of the most important factors in the GA. It is determined by a maximum fitness value and an average fitness value of each chromosome difference value. This can be represented:

$$\Delta f = f_{\max} - f_{ave} \tag{9}$$

where Δf is also known as the iteration error; $f_{\max}$ is the maximum fitness value; f_{ave} is the average fitness value. When is small, it is easy to lead to local convergence and become trapped in a local minima. In order to avoid the local convergence in optimisation, crossover probability and mutation probability need to be adaptively adjusted. These can be represented, respectively, as:

$$P_c = \frac{1}{1+e^{(-k_1 \Delta f)}} \tag{10}$$

$$P_m = 1 - \frac{1}{1+e^{(-k_2 \Delta f)}} \tag{11}$$

where P_c is the crossover rate; P_m is the mutation rate; and k_1 and k_2 are constant; in the iterative procedure, essentially, is repeatedly calculated from equation (1) and subsequently fed back to update equations (10) and (11) to adaptively adjust based on the chromosome condition. In this way we can obtain optimal crossover and mutation probability during each iteration.

OPTIMISATION RESULTS

According to the objective function of equation (1), orders can be generated for each product randomly to deliver to the three vessels for production in parallel as follows:

p_1 :13, 22, 1, 10,5,3,6,11,12,17,13,…

p_2 : 9, 1, 11, 9, 9,7,5,13,6,6,13,…

p_3 : 6, 8, 3, 6, 9,9,2,3,1,5,1,…

The main parameters are used:

- *number of generations: 1000*
- *crossover probability: 0.8*
- *mutation probability: 0.2*
- *generation gap: 0.9*
- *population size: 20*

The results obtained are shown in Fig 2:

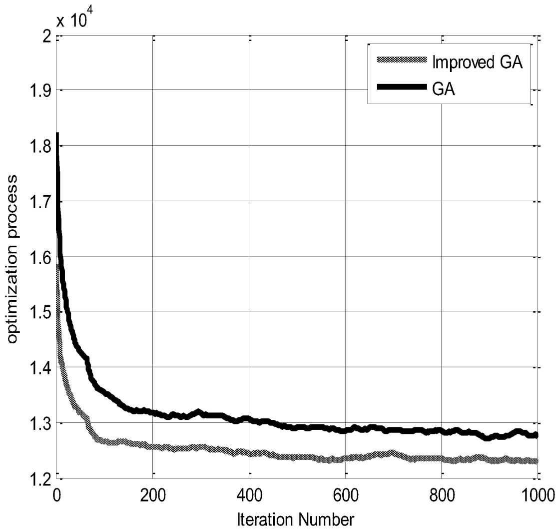

Fig 2: Result of total production time

Fig 2 demonstrates that the improved GA performs better than the traditional GA. This particular result is typical and is representative; being regarding as a general observation, when dealing with the micro-brewery system. In this particular result the shortest total production time is 12277 hours and 12744 hours respectively, for the improved GA and the traditional GA.

CONCLUSION

In this paper, we proposed an improved GA to optimise the JSP problem for a micro-brewery production system. The global searching capability and convergent speed is improved based on the adaptive adjustment of both the crossover and mutation probability. The result clearly shows that the improved GA is better than the traditional GA. As a next stage we will introduce a hybrid GA optimisation to further refine the improved GA, hence optimisation model.

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SIMULATION IN INDUSTRIAL AND CLOTHING PRODUCT DESIGN FOR PERSONALIZATION AND CUSTOMIZATION APPROACH

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KEYWORDS
Mass Customization Program, Sticky information, Fitting Clothing, Products Configurator, Rapid manufacturing

ABSTRACT

This paper examines the potential of clothing configuration within personalization and mass customization concept. Even if, some manufacturers have managed this approach successfully, some of them have poorly mastered the concept. The increase in purchase returns for personalized and customized clothes both in stores and on the Web creates headaches for retailers because it affects their brand image. The first problem is related to the manufacturing aspects with measurements, adaptation of patterns and flexibility in methods and manufacturing deadlines. The second is the lack of knowledge and experience from the manufacturers to use properly the configuration systems. It has become increasingly important to understand how to create an approach for Configurator Implementation for Clothing Personalization and Mass Customization program. For producers to make the most of mass customization they need to better understand what can be done in terms of clothing personalization and mass customization capabilities. We discuss custom clothing for men in conjunction with the effects stemming from the evolution of mass production practices. This led us to explore from different angles the problems related to the automation of standard sizes and integration of "fits" done in traditional ways as well as computerized ways with respect to product adaptation. In this paper, we also analyze the mass customization concept and propose technological and operational approaches aimed at initiating useful discussions to better understand these issues.

INTRODUCTION

Past research has demonstrated the importance of understanding the mass customization of clothing within the context of trade globalization, which has led to ever more ferocious competition in the apparel industry. Moreover, as apparel products now seem to have an ever shorter life cycle, a phenomenon which is exacerbated by the introduction and implementation of new business models, businesses' commercial strategies must face mounting pressure. This situation forces the apparel industry players to revise their organizational strategies in order to survive in this highly competitive market. Organizations must reinvent themselves and find new ways to satisfy their customers. In order to grow, to maintain the current level of employment and possibly increase it, garment producers will need to develop new manufacturing strategies by orienting local production towards a flexible, quick-response system that allows for the production of various types of orders (small quantities, short deadlines, skilled labour, etc.). Thus, it will become essential for businesses to implement new strategies that correspond to the reality of current markets, in order to keep up with the rhythm of short cycle production. Businesses need to focus on flexibility, adaptability and agility (Pine, 1993).

CASE STUDY

Reviewing the writings on this subject tells us that paradoxically, at a time where the global key word in most industries is standardization, the focus in the apparel industry is on ''uniqueness.'' With the recent surge in the use of new media and telecommunication, consumers are more and more demanding and informed. They are no longer satisfied with standardized products that force them to make compromises. The Internet influences customers' buying habits by creating needs that have to be satisfied instantaneously.

In the clothing industry, these expectations not only imply having to constantly provide consumers with new options in terms of styles and colours, but also to allow them to find an affordable well-fitting clothing item and make it available to them almost as rapidly as if it was a standard-sized product. In order to meet these expectations, clothing companies must now propose custom-made products. Brands that offer personalized products (mass customization) are taking over both traditional and online stores. This is made possible by identifying the key points of body measurement necessary to produce well adjusted, well-fitting garments. However, being able to take these measurements effectively and efficiently is crucial. Although efficient and affordable technologies are available to provide a body scan, few businesses are able to meet the requirements of custom-made products for the following reasons: lack of reliability of the measures provided by the body scan, problems related to the transmission of a large quantity of data to ''potential manufacturers, interface issues between the data generated by the body scan software and that used by pattern making, cutting and assembly.

Many apparel businesses are currently researching technological ways to produce, adjust, sell, and deliver, in a systematic and automatized fashion, personalized and made-to-measure products. Nevertheless, mass customization somehow remains misunderstood or is rarely used by actors in the clothing industry mainly because of the widely variable measurements, of the problems in adapting patterns, of the need for flexibility of manufacturing delays and methods. Many authors have produced research on mass customization; however, few of them have sought to identify the problems related to sizing and to so-called 'hidden data' coming from the customers (ease allowance, fulness, etc.).

Our objectives to develop a configurator for clothing mass customization (Figure 1), using computerized information systems, that could be used to analyze and decode measurement data coming from peripheral devices in order to identify as precisely as possible the necessary information to produce a well-fitting garment.

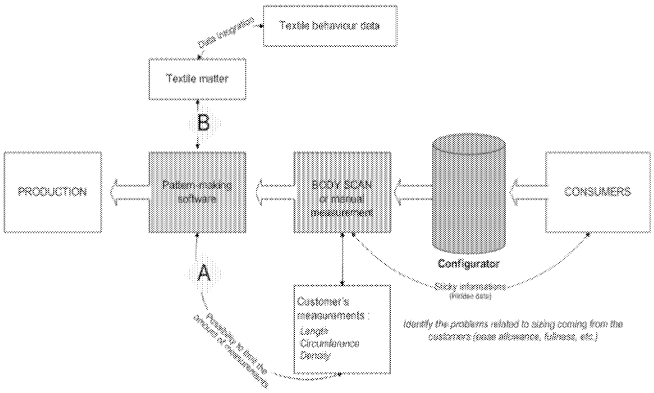

Fig. 1: Configuration for Clothing Mass Customization

Hence, we need to identify the fundamental variables and data that are necessary to produce custom-made clothing. Parsimony in fundamental variables (length, circumference, density and textile matter behaviour) will allow to significantly diminish the amount of data to analyze and send out in order to create an 'intelligent' pattern.

In this research, we hypothesize that the amount of non-essential data for pattern automation can be reduced by 65% (typical measurements), from the current situation. We shall not only try to reduce the quantity of data, but also to determine the minimal number of measures needed (minimum cardinalities). Moreover, using anthropometric measurements, like density, will enable us to identify key referential points which are essential to ensure proper fit. These referential points, when combined with data related to textile textures and behaviours, will allow for personalized pattern grading. To accomplish our primary objective we therefore must reduce the amount of data while increasing the quality of automated clothing patterns, thereby allowing for the production of well adjusted custom-made clothing that meet customers' needs and expectations

LITERATURE

The goal of mass customization is to efficiently provide customers with what they want, when they want it, at an affordable price. Inala (2007) contends that mass customization has become a competitive strategy for businesses that want to offer personalized products. The more a business provides opportunities to personalize its products, the more competitive it becomes (Pine, 1993).

A mass customizer must first identify the idiosyncratic needs of its customers, specifically, those product attributes along which customer needs diverge the most (Piller and Blazek 2014). When clothing was made to measure, each garment was cut and assembled for individual customers (Istook 2002). As a result, it provided a personalized fit (Workman, 1991). This type of production is what Pine (1993) refered to as personalized and handcrafted production. Likewise, in order to be able to meet the demands of mass customization, all of a manufacturer's operations have to be based, according to Zipkin (2001), on flexible processes that allow it to respond rapidly to customers' requests. More often than not, mass customization consists in, for example, assembling basic items according to specific orders.

Mass customization therefore becomes a crucial development solution for businesses specialized in garment manufacturing and distribution (Pine, 1993). In fact, the demand for mass customization of clothing is only growing stronger. It has become possible thanks to the contribution of new technologies. Custom-made clothing requires a very thorough understanding of the expectations and specificities of each individual (Peterson, 2008). According to Pine (1993), the success of mass customization rests mainly on a successful integration of the value chain. In some respects, businesses must accomplish a feat by performing well on two axes that are generally on opposite sides of the spectrum in most businesses: maintaining short supply lead times while offering custom-made products that correspond to clients' specifications.

There are mass markets for some customized products — the emergence of mass-customized apparel demonstrates that (Zipkin, 2001). The main problem of mass customization is related to the preparation of products according to customers' requirements. Moon et Al (1998) states that because of their lack of knowledge and experience, consumers do not know what they really want. It is thus important to simplify their request by offering them some guidance. Doing so not only requires knowing a customer's measurements and style, but also obtaining information that he never reveals: what literature refers to as "sticky information".

The term "sticky information" is defined by Von Hippel (1994) as information hidden by a customer that provides, in certain cases, a company with a key competitive advantage and offers significant opportunities for innovation. For example, consumers know their needs and tastes better than manufacturers. It is therefore difficult for a manufacturer to obtain information that is either confidential or perceived to be so irrelevant that consumers reveal them sporadically, at best. This unknown data, like ease allowance, fit, proportion and the like, are essential to the production of custom-made garments. According to Ashdown (2013), they are at the source of most purchase returns occurring in stores.

PURCHASE RETURNS

In the American industry, clothing size standards were created following anthropometric studies conducted in the 1940s. The aim was to satisfy customers by allowing manufacturers to fine-tune their production in terms of sizing. In recent years, however, we have come to face certain problems related to fit. Body proportions have changed since the 1940s and 1950s, or even since the 1980s. Body measurements have changed: clothing sizes based on body measurements established in the 1980s no longer correspond to reality. The new generation of men between 18 and 35 is much taller than the average height found in the 1980s." Size effects related to nutrition and physical exercise have modified body shapes which make clothing adjustments more complicated. Standard sizing issues for clothing are only becoming more widespread with the advent of globalization (Faust and Carrier, 2009). Because of this, order initiators do not respect standards and create their own size specifications that correspond to their target market or are consistent with their vanity sizing strategy. However, they still continue to use the generally accepted size labels (Ulrich, Anderson-Connell and Wu, 2003). Without clearly established norms or standards, consumers have difficulties finding their way, which generates frustration and confusion when trying on clothes.

The increase in purchase returns for clothes both in stores and on the Web creates headaches for retailers because it affects their brand image (Park and Stoel, 2002). According to a survey conducted by Synovate in 2008, 58% of Canadians claim that it is very difficult to find clothes that fit them perfectly and 77% of people surveyed find that sizes vary from store to store. As a result, it appears important for stores to know their clientele and to offer clothes that fit customers adequately in order to increase their volume of sales per customer. Thus, some problems associated with mass customization must be corrected by the garment industry, they are: the templates (blocks) used to create basic patterns are not adequate; the size standards and measurement charts have become obsolete; the sizing per territory/population rapidly changes; and, some of the information hidden by the customer must be decoded by manufacturers.

Faust and Carrier (2009) contends that errors in measurements still prevail in the clothing industry. Even if a customer is given a sizing chart, it is still difficult for him to take accurate measurements on his own. Ashdown (2004) has identified a few simple problems that might be encountered. For instance, when measuring waist circumference, it is necessary to stand straight in a natural position and to hold the tape measure parallel to the ground. A slight imbalance could result in errors of up to half an inch on the final garment. The main problem occurs when measuring the waist girth. Moreover, Park and Stoel (2002) mention that data transmission errors taking place during the data transfer process create problems at the time of order. As for the 3D body scan technology, it sends more than 300 000 data items during a sample body scan (Ashdown, 2007) which increases the complexity of selecting valid data in order to obtain reliable information.

Both methods (manual or 3D body scanner) of measurement have their strengths and weaknesses. For some authors the biggest strength of the manual measurement is its ability to identify incoherent measurements while its most important weaknesses are the labour costs and the imprecision caused by human error when transcribing data (Fan et al., 2004). On the other hand, the strengths of the 3D body scanning are the speed and the low cost (nowadays) while its main weakness are in the measurement inconsistencies due to movement (Istook et al., 2011), the lack of accuracy when compared with manual measurements (Liu et al, 2014), and the difficulty to obtain correct measurements at feet position, for example (McKinnon & Istook, 2002). Accurate body measurements can be difficult to obtain with 3D body scanning due to factors such as posture, landmark indications, instrument position and orientation, pressure and tension exerted (Fan et al., 2004).

Not so long ago, body scanning was still at the stage of acceptance and maturation in the industry; the benefits of automation were not clearly visible (McKinnon & Istook, 2002). Female consumers who have been scanned generally react well to the results, yet women from specific socio-demographic groups are less comfortable with the idea of being body scanned (Loker et al., 2004).

As Whitestone & Robinette (1997) write, 3D body scanning is now an accepted tool in the apparel industry. As time goes by, the non-contact body measuring technologies generate more and more interest and applications in the apparel industry. It can be put to numerous applications: anthropometric measuring surveys, development of three-dimensional apparel, computer aided design (CAD), virtual garment environments and animation, mass-customization, etc. (Jones et al., 1995; Hardaker & Fozzard, 1998;, A., 2001; Koontz & Gibson, 2002; Xu et al., 2002; Ulrich et al., 2003; Bachvarov et al., 2014).

Ashdown (2013) indicates that computer systems need to accurately generate the information coming from both the pattern-making software and from the body scan. Issues arise when size charts and fit levels for different body types are not clearly established from the start. The key to success lies in the development, the architecture and the support of computer systems used to generate data based on individual body dimensions for pattern-making software, which need to be adapted individually. Despite the fact that all these approaches aim to produce apparel as accurately as possible, it appears that the great number of constraints makes it difficult to find a compromise between performance, accuracy and technicality during the production process.

CONFIGURATOR & CLOTHING PRODUCT DESIGN

Here, configuration processes play a crucial role to manage this task by providing customers support and navigation in co-designing their individual product or service. There is nothing simple about mass customization and it is not a simple strategy to undertake organizationally; it is not even a simple concept to comprehend (Hart, 1994). Today's market heterogeneity, increasing variety, steadily declining product life cycles, decreasing customer loyalty, and the escalating price competition in many branches of industry are the main motivators for firms going into mass customization (Pine 1993).

Configuration is an essential aspect of mass customization because it creates the possibilities to guide customers as they are making choices. Haug et al (2012) contends that the primary objective of a configurator is to facilitate the decision-making process of customers using a Web-based interface. Product configuration systems play an important role in supporting the mass customization paradigm, as it helps to determine the degree of personalisation that a business will offer. Thus, the role of the configurator is to create a link between consumers and manufacturers (Inala, 2007). Mass customization does not equate to an increase in costs. According to Piller and Blazek (2014), using a configurator could significantly reduce costs since its Web-based technolgy dimishes the time required to take orders and the application of toolkits (Figure 2) for customer co-design may be the most used approach to help customers navigate choice in a mass customization system.

Fig. 2: Mass customization configurator for clothing

In the current context, businesses use catalogs and manual production methods. Catalogs provide a predefined and limited number of combinations for a product without necessarily fulfilling all of a customer's specific needs (Quin and Yang, 2009). Manual configuration, on the other hand, essentially relies on human expertise and necessitates competent and highly skilled workers (Rogoll and Piller, 2004). However, a lack of expertise eventually requires investments in terms of time and efforts; moreover, it forces employees to keep up to date with frequent technical changes and improvements. As a result, the configuration of a product to meet a customer's requirements can become a complex task which gets more demanding as the number of components and options increases. When the configuration requires numerous variations, the possibility of making errors also rises which can result in production delays. The repetition of subsequent steps may be required which can be costly. Thus, Ashdown (2007) contends, mass customization creates various technical challenges that need to be overcome before mass customized garments can be produced.

The technological risks associated with a configurator project are essentially related to the development of a system that can share and process data and parameters (the parameter configurator) originating from various sources such as: the data entry tools (e.g. the Body scan), the basic garment patterns, the marker-making software, the automatic cutting table and the administrative and financial data. In short, none of the existing technological system seem to provide a solution for mass customization in the apparel industry. Rogoll and Piller (2004) indicate that the optimal product configurator needs to create an interface between different programming languages and function entirely independently. Incidentally, these criteria add to the level of uncertainty associated to this type of installation. Figure 3 demonstrates how the configurator would operate in a clothing mass customization program.

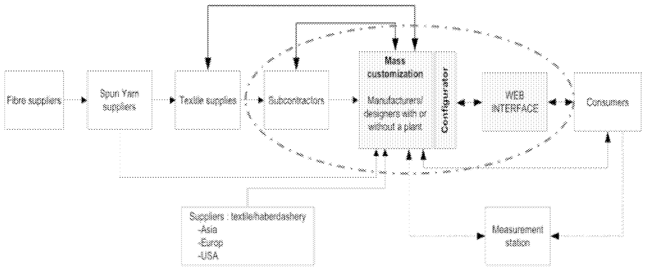

Fig. 3: Mass customization program

A product configurator must be used along with a high-performance technological platform so as to allow for interaction between customer and manufacturer as the product is designed. This creates an interface between the customer and the supplier which provides opportunities for value co-creation in both the apparel and fashion industries.

The most important mass-customization prerequisite is the understanding that mass customization itself is a highly customized strategy and you cannot imitate someone else's successful mass-customization strategy (Hart 1994). If prime producers want to make the most of this prospect, they will need to better understand what can be done in terms of clothing personalization and mass customization so as to formulate an appropriate strategy on how to use their measurement configurator. This research project will provide tools for fashion industry businesses that will allow them to gain a competitive edge through custom-made and short lead time projects. The opportunities created by the absence of such a service or system needs to be used by businesses in this industry to reposition themselves on the garment and apparel markets, both locally and internationally. This research offers great possibilities in terms of innovation and could constitute an outstanding opportunity for several actors in the fashion and clothing industry. Even though the local garment industry and that of emerging countries face each other on an uneven playing field, the local industry possesses a technological environment that could give it a significant advantage.

RESEARCH

The first stage of this research project is a preliminary study of the fundamental variables and data needed to produce a custom-made garment. This first step will allow for the production of a study which is itself an integral part of a larger research project. The proposed approach will aim, in part, to identify the fundamental variables and data essential to the fabrication of custom-made apparel. After this results has been submitted, the data obtained will be analyzed which will allow for the creation of a product parameter configurator. Moreover, in the near future, we will assess the modalities of implementation of this technology and its progressive use in the fashion and garment industries. The preliminary phase of this research project will take place in a manufacturing environment specialized in men's fashion.

At first, we will study the mass production and custom-made environments that exist in this industry. Next, we shall analyze three pants models provided by manufacturers specialized in athletic wear, sportswear and workwear. Each pattern will be analyzed and dissected in order to assess the fitting and grading methods used in relation to size and type of textile. From this first study, we will formulate an hypothesis on the fundamental variables needed to produce a garment using mass customization. In order to validate the fundamental variables that will enable us to create our configurator, we will conduct a study of the process involved in body measurement (length, circumference, density and stature) using both a body scan and manual measurements. We collected complete measurement data for 60 male subjects, aged 18 to 69.

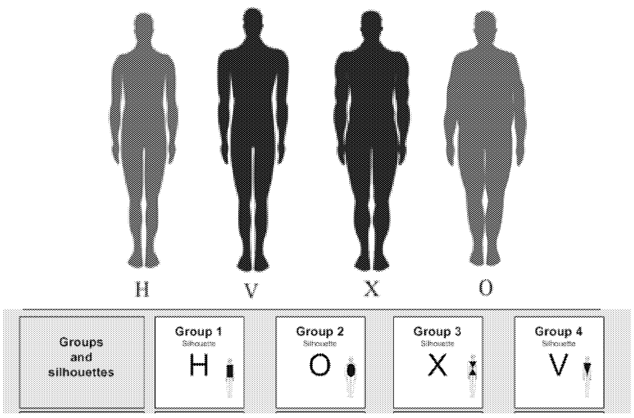

Fig. 4: Analysis of shapes processes and methods

In a same group of 60 men, 12 men will be recruited to allow us to model the variables and data linked to a production model that is part of a real rapid manufacturing process. So as to facilitate research based on individual shape groupings, we will use figure types represented by the letters H-O-X and V to categorize different types of silhouettes and redefining silhouettes from Rasband and Leichty (2006). Four morphotype-groups will be made up of men (of different stature) wearing a size 40 jacket and trousers of sizes 32 to 38. This innovative method significantly improves the recurring problem in the industry regarding classification systems of normalisation.

It will then be possible to validate the data through our configurator and produce garments using rapid prototyping. A thorough examination of the clothing items produced will be carried out during the fitting phases in order to analyze their "fit". This will allow us to determine which variables appear to be problematic.

Mass customization offers a new business model and growth opportunities for small manufacturing businesses and clothing companies. Indeed, from mass or large volume production, businesses in this industry will be able to profit from this value-added advantage. According to Zipkin (2001), this type of production will be possible on a large scale because new technologies will become more easily accessible. This project originated from the idea of creating the "optimal" product configurator which would have the capacity to efficiently translate customers' desires and associate them with their anthropometric and anthropomorphic characteristics.

INDUSTRIAL SIMULATION

It appears obvious, following our measurements and interview activities involving 60 male individuals in the integral part of a larger research project, that the single pattern with respect to standard sizes is inadequate to meet the needs of the population. Personalization therefore is deemed to have a great future within the apparel industry.

Based on measurements systematically made on several pairs of pants, it appears that manufacturers have a major issue with respect to consistency in their productions, not to mention that the underlying patterns are far from perfect. Based on this data, three different pairs of pants of the same quality, brand and manufacturer will feel different on an individual. Independent of our approach to mass customization, we are attempting to solve this problem through this research because it is useless to try and find the perfect pattern for a given individual if the manufactured trousers do not conform to the pattern. In addition, following our measurement activities and meetings with master tailors, it appears that the measurements taken manually or in an automated fashion by body scan will not suffice to guarantee a minimum fit criteria when it comes to custom trousers for given customers. Other types of data are determined more essential and more important than measurements. A particular approach to mass customization will require the acquisition of important data concerning fit, habits and choices. This is confirmed (figure 5) following our meetings with North American pattern makers and manufacturers. When analyzing the process of creating patterns for different sizes from a master pattern, it appears that it will be very difficult to create a specific pattern for every customer. This type of fit patterns automation is deemed neither feasible nor necessary.

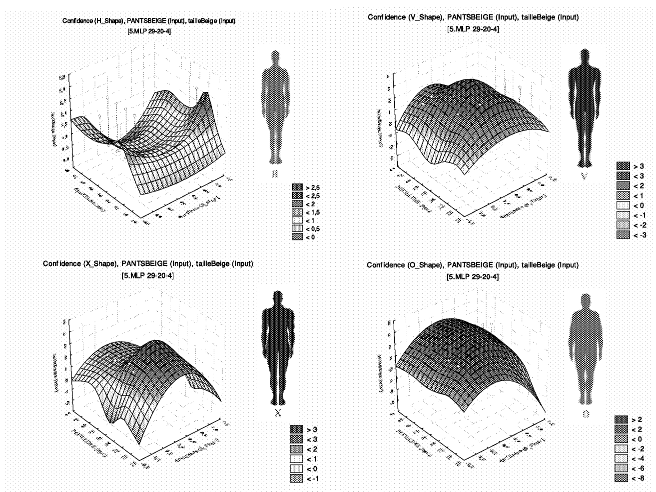

Fig. 5: Result of action and assessment of technological simulation tools used in the industry (cluster *fit*)

Analysis results of the 60 individuals sampled show that we can identify approximately 12 customer profiles for every size. It would therefore be needed to design from known data, not one but 12 patterns for each size to accommodate the entire population with pants that would fit just as well as custom-made ones.

The issue with mass customization would then rest on rapidly identifying the customer profile (figure 6) from the 12 standard profiles, and produce a pair of pants from the corresponding pattern.

hidden neuron 10 --> SHAPE	-0,32745	H	Skinny
hidden neuron 6 --> SHAPE	-0,093516	H	
hidden neuron 8 --> SHAPE	-0,03338	H	Slim
hidden neuron 4 --> SHAPE	0,02314	Y	
hidden neuron 3 --> SHAPE	0,10598	V	Athletic
hidden neuron 5 --> SHAPE	0,190547	V	
hidden neuron 9 --> SHAPE	0,191697	X	
hidden neuron 1 --> SHAPE	0,240553	X	Strong
hidden neuron 11 --> SHAPE	0,305938	A	
hidden bias --> SHAPE	0,379991	O	
hidden neuron 2 --> SHAPE	0,435701	O	
hidden neuron 7 --> SHAPE	0,752189	O	Obese

Fig.6: Neural network and profiles

Tests made with respect to neural network aspects show that it is possible to automatically classify all individuals with relatively fewer sizes than what is conventionally used (only 65% of typical sizes), however adding information from body analyzer/weight data providing fat and bone mass data (in the form of lean body mass statistics), body water percentage and data concerning fit perception. On the whole, these results allow us to envision the logistical aspects within an installation that would use mass customization methods.

The methods also become different for patternmakers since instead of creating one pattern for each type (i.e: master pattern for size 32), 12 patterns for each silhouette type would then be created. Then, the same extraction methods for grade units using master grade units would yield the 12 patterns for each grade. Thus, by obtaining a body scan through Kinect Xbox-3D and data from a short survey/questionnaire, the manufacturer will then automatically obtain the silhouette data of target customers.

Currently, tests with a configurator, confirm the validity of our variables and the future potential for rapid prototyping by a mass individual production and assure a well-fitting garment via an online request. This method can be applied for professional, commercial, technical and mass consumer apparel. Through this work, it is also seen that it would be beneficial to label ready-to-wear trousers with silhouette-type information that best displays the style. This would no doubt allow the customer to filter more quickly through non-desired pairs or models. This simple approach provides new perspectives with respect to new and interesting concepts such as “Fitthinking” theory for this industry and that could serve well in future tasks. This project offers numerous innovative possibilities and could provide a major opportunity for those implicated in the apparel industry.

These findings should encourage the actors that make up this industry to re-adjust. In an age where innovation and technological developments play an increasingly crucial role in counteracting the effects of lower wages found in other countries, the objective of this research is to demonstrate the importance of implementing mass customization and rapid manufacturing systems adapted to the needs of all actors in the clothing industry.

CONCLUSION

Apparel industry businesses must be proactive, adopt, and adapt to new mind-sets and management tools to take full advantage of information technologies. To successfully implement mass customization, it is of the utmost importance that they emphasize analysis, decision making, performance evaluation, and added value. Indeed, flexibility is a must as the market increasingly expects it. Mass customization offers much potential for extending brand awareness, acquiring new markets and generating profits.

However, as stated, in order to do so, manufacturers must adjust their business practices and clearly define the limits of their operational strategy so that they do not radically alter a structure that took years to build. Mass customisation must not be strictly seen as a short-term marketing strategy. When introducing new products or practices, a brand must be in synergy with the new offers, even if the company initially loses money. The manufacturer must commit to a sustainable development with a vision, challenges, directions, areas of intervention and objectives as ‘clear as possible' to be an example to follow and must demonstrate leadership.

If actors in the fashion and clothing industry accept this change of direction, this project could evolve into an extremely competitive business model that could represent a viable option for companies in different sectors. From the start, mass customization needs to directly involve customers in the designing and manufacturing phases.

Moreover, this customization model must provide opportunities to generate savings by reducing stocks and by allowing for a better integration of all actors in the supply chain. Mass customization offers possibilities to reach, or even surpass, customers’ expectations. Therefore, it needs to provide a knowledge base of consumers’ needs and preferences and thus create opportunities for market segmentation.

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VR IN MANUFACTURING

COMBINED SIMULATION AND ANIMATION OF AUTOMATED MANUFACTURING PLANTS

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ABSTRACT

Industrial enterprises dealing with automated manufacturing plants often use 3D tools for several task in the lifecycle of a plant. On the one hand, enterprises need abstract visualizations to support marketing and sales activities during plant design. These visualizations must be created fast, easily, and at low costs. On the other hand, enterprises need technically detailed models of the plant in subsequent stages, e. g. for planning validation, controller development, and virtual commissioning. Today, most enterprises use separate animation and simulation tools to meet these demands.

In this paper, we present a concept for combined simulation and animation of automated manufacturing plants. We give an introduction to this subject and describe the problem in detail. After a glance at the state of the art we present the new concept and the requirements for a successful implementation. Finally, we give two application examples which prove the operational capability of the concept.

INTRODUCTION

Nowadays, the simulation of automated manufacturing plants is part of the state of the art in industrial production. Many companies successfully use simulation. The goals of simulation are e. g. the validation of processes or the planning, optimization, and virtual commissioning of plants. Especially when the real plant has not been built yet, is currently not available, or experiments and modifications are too expensive or too dangerous, simulation experiments may help to improve the total quality of the plant.

Besides these very technical fields of application, simulation is more and more used for presentations at company-internal meetings and to support marketing and sales departments. This is because 3D simulations are an approved tool to simplify and thus enhance communication among stakeholders with different professional backgrounds. The three-dimensional visualization of components and processes in motion reduces the cognitive stress for the observer and leaves resources to carry out the actual intellectual challenge.

PROBLEM

A typical problem regarding the company-wide use of simulation tools is the fact that different goals of involved departments result in different requirements on the degree of abstractness, the precision, and the complexity of the employed simulation models. A simulation intended for marketing or sales presentations has to be created in an easy, fast, and cost-saving way while omitting technical details. For technical models used in plant design or for virtual commissioning, such a reduction is not reasonable. In practice, many companies face this problem by following two parallel and separated approaches: On the one hand they employ a pure animation software for abstract presentations and on the other hand they use a specialized simulation tool for technical engineering.

As a consequence of the separated treatment of animation and simulation, many very similar steps of the required work flows are executed redundantly and thus lead to additional expenses. These extra efforts do not only occur once but repeatedly with every change to the planning and thus the current simulation model. This is because every single change has to be tracked in two separate software tools.

STATE OF THE ART

There are different software tools that allow for the creation of 3D animations, also for the visualization of highly dynamic processes within automated manufacturing plants. The most important tools are

- MAXON CINEMA 4D Studio,
- Autodesk 3ds Max, and
- Blender.

While the first two products are commercially available, Blender is an open source software under the GPL license. To create an abstract animation of a manufacturing plant, the work flow is quite similar with all three tools:

- Import of CAD data from the original construction,
- Structuring and preparation of the geometry data,
- Definition of the movement trajectories of the single components over time,

- Optimization of optical material properties and lighting settings, and
- Creation of a video of the desired sequence.

The result of the work flow is an animation video which shows the complex processes within the plant and which can be played independently of the software used for creation.

In the context of this paper, the definition of trajectories is the main step on the way to an animation. For every single model component that shall move, the required position and orientation at the start time of the movement and at the end time of the movement are determined over the time line.

During animation, position and orientation of components are interpolated along different trajectory types between start point and end point – the so called Keyframes. Typical trajectory types are linear, circular, and spline. Complex collective movement is achieved by defining trajectories for all independent components. At this stage, the main difference between animation and simulation arises: For an animation, every movement is defined statically over time and subsequent movements are not adapted to changes.

Generally, the listed software tools are not specifically designed for the animation of automated manufacturing plants but they similarly allow for the animation of almost any movement up to the complex movement of humans. Nevertheless, some tools offer additional functions that ease the modeling of technical processes. For example, software modules for rigid body simulation enable single model components to react to the movement of other components according to the laws of physics. This happens without the need to define the complete movement sequence explicitly over time. Moreover, there may be algorithms for kinematics and inverse kinematics that allow for the exact calculation of mechanical dependencies. Currently, there is no animation tool that can execute true simulation considering e. g. real controller programs.

While animation videos can be created with appropriate animation tools, it is also possible to create such videos using a simulation tool. The main difference is that movements of the single components are not defined statically over time but they result as a reaction to changes of the model state. Such changes can be geometrical, electrical, or physical in general. However, the effort for modeling movements using a simulation tool is much bigger than using an animation tool. Moreover, the modeler has to ensure that all necessary model changes during simulation really happen to trigger the required movements. For automated manufacturing plants, this means that the plant controller has to be incorporated in whole or in parts into the simulation model. This way, the resulting collective movement will correspond quite well to the real process. Furthermore, the detailed impact of the controller can be observed during simulation because simulation, in contrast to animation, directly reacts to changes.

For technical purposes, simulation has to be preferred to animation. For the simple creation of a video showing abstract processes, the effort for simulation normally is too big.

THE NEW CONCEPT

As a new approach to solve the described problem, we have developed a new concept: The combined simulation and animation, especially for automated manufacturing plants.

Up-to-date software tools for 3D simulation of complex processes in industrial plants offer kinematic, dynamic (physical), or script-based simulation of motion or even hybrid forms of these. For the first time, our new concept allows for the combination of such simulated motion with movement definitions known from animation programs.

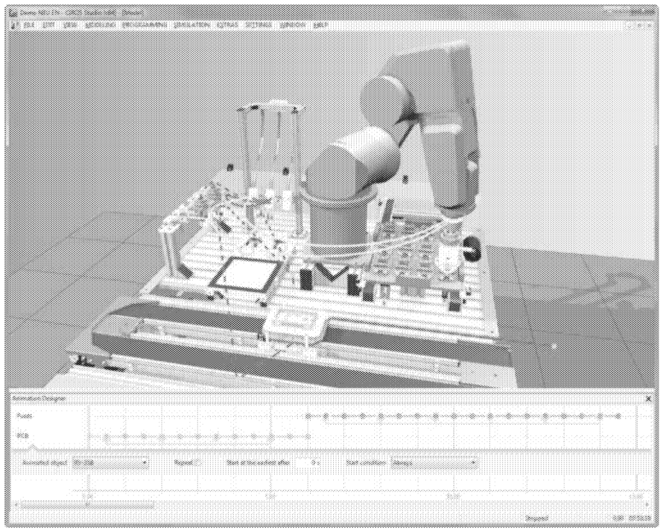

Figure 1: Animated Handling Task

For a first example, figure 1 shows a robot which is animated along a trajectory manually defined based on Keyframes. The resulting trajectories are visualized by red and yellow lines. For the Keyframes, the definition of position and orientation for the tool center point (TCP) of the robot is sufficient. Kinematics modules are employed to calculate the position of the robot's different axes accordingly. The robot grips parts, moves them, and releases them. All this is defined using Keyframes and without any robot programs. Nevertheless, the same virtual robot may optionally be controlled using original robot programs later in case more technical depth is required. This first example shows, how the benefits of animation and simulation can be exploited with one model at the same time.

Figure 2 shows tools and auxiliary means for the creation of an animation. Using an animation plan with a time pattern, the modeler defines the movement behavior of components over the timeline. A track in a row of the animation plan is provided for every component or assembly. The 3D poses at the start time and at the end time are marked by Keyframes. The series of all coherent Keyframes within one track builds up a sequence.

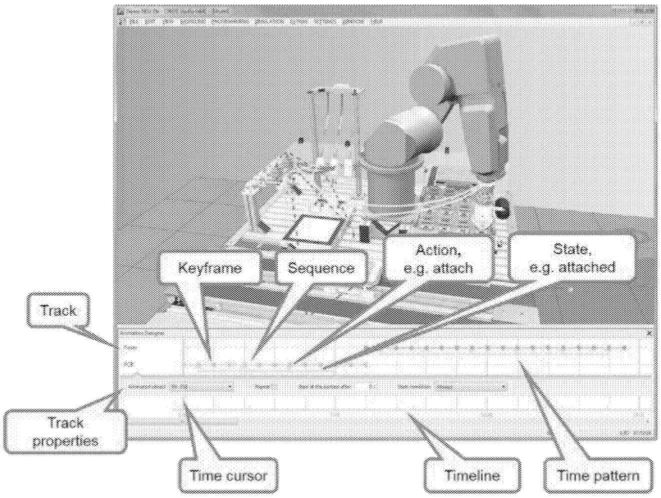

Figure 2: Tools for Animation Creation

During the course of the animation, the time cursor moves along the timeline and the 3D pose of the moved components is interpolated between the Keyframes. Every Keyframe can optionally define additional actions like the attaching and releasing of other components or the setting of electrical outputs within the model. In figure 2, the additional actions at the Keyframes represent gripping procedures of the virtual robot. The resulting gripping state is visualized below the sequence.

The challenge concerning the integration of the animation with the simulation is the combination of the different movement definitions. An animated movement must be able to trigger simulated movements and vice versa. Moreover, an animated movement shall be started upon an electrical signal from a simulated controller and after an animated movement has ended, an electrical signal for a simulated controller shall be set.

The new concept of combined simulation and animation imposes some demands on the model representation and the architecture of the employed software tool. We have decided to integrate the animation capabilities into an existing simulation tool and not the other way round. In the following, we will present some of the characteristics of the simulation tool which allow for the combination of simulation and animation. More details can also be found in (Roßmann et al. 2010).

Model Representation

The simulation model used must comprise both geometric and functional aspects. To describe all environment data, we use the Systematic Environment Decomposition Data (SEDD) for the model representation and the XML-like Geometric Modeling Language (GEMOL) to store models in a file system. Both concepts are first presented in (Rossmann 1993). Figure 3 shows how a 3D simulation *environment* is hierarchically decomposed into the SEDD elements *objects*, *sections*, *hulls*, *vertices*, and *facets*.

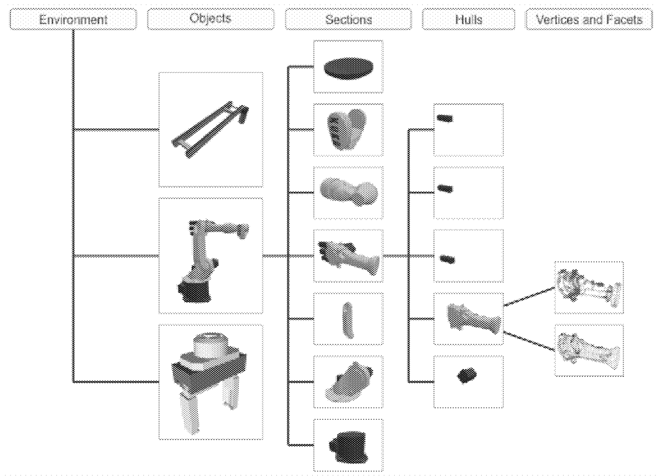

Figure 3: Hierarchical Decomposition of a 3D Model for Simulation and Animation

An *object* is a logical unit of the real world like a belt conveyor, a robot, or a robot gripper. Such an object is further decomposed into *sections* which represent rigid bodies. There may be a degree-of-freedom, i. e. a linear or a radial axis, between two sections but not within one section. For a robot, the sections correspond to the separate axis bodies. A section itself consists of any number of hulls. A *hull* is a purely geometric element. Its surface is described in a 2½-D fashion by planar *facets* in between *vertices*. Moreover, *materials* with optical, electric, magnetic, and acoustic parameters can be assigned to each hull. Every SEDD element's pose in 3D space is given by a 6DOF homogenous transformation matrix (a frame) relative to the superordinate element.

Functional properties are added to the model on several levels. Every object has a unique type denoting its function e. g. behaving like a robot, a robot gripper, a part magazine, a clickable button etc. Electrical inputs and outputs (I/Os) – digital and analog – are also defined at object level. Electrical connections can be established directly between any output and any input. For the definition of arbitrary kinematic chains, a dependent section's *grip point* can be attached to another section's *gripper point*. If the latter moves, the dependent section and its whole object will move accordingly. Furthermore, the SEDD allows for the nested integration of whole environment models (*libraries*) into a superordinate environment.

Simulation Tool Architecture

Figure 4 shows the architecture of the simulation tool (Hypki 2008). The central coordinating instance, the *simulation kernel*, keeps and handles the SEDD-based environment model, updates I/O connections, and provides basic mechanisms. Moreover, the kernel offers the fundamental user interface of the simulation tool and the multi instance 3D render engine. The renderer will even be capable of creating stereo images of a scene if the used graphics adapter supports quad buffered OpenGL as, for example, the NVIDIA Quadro series does.

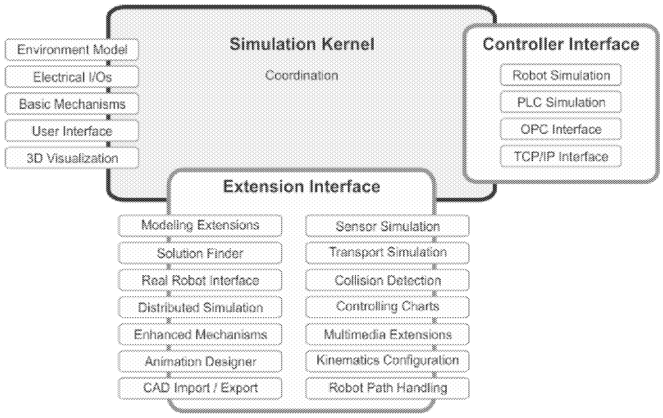

Figure 4: Architecture of the 3D Simulation Tool

Concerning simulation, the simulation kernel employs time-based simulation with a fixed time step. Opposed to many other simulation tools, the visualization of the scene can be updated after every single time step to achieve an "online visualization" during simulation – always showing the current model state and allowing for user interaction like e. g. pressing buttons.

The relation between simulated time and real time is handled by a controller-based real time adjustment (Freund et al. 2002). Simulation time can either elapse synchronously to real time or as fast as possible. Even time scaling is possible to make the simulation run faster or slower than real time by a fixed factor.

The system's architecture provides two concepts to add functionality to the system – the controller interface and the extension interface (Hypki 2008). The *controller interface* allows for the internal integration and the external coupling of controllers, e. g. robot controllers or programmable logic controllers (PLCs). By doing so, a controller determines the behavior of an SEDD object.

The controller interface is based on a client / server-architecture in which the kernel as the one and only client requests data from different controllers which act as servers. The controller interface is kept as small as possible to remain capable of communicating with the controllers in real time.
The *extension interface* is a more comprehensive interface allowing for adding any kind of functionality to the simulation kernel. The interface is based on two features. First, the kernel sends cyclic event notifications to all extension modules to keep them updated about the current SEDD state. Second, the kernel and / or the extension modules can communicate via extension messages with variable parameters at any time. To keep the handling overhead low even for many extension modules, the modules can register for certain messages and thus remain unaffected by the others. In general, extension modules can extend the environment model, extend the time-based simulation calculations, add to the 3-D visualization, and extend the user interface.

Finally, the controller interface and the extension interface offer the possibility to add additional modules dynamically. The separation of enhanced functionality from the kernel supports a fast and stable software development process and keeps the maintenance effort low.

Animation Integration

As mentioned above, the animation has to work together with the simulation especially concerning kinematic, electrical, and controller behavior. To achieve this, we have decided to bring in animation as an additional module using the extension interface to the simulation kernel. As access to the geometric, kinematic, and electric model is provided by the simulation kernel (see figure 4), the animation module (denoted Animation Designer in figure 4) can read and write these data. This way, the start and the end of a movement can be coupled to electrical inputs respectively outputs. For every component moved by the animation module, the new pose calculated in every cycle is notified to the simulation kernel. After this, all other extension modules and simulation algorithms are informed about this new pose and will work accordingly. For example, the sensor simulation module will be able to detect a component which has just been moved by the animation module.

APPLICATION

The new concept of combined simulation and animation has been implemented completely for the 3D simulation tool CIROS Studio.

Figure 1 shows a simple example for the animation of a handling task with a robot. The robot picks microchips from a work piece carrier and place them onto a printed circuit board (PCB). Without any knowledge of robot programming, this task can be modeled by defining pick and place positions for the work pieces within the 3D environment model. For most movement trajectories between pick and place positions, a circular movement has been chosen for the virtual robot. As a result, the robot will move between the poses according to its kinematic restrictions. The kinematically correct movement of the robot's single axes is automatically calculated by the inverse kinematics module of the simulation kernel. The gripping and releasing of work pieces is explicitly defined as actions at the corresponding Keyframes.

For Hannover Industrial Fair 2014, we used the extension module Animation Designer for the first time to create an animation of a manufacturing plant. The concept "iProcell" and the resulting demonstration plant was designed by our industrial partner IBG / Goeke Technology Group. In this plant, three industrial robots unpack pallets and assemble an electric car. All movement definitions were done exclusively using the newly implemented animation methods. The animation can either be exported as a video (IBG 2014) or be presented interactively in a walk-in virtual reality panorama projection environment. Figure 5 shows a screenshot of the 3D model of the "iProcell" demonstration plant. The lower half of the figure shows the animation plan with the Keyframes and the actions.

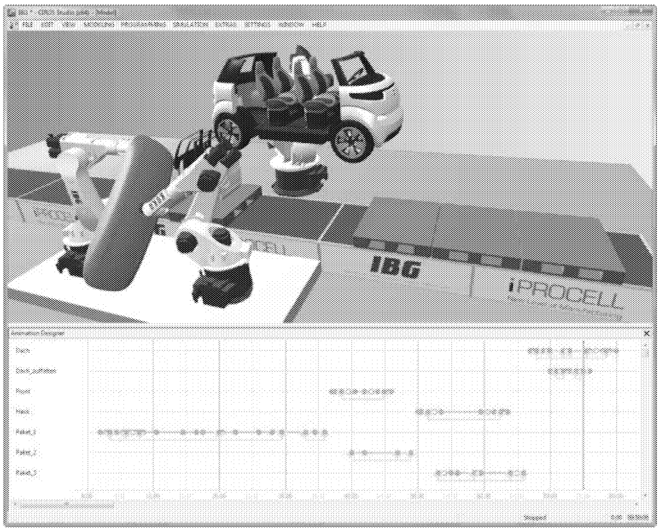

Figure 5: Application iProcell with Industrial Partner IBG

SUMMARY

In this paper, the new concept of combined simulation and animation is presented. The new concept is implemented for an existing 3D simulation tool. The concept allows for the combined use of exact technical simulation and easy to do animation within one common model. Imported CAD data can be animated fast and easily to obtain videos or interactive virtual reality presentation of manufacturing plants. In the same model, technical details can be added for further analysis – up to a use of the model for virtual commissioning.

With the new concept, simulation tools following the concept can be integrated better with company's existing work flows and departments can benefit from the use of common models.

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BIOGRAPHIES

JUERGEN ROSSMANN studied electrical engineering at the universities of Dortmund and Bochum in Germany. After this, he worked at the Institute of Robotics Research (IRF) of the University of Dortmund – first as a scientific assistant, then as a group leader and finally as head of department. He received his Ph.D. in 1993 from the University of Dortmund. After several stays in the USA as a visiting scientist, he was appointed visiting professor for robotics and computer graphics at the University of Southern California in 1998. After his postdoctoral lecture qualification he was appointed professor at the RWTH Aachen University where he now heads the Institute for Man-Machine Interaction.

ROLAND WISCHNEWSKI studied applied computer science with focus on engineering technology at the University of Dortmund in Germany. From 1999 to 2005 he worked as a scientific assistant at the Institute of Robotics Research (IRF) of the University of Dortmund. Since April 2005, he works at the Department of Robot Technology at RIF in Dortmund, now as head of the department Industrial Simulation Systems. In 2007 he received his doctor's degree in electrical engineering from the RWTH Aachen University.

FLORIAN BLUEMEL received his diploma degree in Computer Science from the TU Dortmund University in 2011 with a thesis on services level agreements for cloud environments. He then joined the robotics research group at RIF Institute for Research and Transfer, where his research spans the areas of industrial engineering and computer vision in space robotics.

MOTION CAPTURING FOR THE SIMULATION OF MANUAL INDUSTRIAL PROCESSES

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Motion capturing, manual processes, MANUSERV, service robotics, virtual human.

ABSTRACT

The appearance of service robots and lightweight robots pave the way for a direct collaboration of robots and humans in industrial production facilities. Thus, the areas of industrial robotics and service robotics begin to merge to the new area of industrial service robotics. The evaluation of manual processes regarding their potential for automation remains a highly complex task. The objective of the project MANUSERV is to develop a planning and decision support system for selecting industrial service robots in order to fully or partially automate manual processes. A simulation system compares the initial manual process and the proposed (semi-) automatic process. Before an analysis of manual processes is possible, they have to be included into the simulation of the whole production process. This paper focuses on the process of integrating human motion sequences from an industrial production process into a 3D simulation environment. The human motion is captured and digitalized with the aid of a motion capture system. The gained data is converted into a standard computer animation file format, and subsequently mapped to an existing digital model of the human body. Thus, the described workflow allows the analysis of the manual process based on the generated computer model.

INTRODUCTION

Manufacturing processes have seen a continuous increase in automation in the form of the integration of fully automated production cells into the production process. Still, manual processes are quite common in modern industrial production facilities. With the appearance of lightweight robots and service robots, a paradigm shift seems to take place based on the collaboration of humans and robots creating the new area of industrial service robotics. Some of the persisting manual processes have a high potential for transformation into fully or partially automatic processes. But it is extremely difficult to evaluate the automation potential of these manual processes. The project MANUSERV (from MANUal processes to industrial SERVice robots) (Deuse et al. 2014) focusses on the development of a planning and decision support system to help evaluating the automation potential of manual processes. The first step of the evaluation is the standardized description of a manual process which is then fed into a planning system that generates possible automatic or semi-automatic solutions. In a final step, these solutions are simulated with respect to technical, economic and ergonomic criteria.

In order to compare the initial manual process with the proposed automatic or semi-automatic solution, it is necessary to simulate the manual process. For semi-automatic solutions in which a human works cooperatively with a service robot, the interaction between human and service robots has to be simulated additionally. Thus, it is necessary to integrate human motions into the model of the production process. Furthermore, an analysis of the human motion aiming at optimizing the manual process or improving ergonomic aspects requires an exact modelling.

The presented approach describes how a motion capture system can be used to simulate manual production processes. The captured position and orientation data of the sensors are applied to a biomechanical model of the musculoskeletal system, so that the human motion can be described in terms of the orientation of characteristic joints. Because of several differences between the biomechanical model of the capturing system and the model integrated in the applied simulation environment, the existing model has to be modified and a mapping, which uses a well-defined motion capture file format, takes place.

The paper starts with a basic overview of motion capturing. The following section presents the applied simulation environment and the "Virtual Human" (Schlette and Rossmann 2009), which implements a model of the human body based on a multi-agent approach. We will demonstrate the approach by showing how to integrate human motions captured in a manual assembly process of one of our industrial partners in the MANUSERV project. And finally, we will present the results and give a further outlook of the approach.

BASICS OF MOTION CAPTURING

The complexity of the human musculoskeletal system makes capturing a movement a challenging task. Additionally, the human perception is highly sensitive regarding variation from the natural motion sequence. This makes it necessary to be highly accurate if the captured data is supposed to be used for visualization (MacDorman and Ishiguro 2006). Human motion capturing techniques mainly known from video gaming and the computer graphics industry tackle this problem and a variety of systems have been developed. The general approach is to detect and capture the trajectories of several key points of the human body.

The available systems mainly differ in the method used to track these key points. The applied sensing technology and the relationship between the utilized sensors and their reference source are common criteria to categorize motion capture systems as outside-in, inside-in or inside-out systems (Mulder 1994).

The widely used outside-in systems use so-called markers. These markers are attached to the performer and function as a passive reference source. Optical systems based on several video or infrared cameras track the trajectories of the applied markers. Outside-in systems use multiple images of the considered marker to calculate its position and thus track its trajectory. This method needs a high amount of post processing. The number of applied cameras, as well as possibly occurring occlusions, highly affects the capture quality. (Zhuang et. al 2008). Furthermore, the cameras determine the range in which a motion can be captured.

Contrary to outside-in systems, inside-out systems use sensors, worn by the performer to detect an external reference source. Magnetic systems typically fall into the category of inside-out systems, since sensors attached to the performer's body detect a magnetic reference field. In addition to the measurement of the sensor position, the application of multiple Hall sensors allows the direct determination of the sensor orientation. The dependency on the magnetic reference field results in a quite limited range in which the movement can be captured.

In the third category of motion capture systems, inside-in systems, reference source, as well as sensors are attached to the performer, leading to a theoretically unlimited range of action. Common inside-in systems use a mechanical exoskeleton or inertial sensors.

Besides the considered motion capture systems, optical systems which capture a human movement only by means of optical images have been developed (Moeslund et al. 2006).

Overall, the established techniques offer the possibility to detect, capture and digitize a human movement. Besides the use of motion capturing systems in the film and video gaming industry, other application areas are e.g. the analysis of human motion regarding rehabilitation and sports performances science. Considering industrial applications, motion capturing is more sparsely used, even though the analysis of human motion is highly important in the design of products and workplaces considering ergonomic factors.

Some CAD environments like Tecnomatix (Siemens) or Catia (Dassault Systems) integrate virtual humans. Due to the non-standardized modelling of the human body, only few interfaces to motion capturing systems exist. Since these interfaces highly depend on the used CAD system, the motion capturing system and the biomechanical model, the direct integration of a captured movement is often not possible (Père et al. 2006).

MODELLING THE HUMAN SYSTEM

The simulation of whole production processes including manual stages requires a simulation environment providing extensive 3D simulation functionalities. In this case, the simulation environment VEROSIM ("Virtual Environments and Robotic Simulation System") was used. Application areas of VEROSIM are e.g. the simulation of scenarios in space robotics (Rossmann et al. 2014) and industrial production (Rossmann and Schluse 2011). In general, VEROSIM is capable of generating virtual environments which can be used to analyze and optimize real processes.

VEROSIM uses a model of the human body, the so-called "Virtual Human". The "Virtual Human" is an anthropomorphic multi-agent system, which models the human locomotor system as multiple industrial robot arms, simplified to their kinematic chains (Rossmann and Schlette 2010, Schlette 2012). In total, this model interprets the human locomotor system as the composition of six individual kinematic chains, representing arms, legs, head and torso. Because of this interpretation, approaches of control known from industrial robotics can be applied in order to integrate human motion. In the multi-agent approach of the "Virtual Human" autonomous agents control the different kinematic chains. In this context the term "agent" refers to a system acting autonomously and reacting to environmental influences. A human movement is, according to this approach known from industrial robotics, the result of the interaction between the different agents. Figure 1 shows a model of the virtual human with coordinate systems representing the corresponding joints.

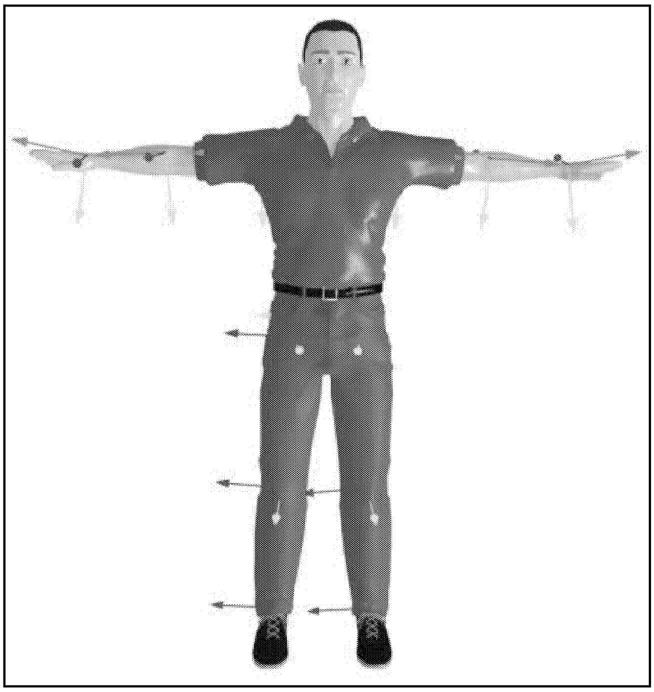

Figure 1: "Virtual Human"

A realistic appearance of the human body is achieved by using a so-called skinning. The idea of skinning is to embed kinematic chains into the detailed outer hull of the body which acts as an outer envelope modelling muscles, skin and clothes. Moving any joint of the kinematic chains will also move the corresponding skin segments.

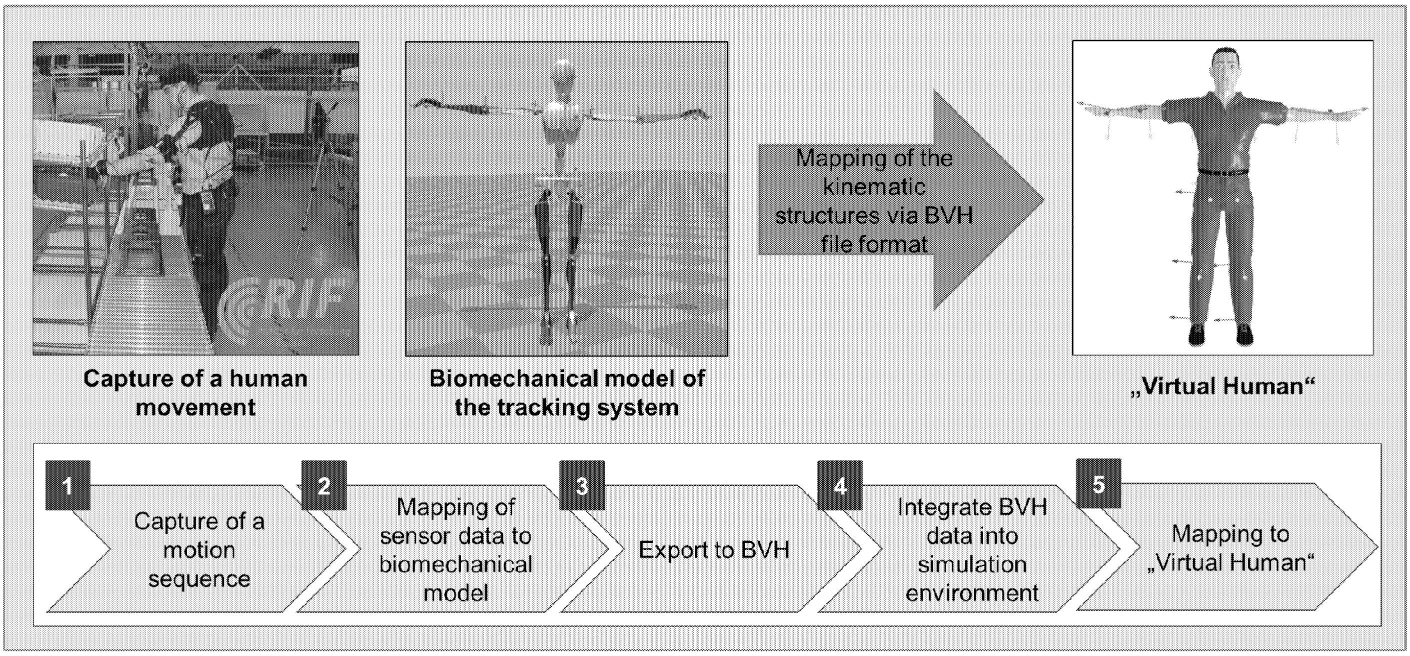

Figure 2: Mapping manual processes onto a digital human model

CAPTURING MANUAL PROCESSES

Figure 2 illustrates the complete process from the data acquisition to the final simulation. The capturing and digitization of manual processes was achieved by the motion capture system "Xsens MVN" developed by the company Xsens. The system is based on 17 inertial sensors attached to the performer's body and can be categorized as an inside-in system (Roetenberg et al. 2013). Compared to optical or solely magnetic systems, the inertial system is insensitive to occlusion or magnetic disturbance which can easily occur in industrial environments. Furthermore, the range of action is only limited by the wireless data transmission which is highly beneficial since the considered manual processes may require a large action radius. A human motion is captured by applying the data gathered by the sensors to a biomechanical model of the human body. This biomechanical model assumes that the locomotor system consists of 23 rigid segments which are connected to each other by movable joints. After a calibration procedure, the system provides a description of a human pose and thus of a human movement by calculating and recording the corresponding joint angles.
The recorded movement is then exported to a standard motion capture file format. In this case the BVH (Biovision Hierarchy) format was chosen to provide a standardized description of a human motion. A BVH file can be split into two parts. The first part defines a skeleton, which consists of nodes having a fixed offset to each other, connected via joints having defined degrees of freedom. Usually the root is defined to have six degrees of freedom, whereas the other joints are considered to be strictly rotational. A joint orientation is described by a fixed, hierarchical sequence of Euler rotations. The second part provides the actual description of the captured motion. Therefore, the total amount of recorded frames, the time between two frames and the corresponding joint values are specified (Meredith and Maddok 2001). Since the BVH format as well as the simulation environment follow a hierarchical approach describing kinematic chains, the BVH format was superior compared to other formats. In addition, VEROSIM provides modules for importing BVH files, so that the recorded joint values are available at each simulation step. In order to apply the achieved representation of the human motion to the anthropomorphic multi-agent system a mapping between the two biomechanical models has to take place.

MAPPING OF THE MOTION DATA

The acquired BVH files specify human motions based on joint angles of a skeleton. The multi-agent approach of the "Virtual Human" models the human body as six hierarchically mounted kinematic chains. This model results in a skeleton composed of 19 joints having three or less degrees of freedom. The skeleton specified in the BVH file defines 23 joints, all having at least three degrees of freedom. In order to achieve a mapping of joint values, a possible solution is to add additional joints to the kinematic chains of the "Virtual Human". Figure 3 presents the four joints that are added to the existing skeleton of the "Virtual Human", so that every joint defined in the generated BVH file has a corresponding joint in the destination skeleton.

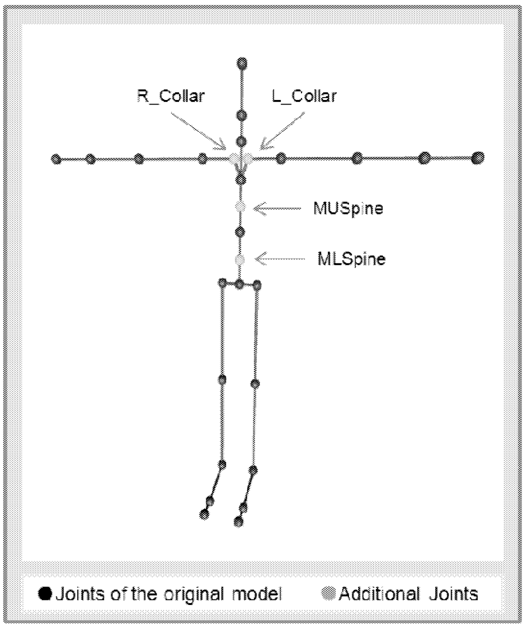

Figure 3: Modified skeletal structure

The additional joints add additional degrees of freedom to the movement of the spine and of the arms and thus enlarge the movement capabilities of the "Virtual Human" such that arm and spine movements become more accurate. The position of the additional joints inside the skeleton makes it possible to reuse the skinning of the original model.
Figure 4 shows the resulting joint hierarchy. The joint hierarchy consists of three kinematic chains, one for each leg and one for the spine. Attached to the upper spine joint are again three kinematic chains, one for each arm and one for the head. The additional joints are highlighted in the figure. Furthermore, each joint has been modified so that it has three degrees of freedom. Three joint angles of a fixed Euler rotation sequence describe its orientation.

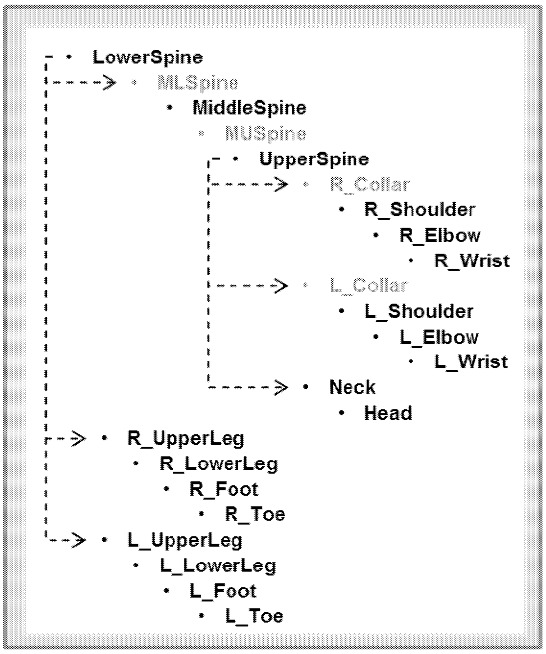

Figure 4: Joint hierarchy of "Virtual Human"

Nonetheless, the joint values cannot be applied directly, due to the differences in the orientation of the joint coordinate systems. In its initial start position, the BVH representation uses the world coordinate system for the specification of each joint value, whereas the orientation of the coordinate systems of the "Virtual Human" results from the modeling of the kinematic chains as industrial robots. The different orientation of the coordinate systems has to be taken into account while mapping the joint values to the skeleton of the "Virtual Human".
Adjusting the kinematic structure to the biomechanical model of the motion capture system allows a mapping of the motion data to the existing anthropomorphic multi-agent system. Using the BVH format as a well-defined interface between motion capture system and simulation environment makes the integration of motion sequences into simulation possible.

INDUSTRIAL APPLICATION

In the MANUSERV project there are three industrial application partners with a very broad range of manual processes. These processes range from manual assembly processes via machine set-up and maintenance to farming applications. This broad range of application areas is helpful to keep the developed system as flexible as possible for future application areas.
For the evaluation of the described human motion capture process we have chosen a manual assembly process of one of our industrial partners. The manual process basically consists of the assembly of a costumer specific display unit, the assembly of a power supply unit that is the same for all products, and the final packaging of the end product. The assembly of the power supply unit includes the marking of the unit with a laser marking machine.
The first step is the data generation with the inertial sensors. In order to get data as useful as possible, we need motion data from an experienced worker who has performed the manual process many hundreds or even thousands of times, to show smooth and optimized movements. An experienced female production worker was equipped with the inertial sensors. She assembled the components while motion data of the assembly process was collected, exported into the BVH representation, and mapped onto the virtual human model. Figure 5 shows the real assembly process with the female worker wearing the motion capturing sensors.


Figure 5: Capturing a manual assembly process

Figure 6 shows the corresponding simulation with a virtual human worker executing the captured motion data in a model of the assembly process with all relevant parts. In both figures the real and virtual workers reach into a laser marking machine to insert the power unit.


Figure 6: Simulation of a manual assembly process

A validation of the described process is based on the visual realism of the motion sequence and on the precision of reaching grasp positions. The motion of the "Virtual Human" looks a lot more realistic than any motion sequence we generated synthetically beforehand by specifying joint angles of the kinematic model of the "Virtual Human". The relative positioning between the grasp positions is also convincing. For the manual assembly process, all grasp positions in the simulation model were reached by the "Virtual Human".

Thus, the acquired motion sequence can provide valuable information for the subsequent simulation and analysis of the manual assembly process. What is still missing in this approach is the detection of any finger movements like the detection of grasping. As grasping of objects can at the moment only be detected by the reaching of grasp positions with the hand we manually added the grasping to the simulation process in a post processing step. In order to detect finger movements, additional hardware would be necessary. In general, the approach is useful for coarse grain and medium grain movements. For fine grain movements, the missing finger movement detection is a strong limitation.

RESULTS AND DISCUSSION

With the objective of integrating human motion into the simulation of industrial production processes, motion capture techniques were used to map a motion sequence onto an existing model of the human body. The overall process from capturing a real manual process to 3D simulation can be described as follows: Using an inertial motion capture system allows capturing the manual process at the production site. After capturing and digitization of the motion, the acquired data is exported to the BVH format which functions as an interface between motion capture system and simulation environment. The description of the human pose, which is now available at every simulation step, is mapped onto the modified "Virtual Human".

An application of the described workflow for a manual assembly process shows that the captured motion data is well suited for the integration of manual processes into the simulation of a production process as long as the captured manual process does not include too many fine grain movements. The strongest limitation is that movements of the fingers are not detectable with the described approach. Instead, additional hardware is necessary to detect finger movements.

Considering human motion in 3D simulation can be beneficial to different domains of analyzing the manual process. Since a complete description of the human pose is available, ergonomic analyses can be easily applied solely based on the available joint values. Additionally, the model of the complete production process including manual stages can be used to improve the overall process. In the MANUSERV project, the captured manual process will be the basis for a planning and decision support system for selecting an appropriate industrial service robot to (semi-) automate the process. The decision whether a manual, fully or partially automated solution should be used is thus influenced by the quality of the simulation of the manual process. Consequently, the validity of the presented approach plays an important role for the recommended system design.

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LOGISTICS SIMULATION

FREIGHT TRANSPORTATION IN EUROPEAN LOGISTICS: A COMPARISON OF NORTHERN AND SOUTHERN RANGE GATEWAYS

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KEYWORDS

Transportation in logistics, multi-modal systems, freight transport, TEN-T corridors, Rail Freight Corridors, railway transport, gateways.

ABSTRACT

In this paper, the problem to the provisioning of an industrial area in the center of the Europe by means of long distance transport is focused. Different modes of transport and relative models to estimate principal attributes (times, costs and prices) are simulated.

The aim of this paper is to compare different route alternatives for international freight transport. The transportation related to European logistics core is considered. The case study relative to logistics of central *Blue Banana* is presented, comparing the provisioning by means of gateways located in the Northern range or in the Southern one.

1. INTRODUCTION

In European Union, mobility of persons and goods is an essential component of the competitiveness of industry and services. The European goal is to ensure sustainable mobility meeting economic, social and environmental needs, as highlighted by the transport 2011 White Paper. European Commission has adopted a comprehensive strategy to build a competitive transport system quantifying strategic goals and targets. For freight mobility, the target is *30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50 % by 2050* (European Commission, 2011a). The final goal is to enhance freight mobility reducing CO2 emissions and decoupling the increasing of mobility from Gross Domestic Product (GDP).

In the context of intercontinental trades, maritime transport plays a relevant role. The great part of intercontinental freight flows reaches the center of Europe through northern range ports. Mediterranean ports could constitute another gateway to central Europe, but this depends on integration between maritime and rail transport for improving performances, increasing transported quantities for single shipment, reducing pollution, minimizing times and costs.

For pursuing the goals, European Commission has defined specific programs to improve European railway system in terms of infrastructures and services. In order to design an integrated transport system, infrastructural and commercial railway corridors are identified (European Commission, 2011b; 2013b). These systems would like to facilitate trades flows within the Europe and between Europe and the rest of the world.

In this paper, in the context of European corridors implementation (infrastructure and services), the problem to reach a territory in the center of Europe is focused. Principal aim of the paper is to evaluate and to compare, by means of simulations, transport attributes of inland modes of transport in the North – South relationships, involving developing railway corridors and existing motorways ones.

After this introduction, the paper has three sections. In section 2, principal characteristics of the central Europe system are described in terms of market, TEN-T and Rail Freight Corridors, considering the transportation elements inside the logistics. In section 3, transport alternatives relative to north-south freight paths are simulated, estimating corresponding attributes. In section 4, transport attributes of north-south paths are compared, defining the targetable market.

2. THE CENTRAL EUROPEAN SYSTEM

2.1 The market

The area of central Europe includes a region called *Blue Banana*, covering Southern England, the Benelux, western Germany, eastern France, Switzerland, and northern Italy. This region represents about 9% of total European surface, about 28% of the European population and great part of

European industrial production, about 33% of the European GDP (Mitusch et al. 2014).

For the programming period 2014-2020, European Commission has introduced three funding categories of regions (European Commission, 2013c): *less developed regions* where GDP per head is less than 75% of the EU average; *transition regions* where GDP per head is comprised between 75% and 90% of the EU average; more developed regions where GDP per head is equal to or higher than 90% of the EU average (Figure 1).

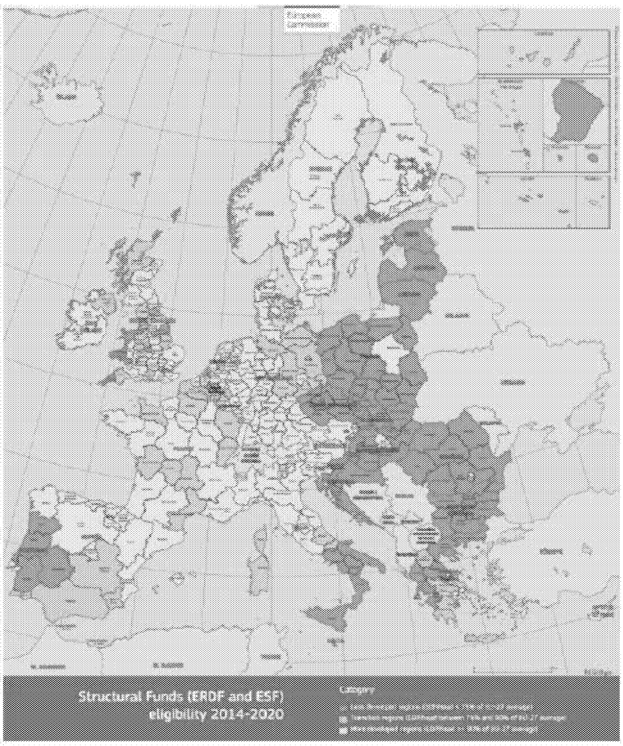

Figure 1: Classification of European regions according to respect to average GDP (Source: European Commission, 2014d)

Mediterranean and North Sea have a relevant role in world freight exchanges with Europe. In the last decades, Asia-Europe and transpacific trades have grown, establishing commercial linkages between continents. Maritime transport, considering its capacity and the continuity of its services, supports these trades. In this context containerized freight flow has grown, from 23% of all non-bulk cargo in 1980, to 40% in 1990 and to 70% in 2000 (Rodrigue, 2013).

Ports in North Sea represent principal gateways to provide freight in the territories collocated in the center of Europe and specifically in Blue Banana. With globalization, the Mediterranean Sea has become a transit point for the flow of goods that use the deep-water routes between Europe, North America and Asia.

In these conditions it could be evidenced that two main corridor directions arrive in the central Europe leaving from a sea port: from North Sea and from Mediterranean Sea. In the Northern range, Rotterdam, Antwerp, Hamburg and Bremerhaven ports are generally considered. A gateway hypothesis in the Southern range does not exist in literature. In this paper the hypothesis to develop a port system in the South of Italy is analyzed. In particular deep water Southern Italian range ports included in the core network (European Commission 2013b) are considered: Augusta, Bari, Cagliari, Gioia Tauro, Palermo and Taranto.

Two gateway ports, belonging to the two selected corridor directions are considered: Gioia Tauro in the Southern range and Bremerhaven in the Northern range.

Gioia Tauro is one of the main transshipment container port in EU and Mediterranean seas. In 2014 the container moved in the port has been about 3 millions of TEU (Contship Italy, 2015). In 2015 railway services from the port to the south east of Italy has activated. In perspective, the port could assume a gateway function promoting railway services using European railway corridors from South to North.

Bremerhaven is one of the main European ports in the northern range. The port is specialized in automobile handling (2.2 million automobiles in 2013) and in container transport (5.8 million TEU in 2013). In ten years, the container transport by rail is increased from 35.9% in 2004 to 46.6% in 2013 (European Commission, 2014c).

2.2 TEN-T corridors

European Commission in 2013 has produced regulations to define Trans European Transport Network (TEN-T) to connect the European continent between East and West, North and South. TEN-T guidelines (regulation 1315/2013) set out general objectives related to *globalisation and international dimension*, *internal market, social and economic cohesion*, *territorial cohesion*, *sustainable development* and *climate change*. TEN-T guidelines define a dual layer approach to the transport network: the basic layer, or *comprehensive network*, to be completed by 2050, should ensure accessibility of all regions of the Union; the second layer, the *core network*, to be completed by 2030, constituted by the strategic parts of the comprehensive network. *All European citizens and economic operators would then be able to access the Core Network, via this Comprehensive Network, at comparable terms*.

Nine core network corridors have been identified.

Italy has four core network corridors crossing its country:

- the *Baltic-Adriatic* corridor 1) extended from the Polish ports via Czech Republic or Slovakia and through eastern Austria to the Slovenian port of Koper and to the Italian ports of Trieste, Venice and Ravenna.
- the *Mediterranean* corridor 3) extended from the Spanish ports of Algeciras, Cartagena, Valencia, Tarragona and Barcelona through Southern France, with link to Marseille, and Lyon to Northern Italy, Slovenia and a branch via Croatia to Hungary and the Ukrainian border;
- the *Scandinavian-Mediterranean* corridor 5) extended from the Finnish-Russian border and the Finnish ports of HaminaKotka, Helsinki and Turku-Naantali, with a branch from Oslo, through southern Sweden, Denmark, Germany, where the ports of Bremen, Hamburg and Rostock are connected, western Austria to the Italian ports
- the *Rhine-Alpine* corridor 6) extended from the North Sea ports of Antwerp, Rotterdam and Amsterdam along the Rhine valley via Basel to Milan and the Italian port of Genoa.

The TEN-T corridor 5) Scandinavian-Mediterranean is a *crucial axis for the European economy*. The corridor links the major urban centres in Germany and Italy to Scandinavia (Oslo, København, Stockholm and Helsinki) and the

Mediterranean (Italian seaports, Sicily and Malta), connecting north and south of Europe. The corridor will integrate Priority Projects (1, 11, 12 and 20), ERTMS corridor B and RFC 3 (European Commission, 2013a).
In terms of network length of rail (9,337 km) and road (6,372 km) as well as the number of seaports (25), airports (19) and rail-road terminals (RRT) (44), the corridor 5) is the longest among the nine TEN-T core network corridors (European Commission, 2014a).

2.3 Railway Freight Corridors

European infrastructure integration, obtained by means of TEN-T, is accompanied by services integration. For railway freight transport, in 2010 European Commission adopted the regulation that sets out proposals for developing a European rail network for competitive freight transport (regulation 913/2010). Nine Rail Freight Corridors (RFC) have been identified. Six of the nine initial RFC overlap with ERTMS-corridors (European Commission, 2011a).
EU regulation 1316/2013 has modified RFCs respect to regulation 913/2010. Consequently, RFC3 and TEN-T 5 are more coherent.
Railway freight transport tends to become economically sustainable for the longer transport distances (Russo, 2007). However, railway infrastructures across European member states are not harmonized in terms of electrical power supply as well as command and control systems. This condition produces no attractive train service for an international path. Moreover, there are deficiencies in parts of the infrastructure (e.g. bottlenecks), and particularly within big network nodes such as in large cities or agglomeration zones (Mitusch, et al. 2014).
The RFC 3 Central North-South links the major centers of Sweden, Denmark, Austria, Germany and Italy from Scandinavia to the Mediterranean, connecting north and south of Europe.
Each RFC should have an implementation plan that contains a Transport Market Study (TMS) with relevant information for trade unions with regard to corridor developments. The current version of TMS indicates that the overall rail transport volumes between the countries involved in the RFC3 increased by more than 25% in the last decade and are currently (2012) estimated at approximately 58 million tons per year (European Commission, 2014b).

2.4 The Northern-Southern competition

The problem focused in this paper is to simulate and to analyse attributes of inland transport infrastructures and services to reach the center of Europe from the two selected gateway ports. In relation to these ports, the north-south infrastructural and commercial corridors are identified (Table 1):

- the Scandinavian-Mediterranean TEN-T infrastructural corridor, that is implementing and is planned to complete in the 2030 (TEN T, corridor 5);
- the Central North-South Rail Freight commercial Corridor, that will be implemented by the end of 2015 (RFC, corridor 3).

The Gioia Tauro port belongs to the two selected corridors. The RFC, corridor 3 does not include Bremerhaven that belongs to North Sea-Baltic and Orient/East-Med railway corridors. However, Bremerhaven is connected to Bremen, belonging to the two corridors, in a distance of about 70 km (by rail and road) (European Commission, 2014c).
In Table 1 synthetic information regarding the two selected corridors are reported.

3. EUROPEAN NORTH-SOUTH FREIGHT TRANSPORT PATHS

3.1 Transport alternatives

Freights originated/destined from/to intercontinental origins/destinations (extra – Europe) are transported to/from the center of Europe by multi-modal systems.

Table 1: Selected TEN-T and RFC corridors

	TEN-T 5	RFC 3
EU regulation	1315/2013 1316/2013	913/2010 1316/2013
Corridor name	5) Scandinavian-Mediterranean	3) Central North-South
Member States	NO, SE, FI,DK, DE, AT, IT, MT	NO, SE, DK, DE, AT, IT
Principal routes	Helsinki-Stockholm/Oslo-Malmö-København-Bremen/Hamburg-München- Brenner Base Tunnel-Verona-Gioia Tauro-Catania – Palermo – La Valletta	Stockholm/Oslo-Malmö-Copenhagen-Hamburg-Innsbruck-Verona-Palermo
Implementation	2030	2015

In this paper, a container shipment is considered, with freight that does not ask specific process as refrigerated or dangerous goods.
Different hypothesis to reach center of the Europe (*Blue Banana*) are simulated considering two alternative intercontinental maritime ports, working as gateways: by North Sea, through ports in the northern range and in particular through Bremerhaven port (*hypothesis 1)*; by Mediterranean sea through ports in the south of the Europe, and in particular through Gioia Tauro (*hypothesis 2*).
For each multi-modal hypothesis, different inland alternatives are simulated:

- in the *hypothesis 1* freight transport is realized using,
  - 1a) full road transport from Gioia Tauro port to the center of Europe (*full road*);
  - 1b) full rail transport from Gioia Tauro port to the center of Europe (*full rail*);
- in the *hypothesis 2* freight transport is realized using,
  - 2a) full road transport from Bremerhaven port to the center of Europe (*full road*);
  - 2b) full rail transport from Bremerhaven port to the center of Europe (*full rail*).

In all hypothesis, intermediate points are considered and in particular from north to south: Nuremberg (Wurzburg), Munich, Bremen in German; Verona, Bologna in Italy.

A representation of the study area is reported in Figure 2.

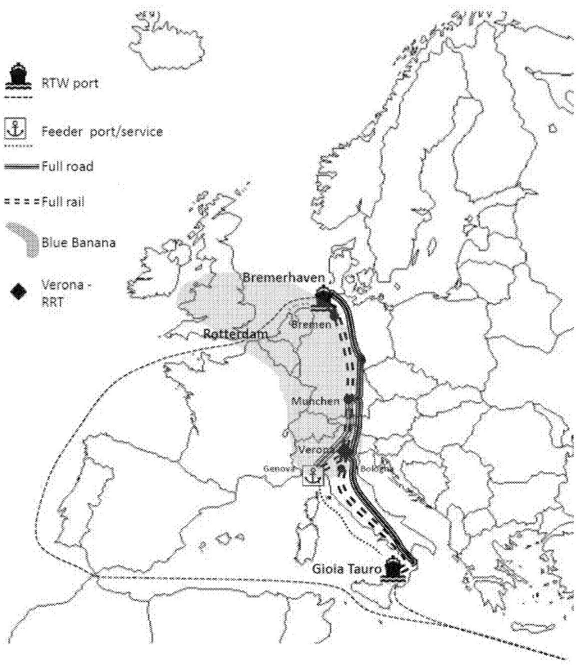

Figure 2: The study area

3.2 Attributes by models

Models specified and calibrated in Russo (2005) are used to calculate attributes of alternative paths in multi-modal systems. Attributes related to the long distance movements can be calculated adopting cost functions, representing time and distance dependent freight costs of transport modes; including loading/discharging, some pivoting factors are used to update original parameters (Russo et al., 2015).
Considering the inland relationships North-South, long distance transport attributes can be simulated in relation to the rail and road modes of transport (Maes et al. 2011).
Road and rail distances, that represent principal input of cost functions, can be obtained via website, for instance adopting information of *google.maps* (Google Maps, 2015) or database of railway operators.
Times, representing all phases of transport operation, is considered as reference utility variable.
For road transport, times include components related to:

- running time in the road network, obtained considering road characteristics, and typology of truck used for transport;
- break and rest period according to European regulations of road transport, considering a service operated with one or two drivers.

For rail transport, times include, components related to:

- running times in the rail network, obtained considering rail characteristics (e.g. maximum velocity, slope, maximum train length);
- frequency of freight services in relation to schedule of operators.

3.3 Attributes by survey

3.3.1 Distances.

Distances are calculated for each hypothesized alternative. Cumulated road and rail distances of paths from south (Gioia Tauro port) to north (Bremerhaven port) and vice versa are reported in Table 3.

Table 3: Distances Gioia Tauro – Bremerhaven

	Road system		Rail system	
	South – North (Σ km)	North – South (Σ km)	South – North (Σ km)	North – South (Σ km)
Gioia Tauro port	0	2352	0	2349
Bologna	1015	1384	1013	1336
Verona	1131	1226	1127	1222
Bolzano	1323	1075	-	-
Brenner			1361	988
Munich	1553	794	1571	778
Nuremberg	1723	625	-	-
Wurzburg	-	-	1844	505
Bremerhaven port	2352	0	2284	0

3.3.2 Road times.

Road times are simulated using the PTV software (PTV, 2015), considering a truck service operated with two drivers. Cumulated road times, including rest periods, of paths from south (Gioia Tauro port) to north (Bremerhaven port) and vice versa are reported in Table 4. In the South – North alternative the obligatory rest period starts approximately in an area around Bolzano where total driving time exceed limits of EU rules for road transport with two drivers. In the North – South alternative the rest period starts approximately in an area around Bologna.

3.3.3 Rail times.

Cumulated rail times of paths from south (Gioia Tauro port) to north (Bremerhaven port) and vice versa are simulated by model and reported in Table 5, using the literature model (Russo, 2005):

$T = m \cdot d + b$

where:

d	is the railway distance in the core railway network;
$m=0.015$ and $b=2$	are calibrated parameters.

Table 4: Road times between Gioia Tauro and Bremerhaven

	South – North	North – South
	Running time (Σ h)	Running time (Σ h)
Gioia Tauro port	0,0	42,6
Bologna (start rest)	14,9	28,7
Bologna (end rest)	-	19,7
Verona	17,4	17,2
Bolzano (start rest)	19,7	14,9
Bolzano (end rest)	28,7	-
Munich	32,2	10,8
Nuremberg	34,7	8,4
Bremerhaven port	43,1	0,0

A specific survey has been developed combining different railway services actually operative along the considered corridor.

Table 5: Rail times between Gioia Tauro and Bremerhaven (by model)

	South – North (Σ h)	North – South (Σ h)
Gioia Tauro port	0	40,7
Verona	18,9	20,3
Munchen	25,6	13,7
Wurzburg	29,7	9,6
Bremen	36,3	3,0
Bremerhaven port	40,7	0

Rail times are also obtained using information provided by railway operators, considering services in selected European corridors.
Times are obtained considering a hypothetic train that provide a *one-shot* service between the two ports. For this reason, times for break in intermediate stations are not considered.
For each direction, a specific stop to change the traction locomotive, related to change of power, and a specific stop, to operate administrative functions, are considered. With these assumptions, the times have been recalculated and reported in Table 6.

3.4 Other alternatives

Other multi-modal alternatives can be considered trough northern and southern range (Schindlbacher Gronalt, 2010). Considering Gioia Tauro transshipment port, it is possible to use maritime transport by feeder line to reach Genoa port. From this port, it is possible to reach center of Europe by rail or road transport.

Table 6: Rail path times between Gioia Tauro and Bremerhaven (by survey)

	South – North (Σ h)	North – South (Σ h)
Gioia Tauro port	0	38,7
Bologna	13,88	24,0
Verona (start rest)	15,88	21,0
Verona (end rest)	17,88	-
Brenner (start rest)	21,38	18,4
Brenner (end rest)	22,38	17,4
Munich (start rest)	25,45	13,9
Munich (end rest)	-	11,9
Wurzburg	28,73	8,6
Bremen	35,25	1,1
Bremerhaven port	36,33	0,0

Considering Rotterdam as gateway port, to reach center of Europe, it is possible to use other than rail or road as Bremerhaven, also the maritime transport by waterways to reach Karlsruhe port and then rail or road transport.
These alternatives introduce at least one intermodal change with relative time, for breaking load, that modify the possibility of a direct comparisons with the one presented in section 3.1.

4. PATHS ATTRIBUTES COMPARISON

Paths attributes obtained as reported in section 3 are compared to delimitate a zone of influence in the central area of Europe associated to ports of northern and southern range.

In the Figure 3 comparisons of road distances from the two origin ports is pictured. The railway comparison of distances is very similar. From Figure 3 it emerges that Verona is the middle point along the path linking Gioia Tauro and Bremerhaven. In next sections the comparison in terms of road times and rail times are represented.

4.1 Inland transport road times

The comparison between road times that needs from the two selected ports towards central Europe is represented in Figure 4. In this figure, road distances and times obtained in section 3 are represented.
It must be noted that the line pictured for times represent only the average values for the attributes; considering the stochasticity of the times it needs to think a sort of dispersion.
From Figure 4 it can be noted that using two drivers from Gioia Tauro, all Italian country can be covered. Using again two drivers from Bremerhaven, other than all Germany also the north Italy can be served. Then all the economy working between Bologna and Bolzano have two real alternatives.

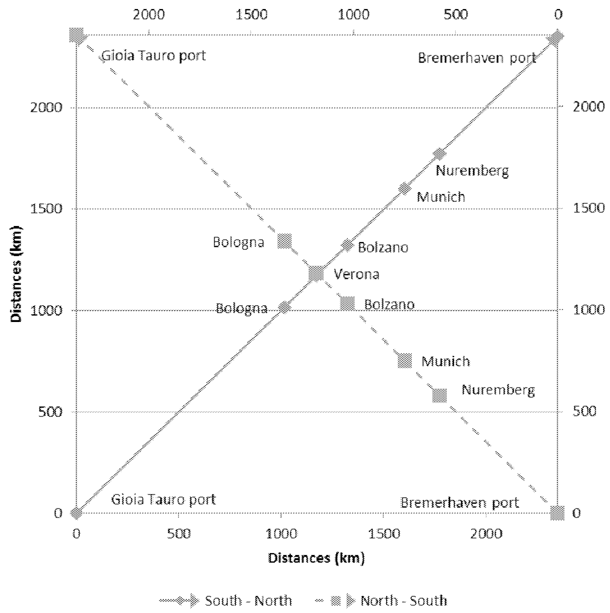

Figure 3: Comparison of road distances from the two origin ports

4.2 Inland transport rail times

The comparison between rail times that needs from the two selected ports is represented in Figure 5. Rail distances and times obtained in section 3 by survey are represented.
Recalling the statement introduced previously, (the deterministic representation of a stochastic phenomenon), it can be considered that only with the realization of RFC 3 and more with the realization of the TEN-T 5, the time values will be, deterministic from a commercial point of view.
With all the considerable precautions it emerges that a container that leaves in the same moment by the two gateways arrives (more or less) at the same moment in the middle point between Brenner and Verona. Considering the short time between this middle point and Verona, it is possible to conclude that operatively Verona can be served in the same time from Gioia and Bremerhaven.

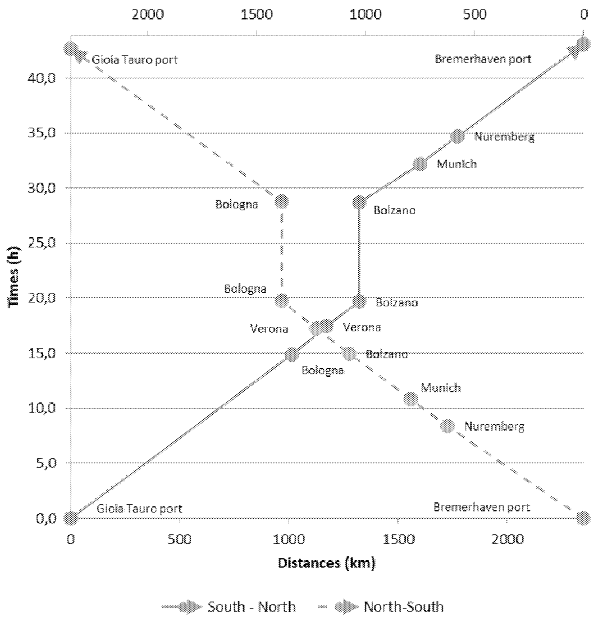

Figure 4: Comparison of road times from the two origin ports

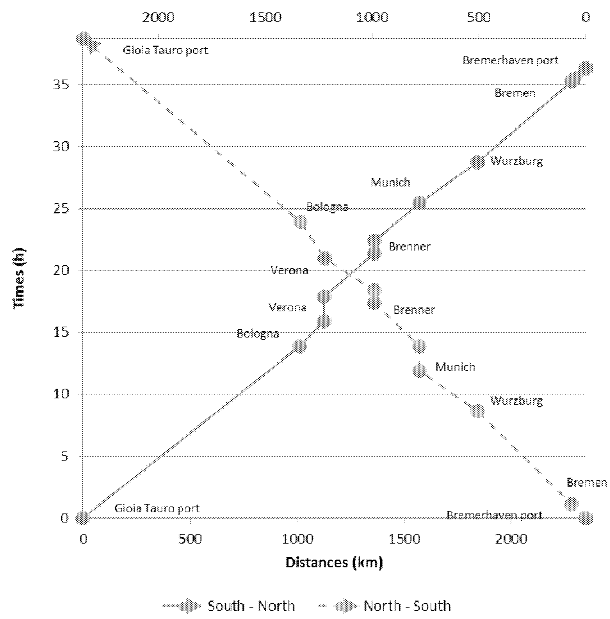

Figure 5: Comparison of rail times from the two origin ports

4.3 Intercontinental transport

The synthetic evidences presented in section 4.1 and section 4.2 are correct for the containers that arrive/leave from/to American East Cost or from Asian by circumnavigation of Africa. In this case, it is possible to assume that the time from origin port to Gioia Tauro or Bremerhaven is the same.
If the containers arrive/depart using the Suez way, the presented comparisons must be upgraded.
In the presented results, maritime times to reach selected ports are not considered. If trades between Far East and Europe are focused, the maritime times are not similar. In the following, maritime times to reach the two ports from East Port Said (in the Mediterranean side of Suez canal) are considered. It is implicit that the time from Asia to East Port Said it is equal for all EU and Mediterranean ports.

A comparison between multi-modal times considering maritime and road transport is presented in Figure 6. From this figure, the advantage in terms of travel times of Gioia Tauro port respect to Bremerhaven port is evident. In Figure 7 multi-modal times considering inland transport by rail are represented. Also in this case the advantage is evident. The huge utility of Gioia Tauro does not have a practical confirmation. Then to understand the real situation, other times and port performances must be considered (Vergara et al. 2011; Russo and Rindone 2011). The times spent in port terminals are not included. The main components are: operation times to transfer containers from maritime to inland transport means, administrative times to produce documentation in member states, control times to allows authorities verification of containers (Italian Government, 2014).
A comparison between average times in Germany and in Italy is reported in Figure 8. Considering these times spent in the ports, the advantage of Gioia Tauro respect to Bremerhaven is drastically eliminated. It is evident that if the gateway of Gioia Tauro (and in general of southern range) does not give specific delay for custom operations, and fixed all other factors, can be a real economic alternative to provide freight from/to blue banana area.

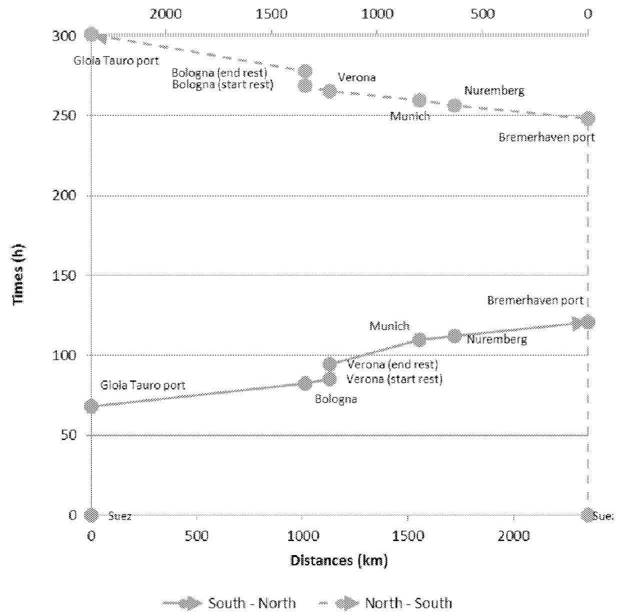

Figure 6: Comparison of multi-modal times between the two ports

5. FINAL REMARKS

European Commission is promoting railway freight transport in order to contribute to economic, social and environmental sustainability. For this reason infrastructural and service railway corridors have been designed and implemented or implementing. In this paper, North-South corridors are focused. A comparison between two core gateways has been presented, in terms of maritime and inland multimodal transport: Bremerhaven port, in Northern range and Gioia Tauro port in Southern range.
Considering trades between Far East and Europe, a possible advantage, of Gioia Tauro respect to Bremerhaven, emerges in terms of travel times.

Moreover, considering other times spent in the ports, the advantage of Italian ports respect to German ports is not confirmed, evidencing the existing gap. The main cause is the delays related to port operations. A gateway hypothesis in the southern range could be a real economic alternative to provide freight from/to center of Europe if the delays can be eliminated.

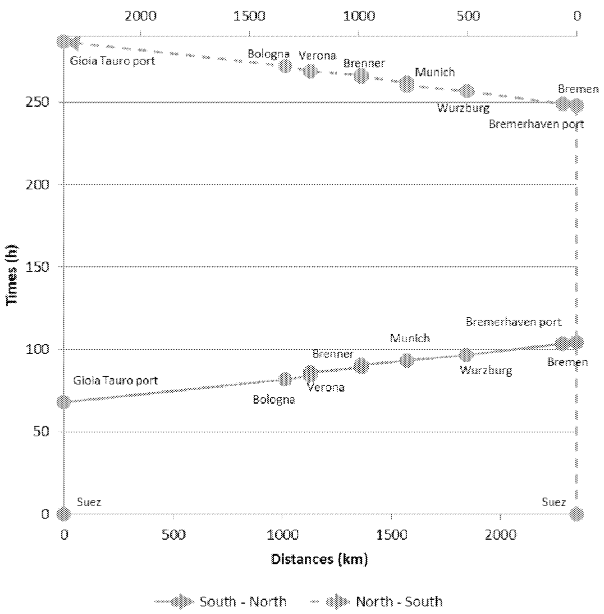

Figure 7: Comparison of multi-modal (maritime and rail) times between the two ports

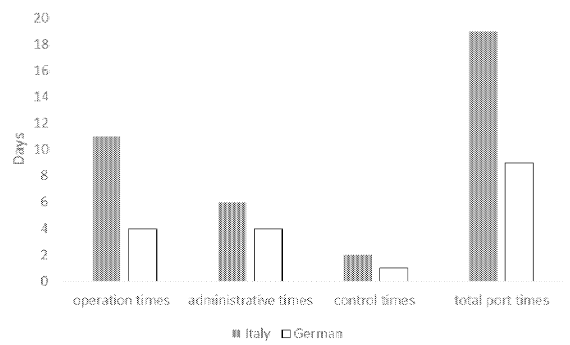

Figure 8: Comparison of other times between the Italian and German ports (Italian Government, 2014)

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FREIGHT TRANSPORTATION IN REGIONAL LOGISTICS: PICK-UP, CONSOLIDATION AND DELIVERY OPERATIONS OF A ROAD CARRIER

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KEYWORDS

Operations research, Transportation, Optimization.

ABSTRACT

The paper presents models and procedures for the design of extra-urban road transportation services operated by a carrier, who have to ship freight from a local production area to different regional consumption markets. It is a many-to-many freight pick-up and delivery problem, where freight consolidation activities are present and they are out-of-vehicle. The transportation services simulated in the paper are operated by a carrier, who travel along the Italian extra-urban road transportation network in order to deliver perishable freight from producers (located in the Province of Reggio Calabria, Italy) to final clients (located in the Northern of Italy). The paper presents the results of the application of two Vehicle Routing (VR) algorithms, greedy and genetic, for optimal design of above road transportation services.

1. INTRODUCTION

The paper focuses on planning and managing freight road transportation and logistics services operated by carriers at extra urban level. Carriers have to move perishable freight from a local production area (*short distance*, i.e. fifty kilometres of diameter), where a large number of origins (producers) are present, to several regional consumption markets (*long distance*, i.e. between five hundreds to one thousand kilometres far from the local production area). The consumption markets can have a distance each other between one hundred to three hundred kilometres (*intermediate distance*).

The road transportation services under consideration in this paper are operated by carriers by means of heavy vehicles travelling along the Italian road transportation network composed mainly by highways and extra urban roads. A scheme of the itineraries of the above services is reported in Fig. 1.

The above general problem, which can be defined as many-to-many freight pick-up and delivery problem, may be decomposed into five parts:

- *pick-up* freight from producers of the local production area;
- *consolidation* of freight in a consolidation center (optional) located in the local production area;
- *long-haul transportation* of freight from local production area to regional consumption market;
- *deconsolidation* of freight inside distribution centers (optional) located in the regional consumption markets;
- *delivering (or distribution)* of freight among final clients inside the regional consumption markets.

The consolidation (deconsolidation) of freight may be:

- *in-vehicle*, if the freight is picked-up from the producers (delivered to final clients) with the same vehicle used for the long-haul transportation and the consolidation is inside the vehicle during the pick up;
- *out-of-vehicle*, if the freight is picked-up from the producers (delivered to final clients) with a different vehicle used for the long-haul transportation and the consolidation is inside a consolidation center.

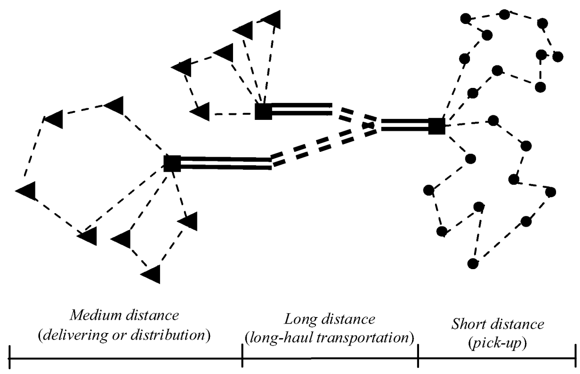


Figure 1: General Scheme of a Road Transportation Service.

If the consolidation (deconsolidation) is in-vehicle, there is not the necessity of the consolidation (deconsolidation) center, while it is necessary if the consolidation (deconsolidation) is out-vehicle. The above cases represent two extremes of what happen in practice, where the consolidation (deconsolidation) could be a mix of the two cases.

In relation to the consolidation and/or deconsolidation activities, four cases may be considered:

I. no consolidation and deconsolidation activities;
II. consolidation activity;
III. deconsolidation activity;
IV. consolidation and deconsolidation activities.

The stakeholders involved in above transportation and logistics services are reported below.

The transportation and logistics operators include: shippers (producers and brokers), that aim to deliver freight at the lowest cost while satisfying client needs; carriers, the transportation company, whose main interest is a low-cost and high-quality transportation service in order to satisfy the shippers' and final clients' needs;

The receivers, whose main interest concerns products delivered at a short lead-time, include: final clients, which may be small retailers or GDO, who ask for quantities of freight delivered inside predetermined time windows; intermediate markets, from where freight reaches its final destinations.

The Government, which is in charge for infrastructure facilities and services operations and transportation and logistics regulations, has the goal to minimize external effects of freight transport.

We analyse in the paper the point of view of the carrier, who acts on the base of the results of a "rational" decision process (Russo, 2013; Russo and Comi, 2002; Russo and Comi, 2010), that can be associated to different time horizon scales: strategic, tactical and operational. At strategic scale, a carrier has to decide what kind of freight, which origins (producers) and destinations (final clients) to serve. Moreover, the dimension and the characteristics of the freight vehicle fleet, the presence and the dimensions of the consolidation and the distribution centers and their locations must be determined. At the tactical scale, an important decision is the design of the network on which transportation services will be offered (the service network). This problem consists of determining the characteristics (frequency, number of intermediate stops, etc.) of the routes to be operated, the operating rules at the consolidation/distribution centers. At an operational level, the decision concerns: the sequence of producers where to pick-up the freight (as well as the sequence of final clients where to deliver the fright), the long-haul transport, the repositioning of empty vehicles. According to the considered point of view, shippers' and receivers' needs and the government's decision about infrastructures, services and regulations are inputs and constraints of the problem.

The paper presents models and procedures for the design of a road transportation service operated by a carrier, who have to deliver freight from a local production area to a regional consumption market. In particular, we have a many-to-many problem, where consolidation activities are present (case II) and where the consolidation is out-of-vehicle. Case II in terms of model and method is similar to case III and it can be solved by means of the same method reported in this paper. Case IV is a more general case and it is not studied in this paper.

After this introduction, the paper is structured into four sections. Section 2 presents the state-of-the-art concerning models and algorithms to support simulation-optimization of the consolidation process in freight transportation and logistics. Section 3 presents the definitions and main elements of the proposed models and algorithms to analyse and design the road transportation services previous defined. Section 4 reports the results of the application to transportation services operated by a hypothetical carrier who have to deliver perishable freight from producers located in the Province of Reggio Calabria (Italy) to final clients, located in the Northern of Italy. Some conclusions are presented in the last section.

2. LITERATURE REVIEW

A consolidation center allows consolidating small quantities of freight into few vehicles reducing the number of routes and, then, the costs of carriers (Daganzo, 1988; Campbell, 1990; Praticò and Moro, 2011; Russo et al., 2013). The consolidation strategies can be made in-vehicle or out-of-vehicle. Daganzo (1990) compares these two cases in order to evaluate when the consolidation (in-vehicle or out-of-vehicle) is needed in specific cases. Other examples (not exhaustive of the whole papers published in this topic) of freight consolidation are summarized by the following authors. Qin *et al.* (2014) consider the problem at international level (freight units are stored in a warehouse and delivered to some retailers). Tyan *et al.* (2003) evaluate the consolidation policies in the global supply chain. Wong (2008) examines the work of a distribution firm that operates in a given area during a typical day, comparing the offered service with the classical vehicle routing.

The problem of consolidation can be formulated and solved by modifying the VRP in order to consider that freight is firstly delivered from depots and/or from producers to intermediary satellites (consolidation or deconsolidation centers), and hence delivered to final clients. This formulation, called Multi Echelon Vehicle Routing Problem (MEVRP), concerns the deliveries of freight from producers to clients by routing and consolidating in one (or more) consolidation center (Dondo *et al*., 2011; Gonzalez-Feliu, 2013). In the specific case of a single consolidation center, the MEVRP changes into Two Echelon VRP (2EVRP), as in Perboli *et al.* (2011). Jaruphongsa *et al.* (2004) that formulates the problem considering the time windows and a consolidation center with a limited capacity. Govindan *et al.* (2014) propose a bi-objective model in the case of perishable freight deliveries. Considering the solution procedures, the problem complexity (to avoid prohibitive calculation times) requires the use of heuristic procedures. Crainic *et al.* (2011) propose a multi-start local search heuristic, Mehihua *et al.* (2011) propose a hybrid ant colony algorithm, Hemmelmayr *et al.* (2012) propose an adaptive neighborhood search. A survey on this problem is reported in Cuda *et al.* (2015).

3. MODELS AND PROCEDURES

The case described in this section concern the many-to-many freight pick-up and delivery problem with consolidation activities (case II or with similar method case III). This problem is called in the literature 2EVRP.

A scheme of the functional structure of a consolidation center is reported in Fig. 2. The consolidation center has some inputs and provides some outputs.

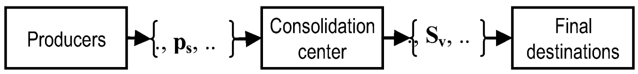


Figure 2: Scheme of the Consolidation Center

Inputs, output and activities in the consolidation center

The combined cargo handling unit considered in this paper, without loss of generality, is the pallet. The input of the consolidation center is a set of pallets (of freight), which arrives from a number of producers: $\mathbf{P}$ = { .., $\mathbf{p}_s$, ..} of cardinality n_p.

Each producer has generally a small amount of freight to be shipped; the minimum quantity is one pallet.

Each pallet shipped by a producer, has the following characteristics (defined with a set $\mathbf{p}_s$ = {p_{sd}, p_{st}, p_{sw}}): a final

destination inside the regional consumption market, p_{sd}; a time window inside which if must be delivered, p_{st}; a weight, p_{sw}.
The consolidation center receives a set **P** of pallet to be delivered, with single element the set $\mathbf{p_s}$.
The outputs of the consolidation center are the vehicles with the consolidated freight on-board.
Each vehicle v is characterized by (defined with a set $S_v = \{\mathbf{A_v}, \mathbf{d_v}\}$): a set of pallets, $\mathbf{A_v} = \{ .., \mathbf{p_s}, ..\}$ with cardinality $n_v, \leq n_p$; a set of destinations to serve, $\mathbf{d_v} = \{1, .., d, .., n_d\}$, (the joint set of the pallets' destinations inside the vehicle).
The freight arrives to the consolidation center from a high number of producers and in small quantities (small number of pallets). It has to be consolidated inside the freight vehicles of a given capacity. The consolidation is performed by means of logistics operations that are not studied in this paper.
The consolidation is performed out-of-vehicle, considering that freight is picked-up at the producer location by means of a vehicle, which is different from the one used for the delivery.
The consolidation process may be the result of an optimization model, in term of a pallet-vehicle incidence matrix, as control variable.

Control and constraints variables

The control variable of optimization model is the pallet-vehicle incidence matrix, Δ. Each element, δ_{ij}, may assume two values: $\delta_{ij} = 1$ if the pallet i is assigned to the vehicle j in the consolidation center to be delivered at the final destination; $\delta_{ij} = 0$ otherwise.
The matrix Δ is the result of the optimization model characterized by an objective function (total cost) to be minimized according to a set of constraints.
The constraints of the optimization model concern: vehicle capacity in term of volume (each vehicle has a maximum number of pallets that can be shipped); vehicle capacity in term of weight (each vehicle has a maximum weight that can be shipped); time windows for freight (pallets) delivery to the final destinations located in the regional consumption market; time windows for allowing vehicles use some services in order to cover a portion of long distance (e.g. ro-ro services); driving shifts of driver and/or increasing driving costs for the presence of the second driver, according to the Italian regulations; all freight (pallets) must be picked-up and all freight (pallets) must be delivered.

Objective function and optimization procedures

According to the four cases defined in the introduction, related to presence of consolidation and/or deconsolidation activities, many cases in term of optimization methods can be considered.
Case I (no consolidation and deconsolidation activities) is very similar to the classic VRP applied in the short, intermediate and long distances. It is solved by means of a single VRP model considering that consolidation is operated inside the vehicle. The solution provides: the best route of vehicles which pick-up freight in the short distance; the best route of vehicles which deliver freight in intermediate distance; the best route for vehicle operating the long-haul transportation.
Case I is studied and solved in many papers present in literature and it is not considered in the application.
Cases II (consolidation activity) and III (deconsolidation activity) are solved by applying two interacting VRPs.

- Case II: one VRP is applied in the short distance (gives as output the best route for pick-up); another VRP is applied in the intermediate and long distances (gives as output the best route for long-haul and intermediate distances and the best allocation of freight in the vehicles).
- Case III: one VRP model is applied in the short and long distances (gives as output the best route for short and long-haul distances); another VRP model is applied in the intermediate distance (gives as output the best route for intermediate and the best allocation of freight in the vehicles).

This paper focuses on solving problems of case II (and in a similar way case III): each vehicle travels from the consolidation center along an optimized route, which reaches a sequence of final destinations. The optimization of sequence of final destinations (and consolidation of pallets inside the vehicle) is reached in relation to the minimization of time and/or monetary costs, according to all the constraints. Pallets inside the vehicles are consolidated accordingly.
The objective function is defined in term of generalized costs (weighted time and monetary cost) for the following operations:

- freight pick-up at producers location;
- freight consolidation inside the consolidation center;
- freight long-haul transportation and delivery to final clients.

The solution is obtained by solving two interacting VRPs. The first VRP is applied in order to generate the best routes for vehicles which pick-up freight from producers in the short distance. The second VRP is applied in order to generate the best routes for vehicles, which deliver freight to the final destinations in intermediate distance and the best routes for vehicles operating the long-haul transportation. The second VRP provides the solution for the consolidation level, in term of pallets-vehicle incidence matrix.
The VRP may be solved by means of several algorithms present in literature. In this work, we used a greedy algorithm and a genetic algorithm. The greedy algorithm is a heuristic able to solve the problem in a simple and immediate way. The heuristic searches a solution of the VRP with sequential insertions (with local optimum search) of producers/final destinations in the route taking into account the problem constraints. Particularly, in route construction, the client closer to the last inserted in the route is chosen. The genetic algorithm is a well-known bio inspired algorithm able to solve the considered VRP (Polimeni and Vitetta, 2014). This algorithm operates starting from an initial population and evolving it for a fixed number of iteration. At each iteration, the population is updated by inserting the new generated solutions. The details of the two algorithms are in Amodeo *et al.* (2015).
Case IV it is not considered in this paper.

4. APPLICATION

An application of case II is tested for a hypothetical carrier, who moves freight from a local production area, located in the Province of Reggio Calabria (Southern Italy), to several regional consumption markets, in the Northern of Italy.
The application started with the definition of the local production area, where 16 hypothetical producers and the consolidation center (CC) are identified. The quantity of freight for each producer to be picked-up varies from 1 to 20

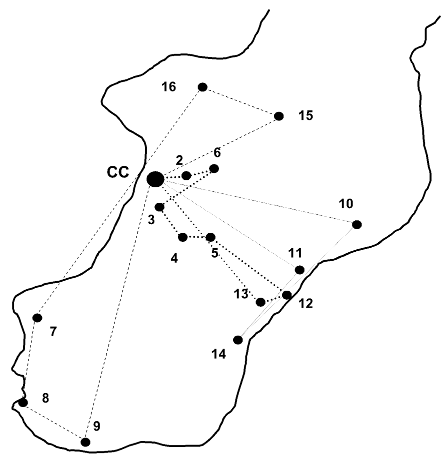
pallets to be delivered to 1 up to 10 hypothetical final destinations. The total quantity of freight that can be delivered per vehicle in the intermediate and long distance is 33 pallets.
The results of the application of the two considered algorithms, greedy and genetic, are presented in the following. Table 1 shows the trip times (minutes) and the sequence of visited nodes, without considering the loading/ unloading time, for the short and for the long and intermediate distances.

Table 1: Trip Times and Sequences of Nodes-Clients to be Visited without Considering the Loading/Unloading Time

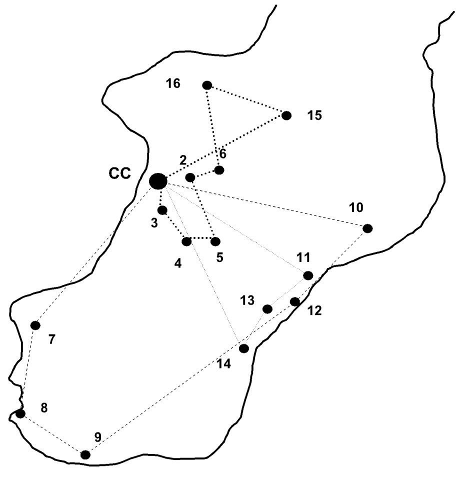
	Distance	*Time (minutes)*	*Sequences of nodes*
Greedy	*Short*	(254+249+330) 833	CC-2-6-3-4-5-12-13-CC / CC-11-14-10-CC / CC-15-16-7-8-9-CC
	Long and intermediate	(884+832+1213) 2889	CC-2-3-6 / CC-4-5-7 / CC-10-9-8
Genetic	*Short*	(235+195+341) 771	CC-3-4-5-2-6-16-15-CC / CC-11-13-14-CC / CC-7-8-9-12-10-CC
	Long and intermediate	(1112+835+929) 2876	CC-7-9-8 / CC-4-5-6 / CC-2-3-10

Table 2. Best routes in the short distance: greedy and genetic algorithms.

Greedy algorithm



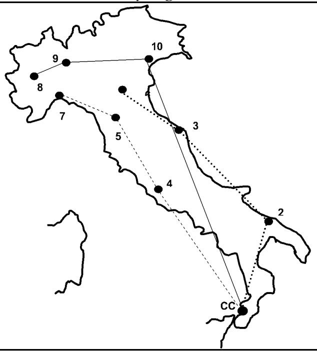
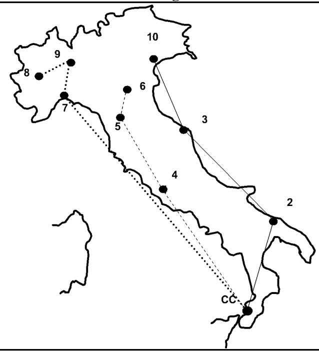
Genetic algorithm



The greedy algorithm estimates 833 minutes for the short distance and 2889 minutes for intermediate and long distances. The genetic algorithm estimates 771 minutes for the short distance and 2876 minutes for the intermediate and long distances. The calculation of the total trip time for intermediate and long distances does not take into account the time and the cost for the return trip from the last destination to the consolidation center. This because it is hypotheses that the cost and time for the return trip is covered by other services; this is realistic considering the trip from the north to the south of Italy.
The gain with the genetic algorithm is 62 minutes (7.4%) for the short distance, while it is negligible for the intermediate and long distances.
In Table 2 the optimal routes designed by means of the greedy and genetic algorithms in order to pick-up freight from the producers (nodes) inside the Province of Reggio Calabria, are depicted. Table 3 depicts the optimal routes designed by means of the greedy and genetic algorithms in order to visit the final clients (nodes) in the Northern of Italy.
According to the results obtained, the following considerations may be drawn:

- the genetic algorithm provides lower trip times than the ones provided by the greedy algorithm in the short distance (-7%); this reduction is not negligible in terms of energy consumption (and monetary costs) from the carrier standpoint;
- routes designed by the genetic algorithm are composed by groups of clustered producers/clients close one-another linked together by means of more extended paths; this configuration is not easy to be designed by the greedy algorithm;
- the reduction with the genetic algorithm is obtained in a simple case, with only 16 producers and one vehicle; greater reductions are expected with increasing number of producers (or final clients) to be visited and more vehicles used.

Table 3: Best Routes in the Long and Intermediate Distances.

Greedy algorithm	*Genetic algorithm*
	

5. CONCLUSION

The paper presents models and procedures for the design of extra-urban road transportation services operated by carriers, who have to ship freight from a local production area to regional consumption markets. We have a many-to-many freight pick-up and delivery problem, where freight consolidation / deconsolidation activities may be present or not and they may be in-vehicle or out-of-vehicle.

Among the several cases considered, the one studied in the paper concerns the many-to-many freight pick-up and delivery problem with consolidation activities, which correspond to case II (Case III is similar) presented in the introduction.
The above case is solved by means of two existing VR algorithms, greedy and genetic, for design optimal routes of freight vehicles operated by a carrier, who travel along the Italian extra-urban road transportation network. The greedy algorithm emulates the decisions of a carrier whose logistics is not optimized, while genetic algorithm obtains a solution similar to the one that could be obtained if the carrier is supported by a decision support system. In general, there is a trade-off between the higher quality of the results obtained with the former and the simplicity and immediate applicability of the latter.
Future work will concern the specification of the VR model and the adaptation of the relative algorithm for the solution of case IV, which considers both consolidation and deconsolidation activities.

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CHARACTERIZATION OF CONTAINERS' LOGISTIC CHAIN

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KEYWORDS
Energy, Industrial processes, Transportation, Computer-aided analysis, Container Terminals, Port simulation.

ABSTRACT

The following paper describes part of the works developed for the European Project Sea Terminals with the objective to analyze and characterize, in terms of energy consumption, emissions and costs, the main machines involved in container handling operations at Noatum Container Terminal Valencia (Port of Valencia, Spain). These analyses will allow to estimate the optimal operation modes at the terminal and to compare the performance of the current machines with that of new prototypes that will be tested in the terminal in the scope of the project, which implement measures of energy efficiency such as ECO working mode or hybridization of technologies.

INTRODUCTION TO THE SEA TERMINALS PROJECT

The Sea Terminals Project is co-funded by the European Commission under the Trans-European Transport Network (TEN-T) program, No. 2013-EU-92058-S. The consortium of ten partners, led by the Valenciaport Foundation, is formed by Port Authorities, Research Institutions, port equipment manufacturers and associations from four different countries in Europe: Spain, Italy, Netherlands and Estonia. The general objectives of the Project are the following:

- Contribution to a progressive and quick decarbonisation of port container activities in Europe, thus reducing GreenHouse Gas (GHG) and pollutant emissions.
- Demonstration of feasibility (financial, technical and environmental) of mature integrated solutions based on smart energy management, eco-efficient technologies and alternative fuels applied to port machinery and equipment.
- Provision of an innovative and market-sided approach in the way that energy is managed at port terminals, considering it as key driver for improving operations and competitiveness.
- Promotion of a collaborative framework among ports, port operators and equipment manufacturers, thus establishing new relationships not only based on commercial interests but also on common innovation opportunities.
- Transfer of the project outputs to as many as possible stakeholders at European level in order to accelerate the evolution of the port sector towards a low-carbon emission operative model.

The Project comprehends three steps, before its end in December, 2015: the first one of engineering and prototyping; a second step of real life trials will take place in the Ports of Valencia (Spain) and Livorno (Italy) and finally a study of market and business plans for the prototypes and improvements presented and tested in the scope of the project will be made.

The present paper addresses the works being currently developed by the Instituto Tecnológico de la Energía (ITE) to characterize and estimate the best possible operational modes in terms of energy and fuel consumption, carbon emission and operational costs for the containers' logistic chain in the Port Containers Terminal (PCT) of Noatum in the Port of Valencia. This work is described in the following sections.

DEVELOPMENT OF THE CHARACTERIZATION METHODOLOGY IN CONTAINERS TERMINAL

Objectives

Usually PCTs implement Terminal Operating Systems (TOS) to manage the operation of containers loading and unloading. TOS are software tools structured in different modules of information management and control connected to a general data base. The TOS is formed by, in general, four main modules:

- Planning and operations control module (land and maritime).

- Management module, which supports the analysis of productivity, costs control and statistical analysis.
- Administration module, in charge of the invoicing and analytical accounting.
- Information and communication module, responsible for the information exchange of the terminal with external agents.

Currently most TOS do not integrate energy monitoring and management perspectives linked to operations, as they are a pure operative-oriented tool. This lack of energy-related dimension makes more difficult the suitable management of energy consumption and associated GHG emissions of port operations. The Sea Terminals Project addresses this gap by designing and piloting in Noatum Container Terminal Valencia (NCTV) a smart, efficient and adaptive energy management system (SEAMS Platform), able to monitor in real time the energy state of the whole yard machinery and decide in a dynamic way the most suitable working modes for each machine which is operating at any time. The SEAMS Platform is an intelligent tool which receives information from the Terminal Operating System (TOS) and from the different terminal machinery and equipment regarding operational and energy status. With this information the SEAMS Platform decides the most suitable operation mode for each machine: inactive, idle, eco-mode and turbo and assigns these modes to each machine remotely in real time. This will result in a direct and significant reduction on energy consumption, GHG and pollutant emissions therefore making operations more efficient and dynamic. This Information and Communications Technology (ICT) architecture is summarized in Figure 1.

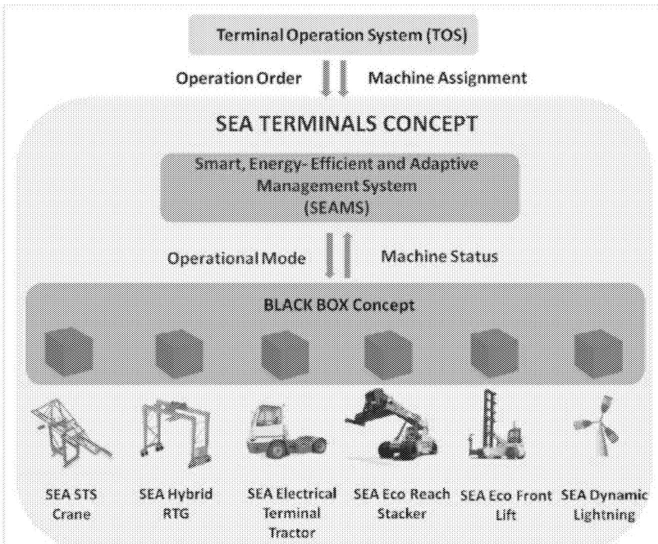

Figure 1: Sea Terminals architecture implemented in NCTV

The objective of the present work is to develop a SW application that, for given types of machines and their possible working modes, is able to produce an estimation of the operational and energy costs associated to the complete working cycle being analyzed, from an estimated or expected demand of operations. From the operational point of view, energy and operation costs are the most significant values when evaluating total performance, productivity and efficiency of port operations. This SW application will obtain the data from the SEAMS, through specific queries to the centralized database that stores the processed data from the working cycles from all the monitored machines. The specific machines that will be analyzed in the scope of the project are the following:

- STS (Ship-To-Shore) gantry crane: which moves the containers from the ship to the truck or Terminal Tractor.
- TT (Terminal Tractor): a truck that carries the containers to the place they are being piled.
- RTG (Rubber Tyred Gantry) crane: moves along the containers pile, handling the containers from the Terminal Tractors.
- Empty Container Handler (ECH) and Reach Stacker (RS): used to move empty or non-empty containers for different purposes.

Besides the existing machines, which represent the current baseline scenario of energy consumption (and therefore fuel consumption and associated operation times, emissions and operational costs) for the whole logistic chain, the following energy efficiency prototypes will be tested in the real life trial in NCTV:

- Full Electric Terminal Tractor (SEA-eTractor): a Lithium Iron Phosphate battery-powered of 215 kWh, developed by TERBERG.
- Low Carbon (SEA-EcoRTG) Rubber Tyred Gantry Crane: the prototype, developed by PACECO, implements a hybrid technology, with a downsized diesel engine, plus an energy regenerative system, by the use of flywheel or electrical storage, able to supply the extra energy for the peaks of demand in the operation of containers.
- Eco-Efficient ECH (SEA-EcoLIFT): developed by HYSTER, implements the latest enhancements regarding energy efficiency, one of them being the option to work in ECO mode (i.e., with a reduced engine power) or hibernate (idle state).
- Eco-Efficient Reach Stacker (SEA-EcoRS): developed by HYSTER, implements the latest enhancements regarding energy efficiency, and dual Liquefied Natural Gas (LNG) fuel supply.

As a summary, the objective of the present work is twofold:

1) To characterize the machines' operation in terms of energy and fuel consumption, emissions and associated costs, being able to estimate the optimal operation modes, taking into account the whole logistic chain, the interaction of machines in the handling of containers, and the uncertainty associated to the operative unit, i.e., the container, since each container may have a different weight.
2) To model and compare the behavior of the current machines and the incoming prototypes, or other future machines that may implement measures of energy efficiency, such as ECO working modes, dual fuel supply, or hybridization technologies.

The data will be provided by the SEAMS, being real data from the monitored machines during the working cycles. The analysis is designed with two perspectives: an analysis by machine or machine family, and an analysis by container or containers handled. This last approach includes the characterization of all the machines involved in the loading/unloading cycle, allowing to characterize the complete process for container ships in terms of energy consumption, fuel, time, emissions and costs.

Many works can be found in the literature addressing the characterization and optimization of the container terminal behavior, mainly its logistic operation[1- 3] and the efficiency in both port and terminal level for every operation [4], however none of these works have attempted to model and estimate the interaction between operational and energy costs associated to the complete working cycle of the machines. For example, [2] uses a Petri net to present berth operations, and a genetic algorithm is used for scheduling container loading/unloading operations by cranes in order to minimize the maximum time it takes to serve a given set of vessels. In [3] some potential research directions are presented for yard management where the terminal authority can negotiate the arrival time and position with final transporters, but this research is focused in the Berth & Block Allocation Problem (BBAP). In [5] an approach to generate scenarios for container terminals is found, which can be used as a basis to perform simulations in the SW tool presented in this work.

There are also some commercial software programs available to manage terminal operations [6, 7] however they do not take into account many of the variables that are presented in this paper to evaluate different operational scenarios.

The characterization and modelling work proposed in the scope of the Sea Terminals project for machines, machine families and terminal logistic chain will provide port operation planning with an energetic dimension. The operation cost and energy consumption of a terminal machine depends on several aspects related to the terminal operation (container weight, required working mode for each machine, waiting time with and without container, etc.) and to the machine characteristics (fuel type, engine properties, working mode, etc.). The combination of these variables sets out an optimization problem with a more complex solution than just using the most efficient machines.

The machine and terminal logistic chain simulation will help PCTs to answer questions like: Should I reduce the rated power of a RTG engine? Is it worthy to buy hybrid ECHs? How much will I save (in €, in kWh and in tones of CO_2) if ECO mode is required for TTs while they are waiting without container?

Characterization of the containers' logistic chain at PCT

The data gathered and stored by the SEAMS from all the machines being monitored in real time include the processed data for each working cycle of fuel and / or energy consumption, average and maximum power, total time and other specific information, such as the working mode (Normal or ECO). A working cycle is defined as the complete set of movements that a machine performs to translate one or more containers (one, two or four) from one place or machine to the following in the logistic chain.

As indicated before, the analysis of characterization is designed with two perspectives: by machine type and by all the machines involved in the loading or unloading process. The variables to be analyzed and compared in the characterization process have been defined as the following:

- Total energy consumption per cycle, defined in kWh.
- Maximum and average power consumption per cycle, defined in kW.
- Duration, in hours.
- CO_2 emissions, computed from the energy measure applying specific factors as a function of the energy source.
- Fuel consumption (when applies), in liters.
- The total costs, obtained as a function of operational and energy supply costs, maintenance and depreciation.

These values will be used to compare the machines according to different levels of aggregation, such as the manufacturer or model, or the engine rated power. Figure 2 depicts an example of the characterization analysis, where the total cost has been computed as the sum of the measured energy costs and the calculated operational cost, based on tests on RTGs with different engine rated power.

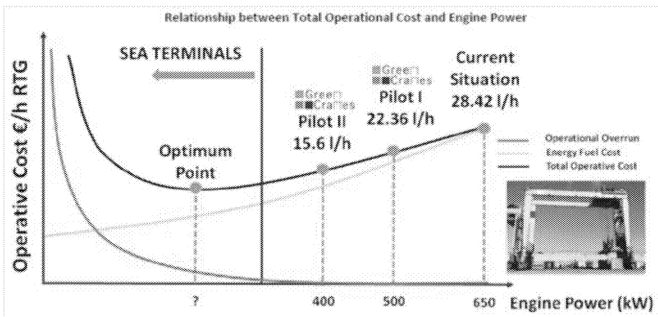

Figure 2: Example of RTG characterization in terms of energy and operational costs

As can be seen in this example, the interpolation of the different measures, after an adequate statistical processing, is expected to display curves that reflect the presence of theoretical optimal working modes, in terms of costs in this case. However, the same concept applies to energy, time, and emissions.

Modelling and Simulation of different scenarios

Once the characterization analysis is developed, one of the objectives is to quantify the improvement in energy consumption and total cost after the operational improvements are implemented, and also to compare the performance of the current machines with the new prototypes being tested. In this sense, scenarios for the comparison must be defined and tested: the current or baseline scenario, the scenario obtained by applying the operational improvements as a result of the characterization analysis, and the scenario provided by the use of the new prototypes being tested. An initial step before the implementation of field tests, due to the complexity of preparing and performing the tests under the ideal conditions, is to obtain models and simulations of the machines and their behavior under the test cases defined.

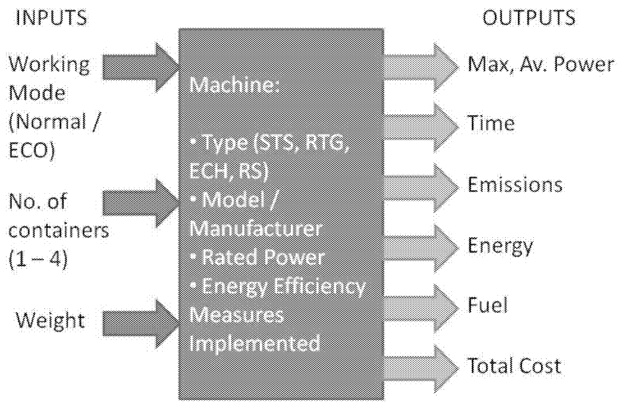

Figure 3: Definition of static input/output model of PCT machine

An appropriate selection of input and output variables and internal parameters of the machines will allow to obtain static models of behavior of the machines in terms of energy and fuel consumption, costs and emissions per cycle. Different regression techniques will be tested and selected for this purpose, such as curve fitting or neural networks [8]. Figure 3 depicts the design of the generic model structure for the different machines: inputs, outputs and parameters.

Software application for the analysis of scenarios, modelling and simulation

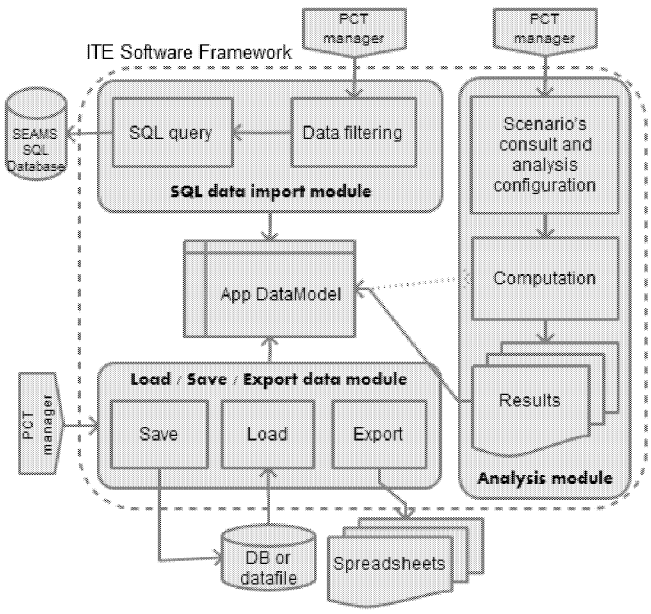

Figure 4: Design of the SW application for the analysis, modelling and simulation of the different scenarios of characterization

All the previous analyses will be implemented in a SW application being developed by ITE. The application will work on configurable queries to the central database in the SEAMS, and will implement the functionalities of characterization, either from the perspective of the machines and the containers logistics costs, and the option to model and simulate scenarios of different configurations and test cases. Figure 4 displays the diagram of the application architecture.

Although this application is currently under development its main functionalities have been already defined. The main queries to the SEAMS database will be performed in a timeframe basis. Then, the SW will offer to the user an additional data filtering by machine id, machine type, ship id, operator id or container id. Depending on the filtering parameters and options the resulting information will be completely different. Therefore different analyses and visualizations will be offered to the user regarding operational, energy, cost and environmental variables depending on the filtering parameters.

Figure 5 shows an example of the kind of operational graphic analysis that the SW will provide if an analysis by machine id is selected.

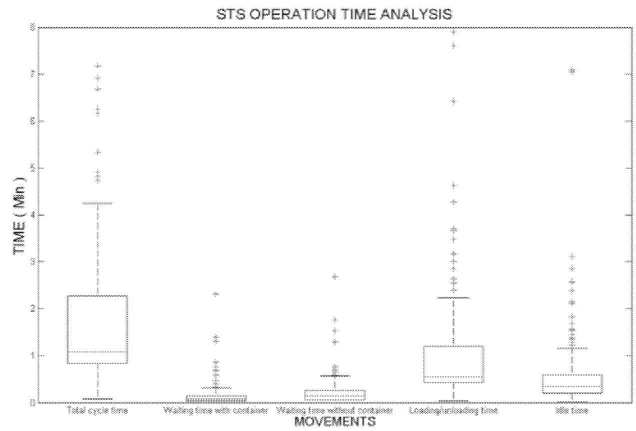

Figure 5: Example of machine operation time analysis based on real STS operation data.

Although the SW will include a significant number of data analytics options it will also include the possibility to define and simulate different scenarios. As described before, the simulation tools will be addressed to cover two main objectives:

- Terminal machine simulation. Modelling and simulation of machine working modes (normal, eco, turbo, etc.) and their relation with the economic energy and environmental costs of the terminal operation. Also further analysis and simulation of machines that are not yet commercially available with energy efficiency measures applied, such as, for instance the reduction of the engine rated power or the fuel type (hybridization).

- Terminal logistic chain simulation. Modelling and simulation of the whole terminal logistic chain combining real machines, Sea Terminals prototypes and simulated machines to support the PCT operation and planning decision process.

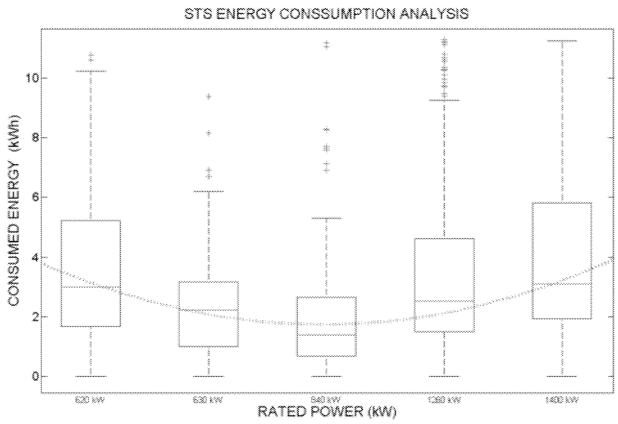

Figure 6: Example of machine family energy consumption analysis based on real STS operation data.

Figure 6 shows an example of the kind of energy graphic analysis that the SW will provide if the SEAMS initial query is filtered a second time by machine type. The green spoted line shows a polynomial fitted curve to the average values of energy per operation cycles for machines with different rated power that may be used in the terminal logistic chain, including the commercial ones and also the prototypes.

CONCLUSIONS

The Sea Terminals Project is currently in its engineering and prototyping phase. The ICT architecture to monitor the state variables form the machines is being implemented and also the SEAMS. There is, therefore, a lack of enough data from field measures to test and validate the projected analysis. Nevertheless, synthetic data has been created based on the Sea Terminals consortium PCT expertise from former projects in order to validate the software under development. This analysis will be enhanced in the following moths, once the SW application for characterization and simulation of scenarios is finalized.

This SW application will be a valuable tool to validate the energy efficiency measures being implemented and tested in PCTs, and particularly in NCTV. The application will also allow to compute theoretical optimal working modes as a balance of costs, energy consumption and emissions. These results will be used by Noatum in planning and operations at the PCT for future improvements in operation and investments in machinery.

The SW application of characterization, along with the SEAMS concept and architecture, fills the gap in PCT operations related to energy consumption visualization and the measure of carbon footprint. The methodology is being designed to be easily transferred to other PCTs in Europe, assuring the dissemination of the methods and techniques implemented and validated in NCTV.

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USING SIMULATION TO SUPPORT THE RESILIENCE OF SUPPLY CHAIN

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KEYWORDS
Supply Chain; Simulation; Resilience; Mitigation Strategies; Flexibility.

ABSTRACT

Supply chains (SCs) are subject to disturbances that frequently implies a loss of their performance. Avoiding such disturbances or reducing their negative effects, i.e. developing resilience, is a challenge for SC managers. SC resilience can be achieved by implementing mitigation strategies, mostly based on redundancy and/or flexibility. However, to improve something it is necessary to measure it. To support the SC resilience decision making process a simulation model was developed to create different scenarios. A case study approach was used to evaluate the resilience of a SC comprising a sub-set of companies belonging to the Portuguese automotive industry. In the case study, the SC is subjected to a transportation disturbance and two scenarios are considered: in the first one a mitigation strategy based on flexibility was implemented and in the second scenario no resilience strategy was considered. In each scenario the SC behaviour was assessed using a model based on the "resilience triangle". The fulfilment rate measure was used to quantify the resilience of each company and respective SC. Finally, a comparative analysis is done regarding the SC resilience of each scenario.

INTRODUCTION

To improve effectiveness and create highly efficient supply chains (SCs), the modern SCs are adopting new paradigms, philosophies and strategies of management, such as lean manufacturing, Just-In-Time, strategic inventory, reduced product lifecycle and outsourcing, among others. Although these new ways of managing have yielded attractive business benefits, they reduced the slack available to deal with uncertain events (Carvalho et al. 2014). Avoiding disruptions or reducing their negative effects is a challenge for today's management. A resilient SC is able to react to the negative consequences of disturbances (Carvalho 2012a). Although some recent studies highlighted the importance of companies and SCs to have the ability to cope with and overcome the negative effects of disturbances, a methodology to support the decision making concerning the resilient strategy that promotes the most resilient SC has not been attempted so far.

The uncertainty of the future is usually modeled using scenarios (Peterson 2003). The comparison of scenarios helps managers improving decision making regarding the selection of the mitigation strategies that promotes the greater SC resilience to a disruption (Carvalho et al. 2012b). The main goal of this paper is present a methodology to support decision making of managers regarding the SC resilience by combining the simulation of SC scenarios (to get results of performance measures) with a model for assessing the resilience level of each individual company's SC and the overall SC.

The paper begins by defining and discussing crucial concepts in the scope of SC resilience management. A case study of a real sub-set of companies structured in three-echelons, which belongs to a Portuguese automotive SC, is presented and a simulation model is developed. Two scenarios are created, one in which the mitigation strategy is implemented, whereas in the other no mitigation strategy is implemented. The comparative analysis of the SC resilience indexes of the scenarios allows managers to select the most resilient scenario/strategy to a disturbance.

SUPPLY CHAIN RESILIENCE

In the past few years, many events have shown how companies and SCs, to which they belong, are vulnerable to disturbances, namely events such as the 11th of September, the Hurricane Katrina or more recently the Japan earthquake in 2011. There is no unanimity among academics about disturbances and disturbances sources concepts. As referred by Barroso et al. (2008), the following terms have been frequently used interchangeably: disturbance, risk, uncertainty, disruption, and nervousness. In this paper disturbance is defined as a foreseeable or unforeseeable event that affects negatively and directly the usual operation and stability of a company or a SC (Barroso et al. 2008).

If the SC is not resilient to disturbance, the negative effects may be reflected in one or several SC entities. Resilience is defined as the ability of a company to react to disturbance and return to its original state or a more desirable one (Barroso et al. 2011; Christopher and Peck 2004).

Tomlin (2006) considers two types of strategies for dealing with disturbances: contingency and mitigation strategies. Contingency strategies are in its essence more reactive, whereas mitigation strategies are more proactive. Mitigation strategies imply taking actions before the disturbance occurrence to reduce its frequency, or its impact, or both. So, the company or SC incurs in a cost associated with the mitigation strategy implementation, regardless of the disturbance occur or not. Conversely, contingency strategies involve actions taken only after a disruptive event has happened. Tomlin (2006) also highlights that more than one strategy can be used to manage disturbances.

The question on “how to assess the SC resilience” still has no answer (Carvalho 2012a). Carpenter et al. (2001) specify some resilience properties, namely: i) amount of change the system can undergo and still retain the same controls on function and structure; ii) degree to which the system is able of self-company; and iii) ability to build and increase the capacity for learning and adapting.

Sheffi (2005) shows how disturbances can affect business performance regarding production levels, sales, profits and customer service. The behaviour over time can be represented by the “resilience triangle” which helps to visualize the magnitude of the disturbance negative impact on system (company or SC) performance. Therefore, the system performance evolution over time can be used to assess its resilience (Carvalho 2012a; Barroso et al. 2015).

The depth of the triangle represents the disturbance severity, i.e. the severity or magnitude of loss damage, and the length of the triangle represents the recovery time, i.e. the damping time. The smaller the triangle is, the more resilient the company or SC is.

Based on the “resilience triangle”, Barroso et al. (2015) propose a model to assess company resilience by an index, considering a specific time period in which its performance was affected and also comprising the recovery time. In this approach an appropriate set of performance measures should be used depending on the business goal, e.g. lead time ratio, total cost, and fulfilment rate, among others.

Considering that company performance is measured at the end of each period t (time period defined between t_0 and t_1), a curve is generated with the performance along time (P_{it}). If there is no disturbance, the performance level of the company i is given by P_i. When a company is affected by a disturbance the performance declines. Then, the recovery starts and after some periods the company performance achieves the initial state P_i. In this way a triangular pattern emerges. The triangle area can be used as the resilience index of company i, computed by Equation (1); its value goes from 0 (means no resilience to the disturbance) to 1 (means resilient).

$$R_i = 1 - \frac{\int_{t_0}^{t_1} (P_i - P_{it}) \partial t}{P_i (t_1 - t_0)} \cong 1 - \frac{\sum_{t=t_0}^{t_1} (P_i - P_{it})}{P_i (t_1 - t_0)} = 1 - \frac{\sum_{t=t_0}^{t_1} \left(1 - {P_{it}}/{P_i}\right)}{P_i (t_1 - t_0)} \qquad (1)$$

Where,

R_i is the resilience index of company i;

P_i is the performance level of company i when it was not yet affected by disturbance;

P_{it} is the performance level of company i in time period t;

t_0 is the lower limit of time period t;

t_1 is the upper limit of time period t.

Since the SC is a network of companies, the assessment of SC resilience to disturbances needs to reflect the perspective of the network. In this line, Barroso et al. (2015) propose an index to assess the overall SC resilience, RSC, based on the individual companies' resilience indexes using four types of aggregation methods, namely, additive, multiplicative, network perspective, and a constraint approach.

RESILIENCE INDEX OF AN AUTOMOTIVE SUPPLY CHAIN: CASE STUDY

To illustrate how the resilience level of both companies and SC can be determined based on the scenarios simulation, a case study will be developed. The case study is based on a sub-set of companies which belong to a Portuguese automotive industry SC characterized by a Lean production environment, and hence vulnerable to disturbances.

The SC under analysis includes six companies in three echelons: one Automaker; two 1st-tier suppliers (Supplier 1 and Supplier 3) and one outsource company (Supplier 2); and two 2nd-tier suppliers (Supplier 4 and Supplier 5), Figure 1.

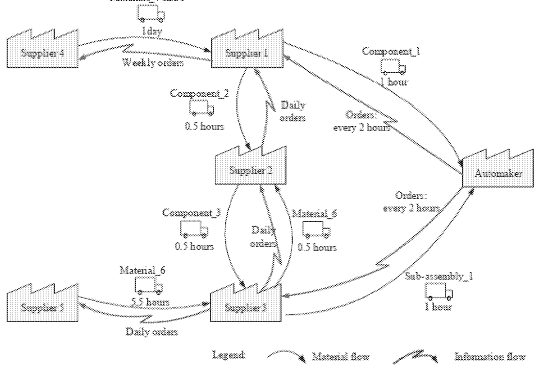

Figure 1: The Automotive SC under Study.

The Automaker plant is responsible for the production of over 180 000 vehicles per year and manages its operations according to the Just-In-Time and Lean philosophies.
The Automaker demand is stable. Four times a day the Automaker places orders of Component_1 to Supplier 1 and Sub-assembly_1 to Supplier 3. If it is not possible to deliver a complete order, Supplier 3 and Supplier 2 can deliver only a fraction of the order.
Despite the Automaker managing its operations in a virtual zero inventory, it requires that 1st-tier suppliers (Supplier 1 and Supplier 3) have a raw material inventory for 3 days.
The 1st-tier suppliers are located in the same geographic region as the Automaker. Component_1 and Sub-assembly_1 are delivered to the Automaker using a milk-run system. The transportation vehicle collects Component_1 and Sub-assembly_1 at the 1st-tier suppliers and delivers them to the Automaker 2 hours after the order has been placed.
Supplier 3 delivers Sub-assembly_1 to the Automaker four times a day. To ensure that the Supplier 3 takt time is compatible with the Automaker takt time, some operations are carried out in advance. Supplier 3 outsources one operation to Supplier 2, which incorporates Material_6 into Component_2, resulting in Component_3. Daily Supplier 3 sends Material_6 to Supplier 2 and receives Component_3. Then, Supplier 3 assembles other parts to Component_3 to produce Sub-assembly_1.
Supplier 5 is critical for Supplier 3 as Supplier 3 has Material_6 inventory for only 3 days. The Material_6 delivery is made by road in about 5,5 hours, according to a triangular distribution, in which the minimum and the maximum are 5,23 and 6,05 hours, respectively.
To evaluate the performance of each SC company during a time period t it is used the fulfilment rate, proposed by Barroso et al. (2015), which is defined as the percentage of units delivered on-time by supplier i regarding the units demanded by their 1st-tier customers (Equation 2).

$$Fulfilment\ Rate_{i,t} = P_{it} = \frac{1}{J_{i,t}} \sum_{j=1}^{J_{i,t}} \frac{Q_{LT_{pmsd},j}}{Q_j} x100 \qquad (2)$$

Where,
$J_{i,t}$ is the total number of orders placed by 1st-tier customers to supplier i during time period t;
Q_j is the number of units of the order j;
$Q_{LTpmsd,j}$ is the number of units of the order j delivered in the promised lead time LT;
t is the analysed time period.

Supply Chain Simulation Model

To reproduce the behaviour of SC companies a simulation model was developed using Arena 9.0 simulation software and Microsoft Excel 2003. The Arena software interacts with Microsoft Excel using Visual Basic for Applications (Excel VBA), which provides the required methods and routines for applications, Figure 2.

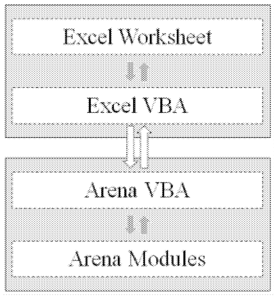

Figure 2: Interaction Between ARENA Software and Microsoft Excel.

Each company has an Excel workbook associated with it. For each company, the model's logic is designed in Arena. The Arena sub-model associated with a company also includes the VBA blocks that communicate with tables in the corresponding Excel workbook, to read or save data, using Excel VBA. This approach was used by several authors, namely, Pundoor and Herrmann (2006). Arena triggers various planning activities in Excel at periodic intervals. Each planning activity checks the system status and takes actions depending on the status. The Excel workbook records the status of the system and the performance measures results.

Simulation Model Characteristics and Assumptions

To understand system behavior and to quantify the simulation inputs, such as processing times and inventory data, interviews with logistics and operations managers of the SC companies were conducted.
Some characteristics associated with SC companies, logistics activities and production processes were identified, namely: i) The Automaker behaves like a customer, placing orders and receiving products; ii) Customer demands are pulled through the SC; iii) Demand is completely fulfilled. A material/product shortage will be backordered and delivered as soon as possible; iv) The sourcing planning follows a periodic review inventory system; v) The 1st-tier suppliers' production planning follows a make-to-order policy; and vi) The orders are schedule to production using a First-In-First-Out (FIFO) rule.
Also, some assumptions were made to overcome the complexity of the SC, namely: i) The stochastic process times follow a triangular distribution; ii) There is no defective material; iii) The 2nd-tier suppliers have an infinite inventory of material, therefore they do not need to perform sourcing activities; and iv) There is no reverse flow of materials.
The model's input is comprised of: i) Demand data: order time, order quantity, and request delivery data; ii) Vehicle subset materials tree; iii) Inventory data: maximum inventory level, and review period; the initial inventory is equal to the maximum inventory level; iv) Resources

data: processing time and capacity; and v) Transportation data: time period between SC companies.
For estimating the warm-up period a graphical method was used. A visual inspection of performance measures time-series of the simulation output was done and a warm-up period was set to 20 days. So, the record of performance measures starts in time period 21 to avoid bias from starting conditions. The run-length of the simulation was determined through experiments by doing some simulation runs. Some simulation output performance measures of all companies were observed to identify the instant of time from which each company recovered it performance (the state prior to the occurrence of the disturbance). Therefore, each simulation runs for 70 days of 8 hours. Multiple replications were used for confidence interval definition. Using a significance level of 5% for the confidence interval definition 30 replications were determined by statistical analysis of the lead time.

The Scenarios

To evaluate the SC resilience to a transportation disturbance, which occurs between Supplier 5 and Supplier 3, daily companies fulfilment rates from the two scenarios are determined. Scenario 1 represents the SC without a mitigation strategy implementation and scenario 2 represents the SC with a mitigation strategy implementation.
The SC is affected by a transportation disruption in day 15, which causes an interruption in the flow of Material_6 from Supplier 5 to Supplier 3 during seven days.
In scenario 1 this disturbance occurrence makes the SC vulnerable, since Supplier 3 has only three days of Material_6 inventory and there are no alternative suppliers, whereby the material flow interruption occurs. The supply of Material_6 is critical due to SC Lean production environment. This disturbance causes the breakdown of Supplier 3, Supplier 2 and Automaker production lines.
Scenario 2 considers the adoption of an alternative transport of Material_6 from Supplier 5 to Supplier 3 after the first day of disturbance.
Scenarios 1 and 2 have the same input values.
The interruption of the material flow between two SC companies, do not affect all companies in the same way (Figure 3). Suppliers 1 and 4 are not affected in the two scenarios.
In scenario 1 the performance of Suppliers 2, 3 and 5 is affected by the transportation disturbance because the three suppliers are not able to sustain their performance level. In scenario 2, in turn, only Supplier 5 is affected by the disturbance. Figure 3 shows that the disturbance of Material_6 supply to Supplier 3 affects in cascade the SC companies performance. For instance, in scenario 1, the fulfilment rate decreases sequentially, firstly in Supplier 5 and then Supplier 3 and Supplier 2. Supplier 2 is also affected by daily uncertainties.

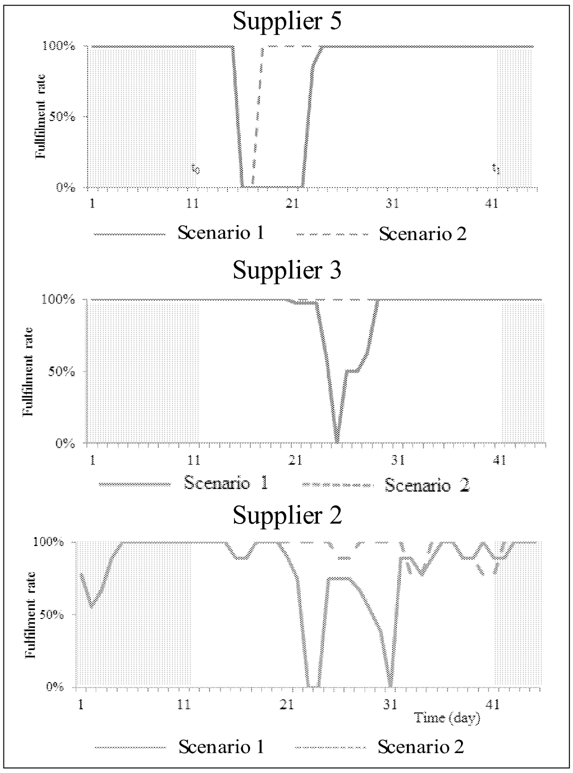

Figure 3: Fulfilment Rate Curves for Scenarios 1 and 2.

Considering the fulfilment rate performance measure and a time window of 30 days, between day 12 (t_0) and day 42 (t_1), the SC company resilience index is computed for each scenario using Equation (2). Next, SC companies' resilience indexes for the two scenarios are analysed.

Companies' Resilience Indexes for Scenarios 1 and 2

In scenario 1 Supplier 5 is enabled to deliver on-time Material_6 to Supplier 3, between days 16 and 22 (Figure 3). Consequently, the Supplier 5 fulfilment rate decreases in this time period and it is obtained a resilience index of 0,76 (Table 1), which means the Supplier 5 resilience level to the disturbance. Supplier 3's performance is also negatively affected by the disturbance and its resilience index is equal to 0,90.
Supplier 2 has a resilience index of 0,78 due to both daily uncertainties and the transportation disturbance. Suppliers 1 and 4 have a resilience index of 1,00 as they are not affected by either the disturbance nor daily uncertainties.

Table 1: SC Company Resilience Index by Scenario.

Scenario	Supplier				
	1	2	3	4	5
1	1,00	0,78	0,90	1,00	0,76
2	1,00	0,96	1,00	1,00	0,93

In scenario 2 the disturbance effects in Supplier 5 are felt only during the first day after the disturbance occurrence.

So, Supplier 5 resilience index is equal to 0,93. The resilience index of the other suppliers is equal to 1,00, with the exception of Supplier 2 due to fulfilment daily uncertainties.

Therefore, it is effective applying a strategy based on flexibility to overcome the negative transportation disturbance effects although the normal behaviour of Suppliers 5 and 2 have been affected.

Supply Chain Resilience Index

The SC resilience index can be computed based on the SC companies' index. Different methods of companies' index aggregation can be used. In this paper the multiplicative aggregation method is used (Equation 3). The SC resilience index for each scenario is presented in Table 2.

$$R_{SC} = \prod_{i=1}^{n} R_i \tag{3}$$

Where,

R_i is the resilience index of SC company i.

Table 2: SC Resilience Index by Scenario.

Aggregation procedure	Scenario	
	1	2
Multiplicative method	0,53	0,89

Regardless the aggregation method used to determine the SC resilience index from Table 2 it can be shown that when the disturbance occurs and a strategy is applied to overcome the negative effects caused by the disturbance (scenario 2), the SC resilience index is higher than when no mitigation strategy is applied (scenario 1).

CONCLUSIONS

To adopt the most suitable mitigation strategies, proactive or reactive, it is crucial to assess the SC resilience. In this paper the SC resilience is determined based on the "resilience triangle" concept.

A simulation model of a case study related to the Portuguese automotive upstream SC is developed in which two scenarios were simulated. When the mitigation strategy is deployed the SC resilience index is higher reflecting the system ability in reducing the negative effects of the transportation disturbance. With the implementation of a strategy based on flexibility (scenario 2) all SC companies increase their resilience indexes in relation to scenario 1, where the strategy is not applied.

The methodology proposed in this paper provides a holistic perspective on improving the SC resilience. Decision makers can consider this methodology when they intend to implement mitigation strategies and improve the decision making process regarding the SC resilience. Managers can try out various scenarios and assess the resilience of each one, before the strategies implementation. This process also allows identifying improvement opportunities within the company and with the other companies belonging to the same SC.

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AN AGENT-BASED SIMULATION APPROACH TO THE CIRCULAR OPEN DIMENSION PROBLEM

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KEYWORDS
Cutting and packing, circle packing problem, open dimension, multi-agent systems, agent-based simulation

ABSTRACT

Cutting and packing problems generally address the cutting or packing of smaller items into a larger container object. Usually, the main methodologies used in the Circular Open Dimension Problem (CODP) are nonlinear programming methods or methods that combine different heuristics. The aim of this project is at devising and using an agent-based simulation approach to determine the length of the open rectangle in CODP; more specifically, we look into the Circular two-dimension Open Dimension Problem. Agents (circles, which can have different dimensions) were given a set of simple rules that allow them to be placed in the world (i.e. an open rectangle). These rules are inferred from the formal CODP formulation and from the behavior defined in the agents.

INTRODUCTION

Cutting and packing problems generally address the cutting or packing of smaller items in a larger container object. The items the container can accommodate are generally regular or irregular shapes. Many practical applications of this problem can be identified, with different specificities, and solving it in each instance may represent an important outcome.

One of the cutting and packing problems is the Circular two-dimension Open Dimension Problem (CODP) (Akeb and Hifi, 2008). In the CODP, the container object is an open rectangular shape, and the items are circles, which can be identical or non-identical. This particular problem is also referred to as strip-cutting-packing problem (Huang et al, 2004) and as the two-dimensional strip packing problem (Wäscher et al, 2007).

The CODP occurs in many industries such as textile, automobile or aerospace (He and Wu, 2012), where a better solution can generate savings on large-scale basis. To solve it, defining a set of constraints associated with items (ensuring that circles do not overlap and stay inside the rectangular container) is imperative. To assure the container has the smallest possible size, which in the CODP means minimizing the open dimension of the rectangle –the length– is also a requirement. The more frequently used methodologies rely on nonlinear programming methods or methods that use combinations of different heuristics.

The approach developed in this work, on the contrary, uses the metaphor of autonomous agents, as well as agent-based simulation techniques that rather provide circles with guidelines so that they can position themselves autonomously in the large container, which in this case is a rectangle with open dimension. The chosen method to address the problem is simulation of models conceived on the basis of the agent metaphor. Agent-based simulation allows for a set of rules to be associated with the items (circles), so that they behave autonomously according to their individual associated utility function. The emergent behavior resulting from the interactions between the multiple circles within the environment thus is expected to arise in a way such that minimizes the length of the container (rectangle).

We intend to contribute in the area of COPD through the use of simulation as a means for optimization, and in this particular case with the use of agent-based simulation. This paper is organized in four more sections: literature review, proposed approach, preliminary results and analysis, and finally conclusions and future work. In the literature review section, the main restrictions of the CODP are identified and some different heuristic-based methodologies are considered. The proposed approach section describes the agent-based methodology used, emphasizing on the main functionalities developed in the project, while the results and analysis section reports on a number of comparative solutions. In the last section, conclusions and future work, we present final remarks and present our ideas for the future.

LITERATURE REVIEW

CODP consists in positioning a given set of items (circles), in a container object (rectangle) with fixed width (W), so as to find the minimum length (L) of the rectangle. The positioning of the items must comply with the following constraints:

- Items must not overlap;
- Items must be located within the fixed boundaries of the rectangle.

In a rather formal way, CODP can be reformulated as described by Akeb and Hifi: CODP is composed of a linear function to be minimized (L), and five constraints, one of them (1) is nonlinear whereas the others are linear.

Therefore, minimize L subject to:

$$(x_i - x_j)^2 + (y_i - y_j)^2 \geqslant (r_i + r_j)^2, j < i, (i,j) \in N^2 \quad (1)$$
$$x_i - r_i \geqslant 0, \forall i \in N \quad (2)$$
$$y_i - r_i \geqslant 0, \forall i \in N \quad (3)$$
$$W - y_i - r_i \geqslant 0, \forall i \in N \quad (4)$$
$$L - x_i - r_i \geqslant 0, \forall i \in N \quad (5)$$

The first inequality (equation 1) translates the first restriction that says that the circles should not overlap. The next four inequalities (equations 2 to 5) relate circles to the boundaries of the rectangle.

To solve the CODP, different heuristics are used. Hifi et al (2004) proposed a simulated annealing method; Birgin et al. (2005) proposed an heuristic based on a nonlinear approach, whereas Huang et al. (2005) proposed two heuristics: B1.0, based on the concept of maximum hole degree and B1.5, an evolution of the B1.0 heuristic.

Akeb and Hifi (2007) developed a heuristic based on an adaptive beam search. Later on, Akeb and Hifi (2008) presented three algorithms: the first is a heuristic that addresses the situation as an optimization problem; the second is a modified version of the first algorithm, which uses a strategy of exchanging order to create diversification; the third is a hybrid heuristic (combining beam search and binary search). He and Wu (2012) presented a study that addressed the CODP by adopting genetic algorithms. Fu el al (2013) presented an iterated tabu search approach.

PROPOSED APPROACH

The proposed approach in this work relies on agent-based simulation. The main idea beyond the project was to define a set of rules of behaviors. Agents (circles) use such rules to position themselves within the world (the rectangle), where they move freely. The software used in this project was NetLogo, version 5.0.5 (NetLogo, 2013), which is a multi-agent programmable modeling environment, very much used within the social simulation community.

The world where the agents inhabit is the rectangle with fixed width (W) and open length. To simulate the open length, the length (L) of the world is larger, than the possible solutions. That way, agents can move beyond the boundaries of the solution, which is yielded as soon as the agents reach a sable state.

The final length (L) used to compute the solution is obtained by the top of the circle farther away from the bottom limit of the world (see Figure 1). The positions of the circles are obtained from the position of the agents, affected by a scale factor, the patch size of the world. This factor scale is necessary to obtain an adequate point of view during the simulation and to represent the different circles at a coherent scale.

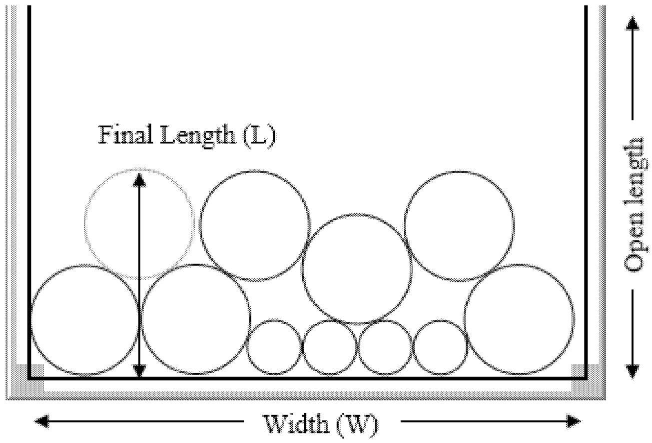

Figure 1 - World of agents (circles)

Each agent is a representation of a circle and has the geometric information needed to represent a circle, which are the following:

- Its center location (x and y coordinates);
- Its radius;
- Its color.

In addition, each agent keeps information needed to apply the rules, such as:

- Is it stopped?
- What was the previous center (xANT and yANT coordinates);
- What are the minimum center coordinates;
- Does it overlap?
- What is the number of overlapped circles?

An implicit rule when an agent is moving in the world is the verification of the constraints related to the overlapping of other circles and the intersections with the boundaries of the world. If there is free terrain to move on, each agent moves accordingly with three types of movements: down, left and slide (see Figure 2).

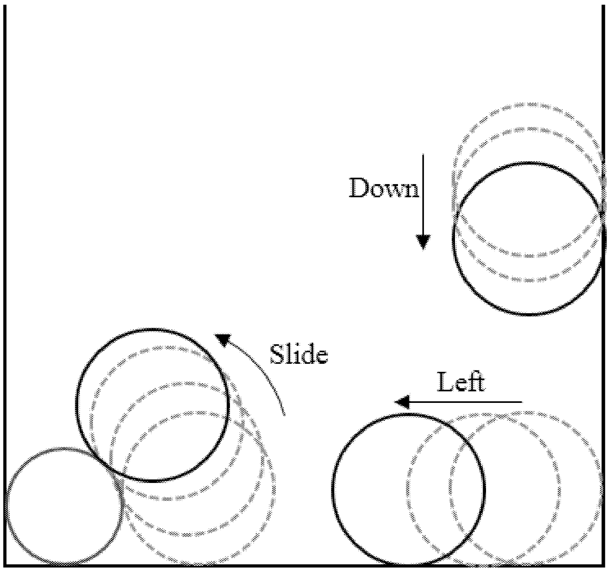

Figure 2 -Movements of agents

When creating the circle, they are positioned above the possible space solution and tangent to the right limit of the world. All circles start by doing a *Down* movement.

The first circle does only the first two movements, *Down* and *Left*, and positions itself on the leftmost bottom position of the world. The remaining circles use the three types of movements to repositiong themselves or use the *Down* and *Slide* movements.

The rule used by the circle to place itself is the minimum Y coordinate traveled. If a circle has diferent X coordinates for the same minimum Y coordinate, the leftmost is used for the final position of the circle.

The general placement scheme of the agents is shown in Figure 3.

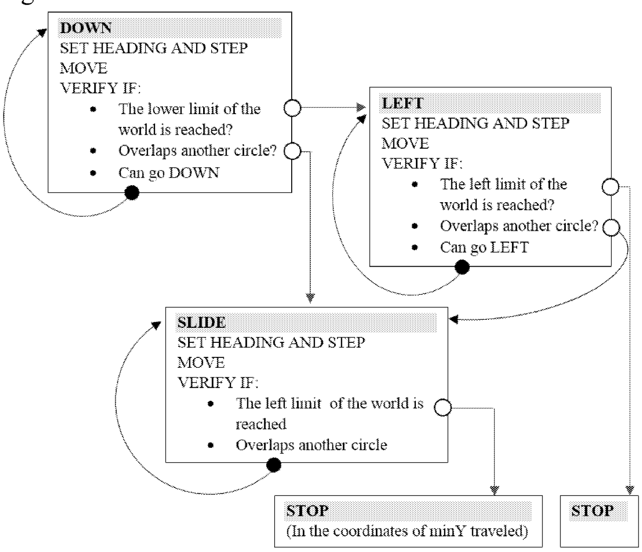

Figure 3 - Agents Position General Schema

The agent when travelling to find its position starts by moving *Down*. The current center position is copied to the previous center position, a heading and a step are defined, and the agent moves. After the movement is made, it is verified if the bottom limit of the world is reached. If the bottom limit is reached, the agent (circle) starts to use *Left* movement. If the circle overlaps another circle, then it starts using the *Slide* movement (see figure 4). If the agent does not find the lowest limit of the world or overlaps a circle, it does another *Down* move.

In the *Left* movement, the agent also copies the center position to previous center position, a heading and a step are defined, and the agent moves. After the movement is made, it is verified whether the left limit of the world has been reached, in which case the circle *Stops*. If the circle overlaps another circle, then it starts using the *Slide* movement again. If the agent does not find the left limit of the world or overlaps a circle, it does another *Left* move, and the process is repeated all over again.

The *Slide* movement is more complex than the *Down* and *Left* movements. In the example of Figure 4, the circle slides over circles 1, 2 and 3.

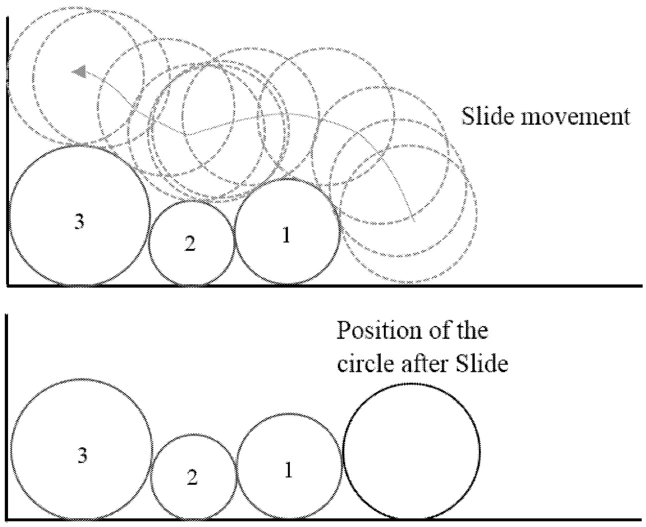

Figure 4 - Example of Slide Movement

When the sliding circle is sliding over circle 1, it describes a circular trajectory over the center of circle 1. The radius of the circular trajectory is the sum of the radius of the sliding circle and the fixed circle (circle 1 in this case).

To calculate the next position of the sliding circle, it was developed a function that calculates the angle of the new position, taking into account the initial angle of sliding contact, the fixed circle, and the sliding circle. In the new position, it is verified whether an overlap occurs with other circles, if the left limit is reached or if the circle starts sliding with another circle.

In the example of Figure 4, the sliding circle ends the *Slide* movement over circle 1 and starts sliding over circle 2. When the slide movement of the circle over circle 2 ends, it starts sliding around circle 3. After the circle reaches the leftmost limit, and no other moments are possible, the *Slide* movement stops and the circle positions itself in leftmost position of the minimum Y traveled fixing its placement.

All the agents (circles) follow the same behavior until there are no more circles to pack. Then, the length L of the rectangle is determined by the circle, the top of which is located farthest from the lower limit.

PRELIMINARY RESULTS AND ANALYSIS

The first results were tested with the Stoyan SY1 dataset, downloaded from (Specht 2002). The SY1 instance contains 30 circles with a radius ranging from 0.527 to 2.05. The width (W) of the rectangle in SY1 dataset was 9.5 and the best length (l) found was 17.039663.

For practical reasons an overall scale of 100 was applied to each circle and to the rectangle defined in SY1. In the agent-based simulation experiences, the radius of the circles ranges from 52.7 to 205. The width of the rectangle equals 95 and the length of the world (that must be greater than the best solution) was defined as 240.

To compare our solution with the best solution of SY1 (Fu, et al, 2013), three variants were tested. In the first variant (Exp1), circles were sorted in ascendant order in the test set.

In the second variant (Exp2) the circles were previously sorted in ascending order. Then a new set of circles was instantiated by merging successively the first circle of the ordered set with the last circle of the ordered set.

In the third variant (Exp3) the circles were previously sorted in ascending order, divided into two groups (the "smaller" circles and the "bigger" circles). Those groups were intercalated randomly in the test set.

Table 1: Comparison with the best solution

Solution	Length (L)	Distance to Best
Best (iterated tabu search)	17.039	-
Exp1 (sorted in ascendant order)	20.557	3.518
Exp2 (sorted in ascendant order merging first and last)	20.027	**2.988**
Exp3 (randomly interpolation between groups)	20.058	3.019

From Table 1, the best solution obtained by using agent-based simulation is variant 2 (exp2). The solution of variant 3 (exp3) is slightly worse. Suggesting that if more random situations were created, maybe a better solution would be achieved. Best results appear in bold, in Table 1.

Only three variants (the same circles in different orders) were tested. In these tests, the distance between the worst and best agent-based simulations was 0.53. To the best solution (which is an iterated tabu search) the minor distance was 2.988, from exp2. Exp3 is very close to the results obtained with exp2 (distance equals 0.031).

From the preliminary results obtained in this experiment, we might say that the methods used in variants 2 and 3 (merging first and last and randomly interpolating groups presented the best approaches.

CONCLUSIONS AND FUTURE WORK

In this work, we have proposed the use of the autonomous agent metaphor to devise a simulation model in order to solve CODP-like problems, with different practical applications.

With an agent-based simulation methodology and three main behavior rules (*Down*, *Left* and *Slide*) it is possible to position circles in an open rectangle. CODP depends on the set of circles and the order in which the circles are placed within the rectangle. More random tests could eventually lead to better solutions. Nonetheless, our agent-based methodology might be improved in different ways so as to produce better solutions.

By incorporating a routine for calling the same circles in random order, it should be possible to improve the solutions. However, for providing further evolution (and better performance) more complex rules should be incorporated and a new set of tests should be performed, not only with SY1, but also with other datasets. The next stems in this research include the improvement of our agent-based approach to optimization problems through simulation, implementation of more complex behaviors in our agents, and featuring agents with learning and adaptation capabilities as a means to improve their behavior.

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TRAFFIC MANAGEMENT SIMULATION

TRANSPORTATION PERSPECTIVES

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Nonlinear transportation examples, complex systems, statistical optimization

ABSTRACT

Presented here are a number of different points of view on the complexities and varieties of transportation problems that can arise in the business and industrial world. Some of them can even be applied to scientific and governmental fields where statistical analysis is involved. The simulation statistical optimization technique of multi stage Monte Carlo optimization (MSMCO) will be featured as the preferred solution technique, particularly if the transportation problem is multivariate and nonlinear. The linear programming based simplex technique (and modified distribution approaches) are still probably preferred for the classic linear transportation problem. However, the presentation here dwells on the nonlinear transportation problems.

INTRODUCTION

The next section gives a brief review of the multi stage Monte Carlo optimization (MSMCO) statistical optimization solution technique. Then a 550 variable nonlinear transportation problem is presented and worked on with MSMCO.

This is followed by a helicopter trying to fly on a shortest route to a number of locations and return to home base saving as much time and money as possible.

The third example talks about delivering newspapers on a 125 house paper route again following the shortest route. The fourth example mentioned refers to the MSMCO and shortest route technology approach that looks into spreadsheets of data to see whether the variables represented by them are correlated or not. This does not seem like a transportation problem, but it really is because the MSMCO shortest route idea can deliver information as easily as it can deliver goods and services in our computer age. The fifth presentation mentions a number of other approaches to transportation problems.

MULTI STAGE MONTE CARLO OPTIMIZATION

Multi stage Monte Carlo optimization (MSMCO) has a first stage (in its computer program) that looks at many thousands of feasible solutions and stores the best one. Then centered about this “best answer so far” a second stage (centered around the first stage “best answer”) samples thousands more feasible solutions in a slightly reduced region and stores its best answer found. Then a stage three draws thousands more feasible solutions in a further reduced region always centered about the “best answer so far found,” etc. This process continues for as many stages as are necessary to find the true optimal solution or a useful approximate solution.

Please see Figure 1 for a partial geometrical and statistical representation of MSMCO crossing the sampling distribution of the feasible solution space of the optimization problem in question, to a minimum solution.

Another appropriate name for MSMCO is, of course, statistical optimization in the business and industrial world.

DELIVERING A PRODUCT TO MANY CUSTOMERS

A company has ten manufacturing plants producing a product in bulk. It desires to ship its product to 55 customers at a low cost. There are discounts for shipping in quantity and 550 different nonlinear shipping costs for the 10 times 55 different possible shipping routes. The problem is further complicated by, a hopefully, temporary shortage of supply.

Customers $j = 1, 2, 3, \ldots 55$ request shipments of $28{,}500+100(j + 10)$ units or a total demand of 1,776,500 units. However, the company’s ten factories can only currently supply $45000 + 10000i$ units for factories $i = 1$, 2, . . . 10, or a total of 1,000,000 units during this shortage.

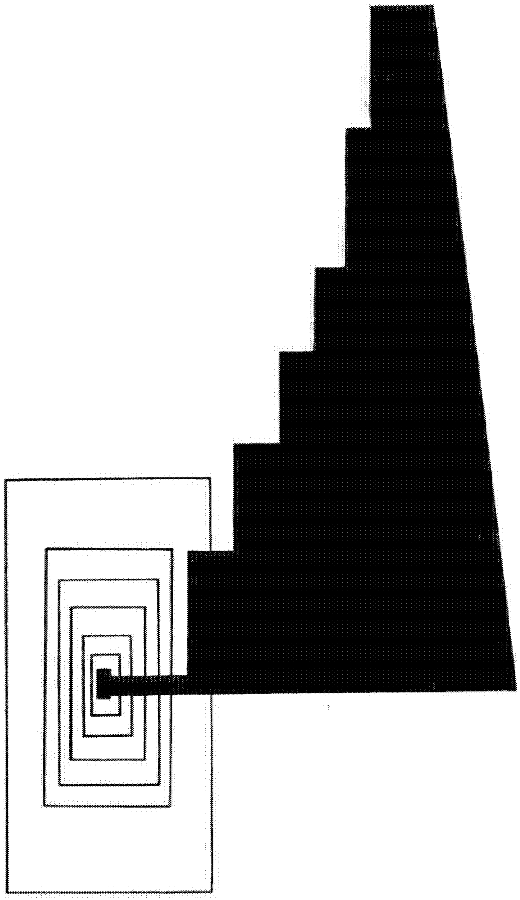

Figure 1: Multi Stage Monte Carlo Pursuing the Minimum

The shipping costs from factory i to customer j are c(i, j) = .23 (i + j) x(i, j) ** (.79 + .0028 (i + j)) for i = 1, 2, 3, . . . 10 and j = 1, 2, 3, . . . 55 and ** means raise to a power.

The company managers would like to ship all one million units to its 55 customers (during this shortage) at a cost of less than 4 million dollars so they select a target goal of 3.4 million dollars and set it equal to the summation of the 550 costs times the number of units shipped on each route. This equation and the ten factory production equations (equal to 55000, 65000, 75000 . . . 145000) yield a system of eleven equations with 550 variables to be solved.

Therefore, the sum the absolute values of the differences between the left and right hand sides of the eleven equations is minimized using a fifty stage MSMCO statistical optimization simulation drawing 50,000 feasible solutions at each stage. Running this computer program took about 5 minutes of computer time on a desktop PC computer and yielded 550 amounts of product to be shipped from the 10 manufacturing plants to the 55 customers. These 550 shipping amounts are available by e-mail upon request.

A total shipping cost of 3,418,520 dollars, and shipping errors in the ten manufacturing plants of

0.01563
0.00000
0.00000
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0.00000
0.00000
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were realized.

This is really a goal programming problem because the ten shipping equations were solved and the eleventh equation (the cost equation) was driven down close to the 3.4 million goal (a value of 3,418,520 dollars) or an equation error of 18520 dollars.

A HELICOPTER AND SHORTEST ROUTE

A travel film company wants to have its film crew, editor and film narrator fly in its helicopter (with its two pilots) to 125 locations in the country it is filming and return to home base all in one day to save time and money.

The 125 locations and a shortest route to fly on are represented by the 125 points inside the border of Figure 2. The MSMCO shortest route computer program could be used to solve this problem, as has been done repeatedly by Conley on famous mathematical literature problems such as 30, 32 and 33 involving 150, 200 and 200 points in (Conley 1991a) and (Conley 1991b).

A PAPER ROUTE

An employee of a newspaper has a paper route of 125 homes on seven streets to deliver a newspaper to seven days a week. The 125 points along the border in Figure 2 represent the 125 homes. Although a sophisticated statistical optimization MSMCO program could solve this problem, the shortest route for the delivery is obvious because of the nice pattern apparent by looking at the homes of the 125 customers on the seven streets. Now let us combine the ideas in the helicopter example (no pattern to the points) and the newspaper one (a pattern) and talk about statistical correlation.

THE CTSP CORRELATION COEFFICIENT

Looking at Figure 2, now think of it as an x, y, plane in analytic geometry. The question is, are the variables x and y correlated or not?

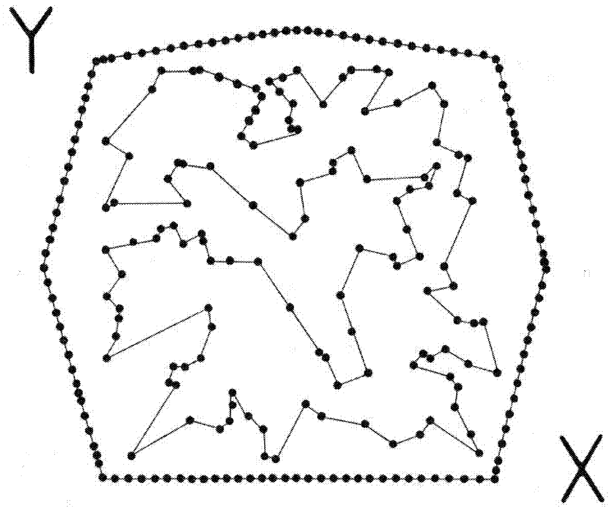

Figure 2: Inside Points Not Correlated
Outside Points Are Correlated

The first data points consisting of the 125 graphed inside the border are just going around in circles and hence the x and y variables they represent are not correlated (no pattern) at all.

However, the 125 points that form the seven sided border are definitely following a pattern and therefore the x and y variables that they represent are highly correlated. Note also that a shortest route connecting the outside points is much shorter than a shortest route connecting the inside points.

This fact is obvious in two and three dimensions. However, (Conley 2007) has tested this repeatedly on correlation analysis problems with four through nine variables (so far) using the MSMCO shortest route computer program adjusted for more than the two variables represented in Figure 2.

The problems do become more difficult as the number of variables and dimensions increase but they are still solvable because if the variables are correlated they follow a pattern and their shortest routes in n dimensions are much shorter than shortest routes for comparable n dimensional data that came from data that represents variables that are not correlated.

Eight dimensional examples of the phenomena are presented in (Conley 2013) for example.

Therefore, shortest route technology can do more than deliver newspapers and products. It also can deliver information (correlation analysis) in our computer age.

Please note also that (Anderson 2003) and (Hayter 2002) presented the more traditional theoretical mathematics approach to linear correlation analysis.

ADDITIONAL TRANSPORTATION IDEAS

There are so many different types of important transportation problems. While a company is trying to route delivery trucks in an optimal fashion, would shipping its products by barges be more cost effective? Would rail freight be cheaper than air freight for some companies?

Moving factories so that they are closer to the raw materials that the manufacturer uses, could cut shipping costs. Would it be cheaper to open a new factory nearer to a company's major customers?

Would designing products so that they are cheaper to ship (without hurting product quality or product design) be a good idea in some cases?

The multi stage Monte Carlo optimization technique (MSMCO) (with its basis in the simulation field of statistical optimization (please see Figure 1)), is versatile enough to address many of these different types of transportation problems that occur in the real world of economics and big business.

CONCLUSION

Presented here was a 550 variable nonlinear transportation problem involving the bulk shipping of a product from ten factories to 55 customers. This was followed by a film crew flying in a helicopter on a shortest route (please see Figure 2 again) to 125 popular tourist locations and attractions in a country it is trying to do a travel film on. Next is presented a paper route delivery optimization problem (again saving time and money) where the answer is more obvious. That is followed by the sophisticated CTSP multivariate correlation analysis, which finds shortest routes through n dimensional space to see whether the n variables are correlated or not. Examples and illustrations of this phenomenon are presented in Figure 2 here and in (Conley 2007) and (Conley 2013).

The versatility and generality of simulation based statistical optimization techniques such as multi stage Monte Carlo optimization (MSMCO) are illustrated with engineering (Szarkowicz 1995) and (Conley 1992), general mathematics (Wong, 1996), environmental problems (Conley 2008), (Conley 2011) and policy analysis (Clark 1984) examples.

Additionally, MSMCO can be very competitive with other shortest route algorithms. The well-known (in the mathematics literature) n=75 points problem by (Eilon, et, al, 1971) (with 75 factorial or 75! = 75x74x73 . . . . x3x2x1 = 2.480014081 $x10^{109}$ complete tour routes) was worked on by (Conley, 1989) producing 30 shorter routes than the shortest ever found using other methods (please see chart of shortest routes listed in (Lawler, et al, 1985) for comparisons). Additionally, the again well known in the mathematics literature n=249 point shortest route example from (Gillette and Johnson 1976) had a shortest route ever found of 2363.6 listed in the previously mentioned test problems chart in (Lawler et al, 1985). The MSMCO shortest route algorithm approach was tried on the n=249 point problem and 495 routes shorter in total distance than the 2363.6 standard minimum were found and a selection of them were presented in (Conley, 1990).

The field of statistical optimization (using simulation techniques such as MSMCO) may become more viable as computer speeds increase.

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BIOGRAPHY

WILLIAM CONLEY received a B.A. in mathematics (with honors) from Albion College in 1970, an M.A. in mathematics from Western Michigan University in 1971, an M.Sc. in statistics in 1973 and a Ph.D. in mathematics -computer statistics from the University of Windsor in 1976. He has taught mathematics, statistics, and computer programming in universities for over 30 years. He is currently a professor emeritus of Business Administration and Statistics at the University of Wisconsin at Green Bay. The developer of multi stage Monte Carlo optimization and the CTSP multivariate correlation statistics, he is the author of five books and more than 200 publications world- wide. He is a member of the American Chemical Society, a fellow in the Institution of Electronic and Telecommunication Engineers and a senior member of the Society for Computer Simulation. Career highlights include presentation of two papers at National Aeronautics and Space Administration (NASA) conferences in Houston, Texas and Washington, D.C.

DESIGN OF RAIL PASSENGERS SAFETY AND COMFORT SYSTEM AS THREE-OBJECTIVE DISCRETE STATIC OPTIMIZATION PROBLEM

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KEYWORDS

Safety in Passenger Railway Traffic, Video-Monitoring, Counting Passenger Flows, Dynamic Information For Passengers, Central Processing Unit, Surveillance Center, Vehicle Diagnostics, Multi Objective Optimization, Discrete Static Optimization.

ABSTRACT

The paper presents a concept of an Integrated System of Supporting Information Management in Passenger Traffic. Currently on the polish and, as far as we know, international market such integrated solution is not developed and proposed. In this concept the final customer, e.g. the manufacturer or carrier company, will install one complete solution instead of multiple different installations that are usually difficult to integrate. In our opinion the integration leads to increase in safety level of public transport and to improvement the quality of services offered. The novelty of the system is an integration of six modules: video-monitoring, counting passenger flows, dynamic information for passengers, the central processing unit, surveillance center and vehicle diagnostics into one coherent solution. For each module three different construction methods were proposed and considered. Then, each method was evaluated under three different criteria: functionality & upgradeability, compliance with standards and costs. Basing on obtained results, we propose to present configuration design problem of the system as three-objectives discrete static optimization problem. Solution of the problem leads to optimal configuration of the system.

INTRODUCTION

Ensuring passenger safety is the most important objective for operators and providers of railway services, manufacturers and carriers. Safety of rail transport is therefore a basic criterion for assessing its performance and determines its efficiency, as well as the broader criterion of transport service quality (Mlynczak 2011).

Monitoring the state of rail safety in Poland is maintained by the Office of Rail Transport, Chalubinskiego Street 4, 00-928 Warsaw. Within the framework of the statutory tasks the office prepares quarterly reports summarizing the state of rail safety. Last analysis show that the number of three types of events is growing (Railway Transport Office 2013):

1) collisions of trains,
2) the derailment of trains,
3) fires of railway vehicles.

These conditions justify starting work on a system which helps to reduce the negative effects of railway incidents. Design experiences of ENTE company indicates that it is possible to develop an integrated system focused on the following aspects:

1) detection of collisions of trains,
2) monitoring the work of the driver,
3) detection of fires and potential causes of fires (overload circuits, overheating systems, etc.)

Currently on the Polish market there is no offer of an integrated system that performs assumed in the design functionality in such a wide range. Polish producers of systems are specialized in the production and development of devices, which potentially can be included in the proposed system. Potential customers during trade talks clearly indicate the need to develop an integrated system joining:

- the traffic data taken from a railway vehicle,
- warnings of possible dangers during the journey,
- transmission the data in case of disasters.

In the project the concept of a prototype of Integrated System Supporting Information Management of Railway Passenger Traffic (polish acronym is “Demonstrator+”) has been proposed (Hekczyk et al. 2014). The concept is presented in fig.1.

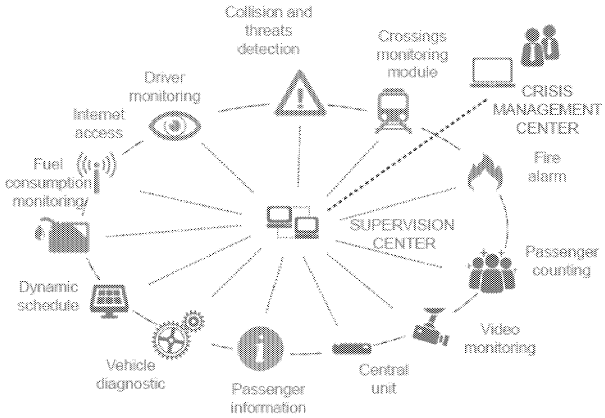

Figure 1: Concept of Integrated System Supporting Information Management of Railway Passenger Traffic

The project uses a multilayer distributed architecture, which provides the expected scalability of the whole solution. In fact the will be powered by data from the following modules:

- Video-monitoring.
- Counting passenger flows.
- Passenger information unit on the train.
- The central processing unit.
- Surveillance center.
- Vehicle diagnostics

The paper is built as follow. In section 2 the basic features and functionality of the recommended solutions for each module in Demonstrator + are presented. In section 3 basics of multi-objective optimization problem are introduced. In section 4 problem of configuration design of the system as three-objectives discrete static optimization problem is formulated and solved. Results are concluded in section 5.

BASIC FEATURES AND FUNCTIONALITY OF THE RECOMMENDED SOLUTIONS FOR EACH MODULE IN DEMONSTRATOR+

Video-monitoring module will enable video recording taken from: inside the vehicle with cameras in passenger spaces, the rail trail and behind the vehicle in front of the cameras of track, and cameras operating as side mirrors and the registration of the camera that monitors pantographs for diagnostic purposes. The driver will have complete freedom to manually select a camera or camera group, which wants to see on the monitor. Switching sequence between internal and external cameras displayed on the monitors will be controlled automatically or by GPS, for example, at the entrance of the train to the train station (the image is displayed with the side camera). After leaving the station, the monitor will display images from cameras in the passenger sections. The system will be based on digital cameras using IP technology. It will be possible to sound recording in vehicle cabins and integration it with fire alarm system. Activation of the fire sensor will automatically switch the monitor image to the scene. The image will be sent to the Control Centre. Collision detection, thanks to the integration with collision and threats detection will automatically transfer recorded scenes to the Surveillance Centre and conversations with the driver cab just before the event.

Passenger Flows Counting Module will work on the basis of data from the sensors (cameras stereoscopic 3D) located above each door. It will calculate the number of passengers being on and off for each station along the route. Data will be sent in real time to the Surveillance Centre and archived on the server. It will be possible to display information about the vehicle fulfillment on panels in the cabin of the vehicle operator and presentation of data in the Surveillance Centre: for example, statistics in the form of reports and charts (number of inputs and outputs on the station, the total number of passengers carried on a given day etc.).

Passenger Information and Dynamic Timetable Module will enable to display information about the position and route of the vehicle on information boards placed inside the vehicle. Information about the current and the next stop will be administered in the form of voice announcements. The driver will have the possibility to give special messages and have access to information on the current journey. The module will enable the issuance of promotional materials for internal boards. The driver will have the possibility of obtaining the Surveillance Centre updates information on travel routes, text messages, displayed on bulletin boards, message for voice announcements, timetables. Expansion functionality will be to display on notice boards located inside the LCD information about delays and possible transits available. On the terminals with LCD monitors installed in driver's desktops, there will be displayed current train schedule in the form of PDF reports that will be automatically positioned basing on GPS data. The primary purpose of being placed in the passenger information and dynamic timetable module is to increase the comfort of the passengers through dynamic information about the current situation, and also to facilitate the work of drivers with dynamic information about the current position of the vehicle, current observations, warnings and speed limits on the trail, located in one place, i.e. driver LCD terminals. Thanks to the official timetable in PDF format driver will have access to electronic documents that are identical and consistent with their paper counterparts, such as a paper notebook timetable. For this purpose, it is planned to use the WebService interface and integration with Polish Rails (PLK) servers, as well as carriers and owners of trains. On external boards there will be displayed the number and type of train, on side boards: train number, type of train, train route, and intermediate stations. It is also planned to expand the module for LED interior panels, installed in the vehicles. For internal tables will be displayed on the train number, train name (if defined), current date and time, initial and final station, the rest to go along with the planned route, also arrivals downloaded from the official timetable of the driver and the distance to the next station.

Central Module will act as the master controller of the system in the vehicle. It will be equipped with GSM modules and GPS, digital inputs and outputs, and analog and digital interfaces. The central unit will be equipped with high-performance processor which will initiate operation of the unit, assign tasks, communicate with external devices, collect all the data from measurement systems and regulations, process them, archive and send data to a server in the Control Centre. The module will be developed in the operation of individual modules within the system and will have the following characteristics:

- CPU using the collision and threats detection module will detect the event and obtain current information about the position of the vehicle, number of passengers in the vehicle during the event, traffic parameters at the time of the event, the speed at the moment of impact, as well as directly from the module detection of accidents and threats of force impact and tilting (eg, rollover) of the vehicle and transfer them all to the Control Centre, where Crisis Management Centre will be notified immediately,
- CPU will obtain information about events (fire, accident) and then monitoring module to share video recordings from cameras installed on the vehicle, which will be forwarded to the departments responsible for ensuring security.

Table 1: Criteria Values for the Individual Modules and Methods of Implementation

Module 1. Video-monitoring module

Method	Criterion 1	Criterion 2	Criterion 3
1	1	1	4
2	3	4	3
3	5	5	2

Module 2. Counting passenger flows

Method	Criterion 1	Criterion 2	Criterion 3
1	1	5	4
2	2	5	4
3	5	5	2

Module 3. Passenger information unit

Method	Criterion 1	Criterion 2	Criterion 3
1	1	2	4
2	3	3	3
3	5	4	1

Module 4. The central processing unit

Method	Criterion 1	Criterion 2	Criterion 3
1	1	3	5
2	3	3	3
3	5	4	3

Module 5. Surveillance center

Method	Criterion 1	Criterion 2	Criterion 3
1	3	5	5
2	4	4	4
3	5	4	5

Module 6. Vehicle diagnostics

Method	Criterion 1	Criterion 2	Criterion 3
1	2	5	4
2	4	5	3
3	5	5	3

As part of the work associated with the development of the conceptual framework for each module, three different methods of its implementation has been analyzed. Each of these methods has been evaluated by independent experts, assumed three evaluation criteria:

- criterion 1: functionality & upgradeability
- criterion 2: compliance with standards.
- criterion 3: costs.

Assessments used the following rating: 1- very low, 2-low 3-average, 4-high, 5-very high. It should be noted that for the criterion 3: costs, high rating (high evaluation of solutions in terms of cost) means the low cost. Values for each criterion for all modules and methods of their implementation are presented in table 1.

MULTI-OBJECTIVE OPTIMIZATION PROBLEM

In this section multi-objective (or multi-criteria) optimization problem is introduced. The problem is concerned with the minimization of a vector of objectives $F(x)$ that can be the subject of a number of constraints or bounds (e.g. Skrzypczyk 2009, Galuszka and Swierniak 2010). Denoting that n is a number of decision variables, k is a number of criteria, m is a number of inequality constraints and p is a number of equality constraints, we have:

$$x = [\, x_1, x_2, \ldots, x_n \,]^T,$$

$$F(x) = [\, f_1(x), f_2(x), \ldots, f_k(x) \,]^T, \quad (1)$$

$$g_i\,(x) \leq 0, \text{ for } i = 1, 2, \ldots m), \quad (2)$$

$$h_i\,(\mathrm{x}) = 0, \text{ for } i = 1, 2, \ldots p). \quad (3)$$

It should be noted that, because $F(x)$ is a vector, if any of the components of $F(x)$ are competing, there is no unique solution to this problem. Instead, the concept of non-inferiority (also called Pareto optimality) must be used to characterize the objectives. It is assumed that non-inferior solution (Pareto optimal solution) is one in which an improvement in one objective requires a degradation of another. To describe the concept of non-inferior solutions, introduce the set of all possible solutions that satisfy constraints, such as the project budget, available technologies, etc. It is called set of feasible solutions:

$$\Omega = \{x \in \mathcal{R}^n\} \quad (4)$$

that satisfies constraints (2) and (3). This allows to find all values of different objectives included in the objectives vector:

$$\Lambda = \{y \in \mathcal{R}^k\}\,, \quad y = F(x)\,,\, x \in \Omega \quad (5)$$

If, for example, take the problem of two objectives, which should be minimized, for each feasible solution one can determine values for the two objectives.

It follows that the non-inferior solutions are those that lie on the boundary of the functions targets. Taking for example the area shown in Fig.2, the non-inferior solutions are those that are at the edge between points C and D. Points A and B are examples of non-inferior solutions relative to each other (i.e. Pareto optimal).

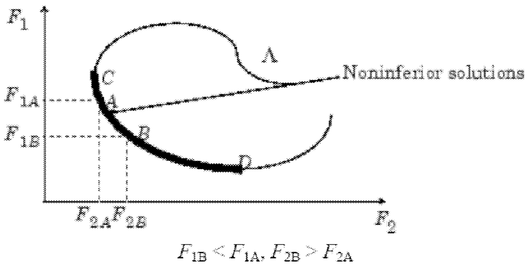

Figure 2: Non-inferior solutions (Fig.: Emmerich 2005)

There are many methods of selecting a particular solution of the Pareto solutions. In this paper, one method will be described and used, i.e. the weighted sum method. Other methods can be found in the literature.

This weighted sum method involves converting the problem of multiple criteria to the problem of single-criteria, where each component of objectives vector describes the impact of this criterion for the final selection. The impact depends of the weight value w_i. This leads to the following problem objective formulation (Emmerich 2005, Studzinski 2013):

$$\underset{x \in \Omega}{Min} f(x) = \sum_{i=1}^{k} w_i f_i(x), \qquad (6)$$

Depending on the choice of weight one can select any solution located between the points C and D in fig.2. Usually it is assumed that the weights take values in the range <0, 1>.

For discrete formulation of multi-objective problem, we substitute formula (4) by $\Omega = \{x \in \mathbb{Z}^n\}$.

PROBLEM OF CONFIGURATION DESIGN OF THE SYSTEM AS THREE-OBJECTIVES DISCRETE STATIC OPTIMIZATION PROBLEM

It is assumed that the optimal solution is an indication of the method of implementation of each module resulting from solving multi-objective maximization problem. The problem is built on the basis on values in Table 1. Assume:

i – module index, i = 1, 2, ….6;
j – criterion index, j = 1, 2, 3;
k – method index, k = 1, 2, 3;

then:

$x_{i,j,k}$ – denotes value taken from Table 1, e.g. $x_{4,2,2} = 3$.

Set of all $x_{i,j,k}$ forms space of feasible solutions $\Omega = \{x_{i,j,k} \in \mathbb{Z}^n : 1,2,3,4,5\}$ for all admissible i, j, k. Objectives of the problem to be maximized are overall evaluation of criteria, i.e.:

f_1 (x) – is the first objective defined as a sum of all modules criterion 1 values depending on the method, i.e.:

$$f_1(x) = \sum_{i=1}^{6} x_{i,1,k}; \quad i = 1, 2, \ldots 6; \; k = 1, 2, 3;$$

f_2 (x) - is the second objective defined as a sum of all modules criterion 2 values depending on the method, i.e.:

$$f_2(x) = \sum_{i=1}^{6} x_{i,2,k}; \quad i = 1, 2, \ldots 6; \; k = 1, 2, 3;$$

f_3 (x) - is the third objective defined as a sum of all modules criterion 3 values depending on the method, i.e.:

$$f_3(x) = \sum_{i=1}^{6} x_{i,3,k}; \quad i = 1, 2, \ldots 6; \; k = 1, 2, 3;$$

So stated problem is the task of maximizing the three-component vector of objective functions:

$$\text{Max} \leftarrow F(x) = (f_1(x), f_2(x), f_3(x)).$$

Example.
Let No.1 of possible variant (acceptable) solution will be the choice of method 1 for each of the built modules. Therefore, on the basis of the table 1, one can built table 2. The values of each objective function for data from table 2 are presented below:

$$f_1(x) = \sum_{i=1}^{6} x_{i,1,1} = 1 + 1 + 1 + 1 + 3 + 2 = 9;$$

$$f_2(x) = \sum_{i=1}^{6} x_{i,2,1} = 1 + 5 + 2 + 3 + 5 + 5 = 21;$$

$$f_3(x) = \sum_{i=1}^{6} x_{i,3,1} = 4 + 4 + 4 + 5 + 5 + 4 = 25;$$

Table 2: An example of possible variant solution

	Module 1				Module 2				Module 3				Module 4				Module 5				Module 6			
Variant No	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3
1	1	1	1	4	1	1	5	4	1	1	2	4	1	1	3	5	1	3	5	5	1	2	5	4

So variant 1 has a low functionality (low sum of ranks 1), but has a low cost (high sum of scores 3), so that the criteria are inconsistent with each other and there is no one perfect solution to the problem, which is a clear indication of the best ways to build modules. End of example.

The number of possible variants (L), based on the number of modules built and possible methods, is:

$$L = 3^6 = 729.$$

In section 3 multi-criteria optimization problem was formulated as a minimization problem, and because we know that:

$$Max\ F(x) = -\ (Min\ (-\ F(x)\ ),$$

It is assumed following objective function:

$$Min \leftarrow \; F'(x) = -\ F(x) = (-f_1(x), -f_2(x), -f_3(x)). \quad (7)$$

The following figures are introduced to show set of Pareto optimal solutions. They presents two-dimensional sections of objectives space In fig.3 objectives subspace ($-f_1$ (x), $-f_2$ (x)), in fig. 4 objectives subspace ($-f_2$ (x), $-f_3$ (x)), in fig.5

objectives subspace ($-f_1(x)$, $-f_3(x)$) are presented. Pareto optimal solutions are marked by red dots.

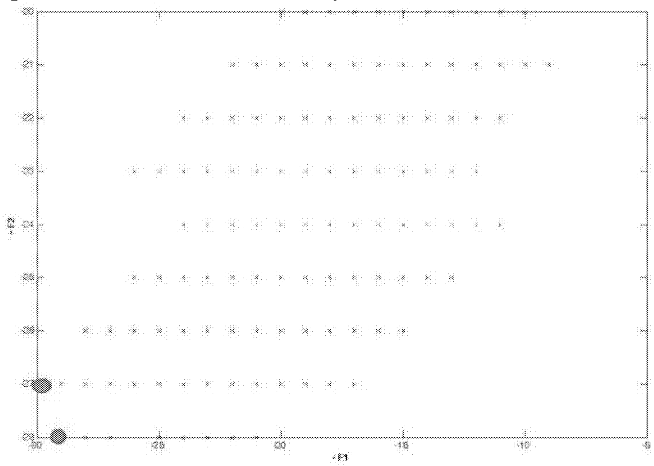

Figure 3: Objectives subspace ($-f_1(x)$, $-f_2(x)$) with Pareto solutions

Basing on formula (6) objective function (7) is transformed to one-objective optimization problem:

$$Min \leftarrow F''(x) = -w_1 * f_1(x) - w_2 * f_2(x), -w_3 * f_3(x)).$$

Three sets of weights of the respective components of the objectives vector has been considered, wherein the further assumed that compliance with the standards is always a high priority, so that $w_2 = 1$ in each set:

Case 1: $w_1 = 1$, $w_2 = 1$, $w_3 = 1$. Each criterion is equally important. The optimal solution is a variant of No. 729, the maximum value of $F''(729) = 73$.

Case 2: $w_1 = 0.3$, $w_2 = 1$, $w_3 = 1$. The most important criterion is related to the costs. The optimal solution is a variant of No. 613, the maximum value of $F''(613) = 54$.

Case 3: $w_1 = 1$, $w_2 = 1$, $w_3 = 0.3$. The most important criterion is related to functionality & upgradeability. The optimal solution is a variant of No. 729, the maximum value of $F''(729) = 61.8$.

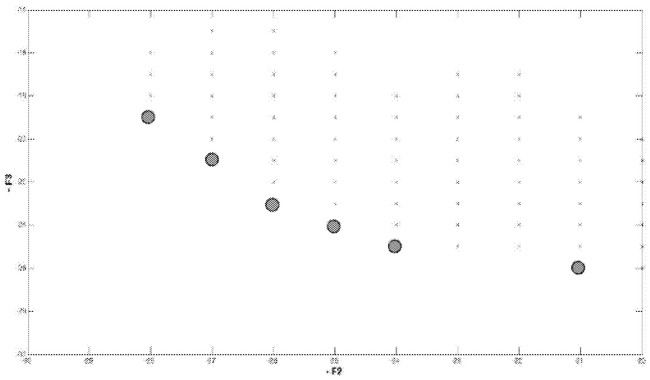

Figure 4: Objectives subspace ($-f_2(x)$, $-f_3(x)$) with Pareto solutions

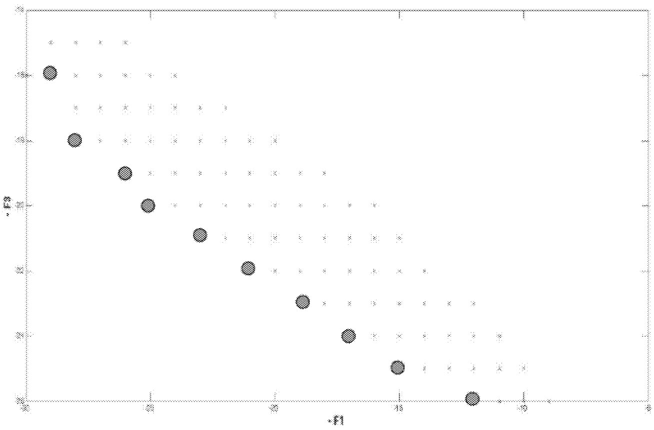

Figure 5: Objectives subspace ($-f_1(x)$, $-f_3(x)$) with Pareto solutions

Table 3: Solution of cases 1 and 3

	Module 1				Module 2				Module 3				Module 4				Module 5				Module 6			
Variant No	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3
729	3	5	5	2	3	5	5	2	3	5	4	1	3	5	4	3	3	5	4	5	3	5	5	3

Solution of cases 1 and 3 is shown in table 3 (the same configuration), of case 2 in table 4. As can be seen from the results made above, weight reduction criterion did not affect the solution obtained assuming all criteria are equally weighted (Case 1). This entails that the optimal solution is a variant of No. 729.

Table 4: Solution of case 2

	Module 1				Module 2				Module 3				Module 4				Module 5				Module 6			
Variant No	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3	Method	Criterion 1	Criterion 2	Criterion 3
613	3	5	5	2	2	2	5	4	2	3	3	3	3	5	4	3	1	3	5	5	1	2	5	4

CONCLUSION

The paper presents problem of design of rail passengers safety and comfort system as multi-objective optimization problem The system is an integration of six modules: video-monitoring, counting passenger flows, dynamic information for passengers, the central processing unit, surveillance center and vehicle diagnostics into one coherent solution. For each module three different construction methods were proposed and considered. Then, each method was evaluated under three different criteria: functionality & upgradeability, compliance with standards and costs. Basing on obtained results, we propose to present configuration design problem of the system as three-objectives discrete static optimization problem. Solution of the problem leads to optimal configuration of the system.

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THE RELEVANCE OF PREFERENCES IN A VOTING SYSTEM FOR DYNAMIC PARKING MANAGEMENT

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KEYWORDS

Intelligent Transport System, Negotiation protocols, Voting systems

ABSTRACT

Intelligent Truck Parking (ITP) is a main goal to improve safety in Long Distance Corridors (LCD). Truck drivers need to know the parking availability in their route in order to achieve their destination respecting laws. To cope with rest periods legislation and give some intelligent solutions to truck drivers in the selection of parking spaces, this study evaluates the use of a multi-agent system to assign rest area parking spaces to truck drivers according to their preferences. A distributed voting based negotiation protocol to assign parking spaces was developed in previous work. In this paper, different methods to apply the truck driver preferences are defined, simulated and evaluated. Results are very positive and show, not only the reduction of illegal parking using a negotiation protocol, but also the influence of applying different normalization methods to determine the final parking spaces assignation.

INTRODUCTION

The importance of parking assignment for heavy good vehicles is reflected in the actions developed by the European Commission: The Intelligent Transport System Directive (dir 2010) and the action plan for the deployment of the ITS (European Commission 2011). Following the directive, several ITP services with different levels of dynamism have been developed. I. e., a dynamic information system has been deployed by VINCI private motorway company (VINCI 2015). The system consists in the provision of specific information regarding free places using Variable Messages Signs.

However, few dynamic information and booking systems have been deployed. The advances of cooperative systems (Paier et al. 2013) connecting vehicles and infrastructure, make possible the development of new ITP services where the current situation of rest areas and traffic flows could be taken into account to enhance the reservation of rest area parking spaces by truck drivers. In (Bo Chen and Cheng 2010) a review of the applications of Agent Technology in Traffic and Transportation Systems is presented and results show that the integration of new technologies, such as mobile agent technology, should be considered to enhance the flexibility of systems and the ability to deal with uncertainty in dynamic environments.

In (Capdevila et al. 2013) a voted-based system to make reservations has been deployed. The voting protocol is based on Borda voting system (Zahid and de Swart 2015). It is able to manage dynamically the request of parking spaces taking into account the drivers preferences using a main manager. In (Garcia et al. 2014) the system was improved using a multi-agent approach and removing the central manager and modelling a complete distributed system where rest area agents manage their own negotiations when needed.

In this paper, a new system to book parking areas is presented, the system is based in (Garcia et al. 2014) and explores different methods to normalize truck driver preferences to manage negotiations and distribute trucks along the rest area parking spaces. To analyse the influence of managing preferences in the results, the methods has been simulated in a real segment of a European Long Distance Corridor, the E-15 Mediterranean corridor.

The paper is structured as follows: Next section describes the problem definition and defines the new features to improve the protocol. Then, the protocol and its characteristics are defined. In the following section, a case of study showing the normalization methods of votes is presented. Later, a simulation using a real segment of road network is presented. And finally, results and conclusions are presented.

PROBLEM DEFINITION

The new system proposed tries to find a solution to the problem of allocating a set of trucks on a set of parking places distributed in the rest areas located in a road network. In the following approach, a class of autonomic system has been defined where areas intend to get an agreeable distribution of rest area parking spaces between trucks.

The proposed system is intended to work as a black box completely transparent to drivers. When trucks enter in the road network the system will determine the best parking space to park according to their preferences. This allocation does not guarantee the final parking space where each vehicle will park. The concrete parking place is only guaranteed when the vehicle is close to the related rest area. In this sense, the system will manage:

- Pre-booked parking spaces. Those assigned by the system according to driver preferences. The system can reallocate these parking spaces when new trucks enter in the system managed taking into account the preferences and negotiation rules.

- Final reservations. These are the parking spaces guaranteed. The driver is informed by the system about the location of the parking place reserved.

The system aims to find the best area where a truck can be parked in a determined time without exceeding the Maximum driving Time (MT) according to legislation (EC 2006). The parking space assigned depends, not only from information of the corresponding truck, but also on the preferences of the other truck drivers who have the same area objective and their driving times and the location of those trucks involved. The system will determine the trucks, from those interested ones in one area, are those who will obtain a pre-booking in the area without exceeding the maximum number of parking spaces available.

When a truck asks for a pre-booking in a rest area where there are parking spaces available the system will assign a pre-booking in the rest area. However, if all parking spaces in the objective rest area are pre-booked , the system will calculate, using the negotiation protocol, the trucks that will maintain the pre-booking and the one that will have to ask for a pre-booking in its following preferred rest area.

THE NEGOTIATION PROTOCOL

A negotiation process is fired when a rest area has all its parking spaces pre-booked and a new truck requests a parking space into the area. In most voting systems, voters have the same weight in their votes, but sometimes this rule is not applied. In Borda (Zahid and de Swart 2015), voters provide a different score to each of the feasible solutions. First choices will have a higher score than later ones. The negotiation protocol used is conducted by a variation of Borda voting-based protocol. In this proposal, trucks will vote different solutions. These solutions are the set of possible distributions of parking spaces of the corresponding area between the trucks involved in the negotiation (trucks maintaining the pre-book in the area and the truck that has to look for a parking space in its following preferred area).

Since the main objective is minimizing the illegal parking, trucks with more Road driving Time (RT) must have a higher weight in their votes. These trucks need a high priority since they have less opportunities to reach other rest areas. At the same time, the weight of votes tries to avoid reallocation of vehicles when they are close to the rest area. The weight of the vote of a truck j is defined by:

$$w_j = \frac{RT_j * 100}{MT} \tag{1}$$

Moreover, trucks will assign a greater value to solutions where the corresponding truck is allocated in its most preferred rest area and this value will be decreased when it is allocated in less preferred rest areas. So, in this approach weights are pondered regarding the position of the area where a truck is allocated in the solution according to the order in its list of preferences.

$$Preferences = [a_1, ..., a_n] : a_1 \succ a_2 \succ ... \succ a_n \tag{2}$$

$$Vote_j = w_j * [n, n-1, ..., 1] \tag{3}$$

But, trucks with more candidate rest areas would get a higher score than other trucks on the same rest area with a less number of candidate rest areas. One of the objectives of this paper is to present the different proposals defined to normalize the vote of the values applied to each truck involved in a negotiation and the evaluation of these proposals.

Method 1: using a parameter to normalize

First method proposed the use of a Φ parameter to normalize the values of the votes regarding the set of solutions. This parameter is the maximum number of preferences from all trucks implied in the negotiation. Using this method we ensure that weights are pondered by the same value for the most preferred area of the trucks involved and decreasing homogeneously in the followings:

$$Vote_j = w_j * [\Phi - 0, \Phi - 1, .., \Phi - (n-1)] : \Phi \geq n \tag{4}$$

Method 2: using a percentage to normalize.

Second method uses a percentage that depends on the number of preferred areas of the truck involved in a negotiation. The first preference will be pondered with a 100%, and this percentage will be reduced gradually according to the number of preferences. Using this approach trucks pondered again the most preferred area by the same value (100%), but the next ones will be pondered according to the pending active preferences of the truck involved.

$$Vote_j = w_j * 100 * [\frac{n-0}{n}, \frac{n-1}{n}, ..., \frac{n-(n-1)}{n}] \tag{5}$$

CASE OF STUDY

A simple case of study has been developed to analyse the behavior of the negotiation protocol using both methods. Figure 1 presents a road network segment that includes 4 rest areas (A0, A1, A2, A3). Each area has 2 parking spaces. There are 5 trucks (T0, T1, T2, T3, T4) in the road network.

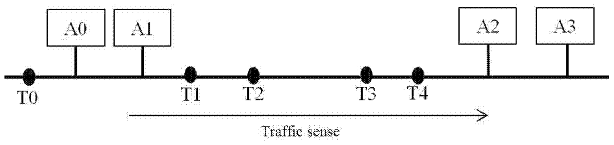

Figure 1: Case of Study

Because of the driving time of the different trucks: trucks T3 and T4 only can reach area A2, trucks T1 and T2 can reach areas A2 and A3, and, truck T0 can reach all areas. Vehicles can choose any criteria to order their preferences from the list of achievable areas. In this simple case, the criterion chosen by driver is parking in the farthest achievable area. Table 1 presents the example of the preferences for those trucks.

Table 1: Truck parameters: road time, calculated weight and sorted preferences

Trucks	Road Time	Weight	Preferences
T0	120	50	A3, A2, A1, A0
T1	108	45	A3, A2
T2	96	40	A3, A2
T3	216	90	A2
T4	228	95	A2

At time t1, truck T3 appears on the road segment and it requests a pre-book in rest area A2. Later, at t2, truck T4 requests a pre-book in the rest area A2. At t3, T1 requests a pre-book in rest area A3. And, at t4, T2 requests a pre-book also in A3. Then, truck T0 appears in the road segment, at t4, and requests a pre-book in A3. Rest area A3 has all its parking spaces pre-booked and the area A3 fires the voting negotiation process. Trucks involved in the negotiation are T0, T1 and T2. The agent area asks for the preferences of each truck involved (table 1). Table 2 shows the solution set. It is composed by the different solutions indicating the trucks that maintain the pre-book in the area and the truck that would has to try to get the pre-book in its next preference.

Table 2: Solution Set

Solution	T0	T1	T2
S0	A2	A3	A3
S1	A3	A2	A3
S2	A3	A3	A2

Now, the area proceeds to solve the voting. The area calculates the weights of the votes applying the presented equation. In this case, it is assumed that the maximum driving time for any truck is 240 minutes. The calculation of the weight for each truck is shown in table 1. Tables 3 and 4 show the score value for the different solutions using method 1 and method 2. For method 1, the parameter has been set to 4, since it is the maximum number of preferences from all trucks involved (preferences from T0). For method 2, all truck weights are pondered using the length of its own list of preferences.

Table 3: Negotiation Results. Method 1

Solution	T0	T1	T2	Total
S0	150	180	160	490
S1	200	135	160	495
S2	200	180	120	**500**

Table 4: Negotiation Results. Method 2

Solution	T0	T1	T2	Total
S0	3750	4500	4000	**12250**
S1	5000	2250	4000	11250
S2	5000	4500	2000	11500

As it can be observed, the winning solution is different from applying method 1 or method 2. Using method 1, S2 is the winning solution. Truck T2 will be expelled from area A3 and consequently it will request a pre-book in its following preferred area, A2. Since A2 has already occupied all its spaces and all trucks has not more preferences, one of them will be forced to park illegally. Whereas using method 2, S0 is the winning solution. Truck T0 is expelled and it will request a pre-book in its following preferred area, A2. A2 will launch a negotiation process and T0 will be expelled again since T3 and T4 have no more preferred areas. So, finally T0 will request a prebook in A1 and it will be assigned since A1 has free spaces. The final assignation of parking spaces can be shown in table 5.

Table 5: Final Assignations. Methods 1&2

Truck	Method 1	Method 2
T0	A3	A1
T1	A3	A3
T2	-	A3
T3	A2	A2
T4	A2	A2

PRACTICAL APPLICATION

A real network was modelled and simulated using the test-bed presented in (Garcia et al. 2014) and developed to demonstrate the benefits of applying a distributed multi-agent system in front of a centralised one. In this paper, the different normalization methods of the votes of the trucks are implemented and analysed. This model represents a segment of a Spanish road network, the A7 motorway along the Community of Valencia, (figure 2). This road network is part of the Spanish Trans-European Road Network (TERN) and belongs to one of the main European corridors, the E-15 Long distance corridor. The modelled part covers the 400 km. of the Valencian Community.

Figure 2: E-15 road segment.

In this test, only the negotiation protocol is evaluated. Another features of drivers, as for example, the time spent by the drivers in rest areas is not taken into account. When a truck reaches its rest area, it never leaves it, but this truck does not participate again in future negotiations. Congestions, accidents or other causes that make impossible for a vehicle to reach its assigned rest area are not taken into account. Also, it is considered that the trucks are benevolent, i.e., the trucks respect the assignments provided by the rest areas because trucks look for common welfare.
The scenario is modelled by using the multi-agent structure of the test-bed. The agents involved are the following:

- Truck agent: A truck enters the system with an initial position and a road time. These data are assigned at random from a given seed. Also the truck agent notifies its preferred rest areas for making a stop.
- Area agent: Area agents are registered in the system at start up. The location of each one of these area agent is known by truck agents. Area agents maintain a list of pre-books made by trucks.

When a simulation begins, trucks enter in the system in different locations and in different time intervals. A random function has been added to the test-bed to do it. When a new truck enters in the road network simulated, it requests to the most preferred rest area a pre-book to make a stop.
If the rest area has no available parking spaces, the negotiation process starts. Then, the area requests the preferences to the trucks with a pre-book in the area. Next, it calculates the feasible solution set and resolves the voting process according the method to be evaluated. Finally, it communicates the new pre-books to the appropriate trucks.

RESULTS

The evaluation of the different methods is performed by comparing the provided results of three different scenarios: first, without negotiation process, second, using the negotiation process with normalization method 1, and finally, third, using the negotiation process with normalization method 2. Results from the three scenarios are presented in figure 3.

Figure 3: Degree of trucks parked illegally

Figure 3 represents the amount of trucks that park illegally since they could not obtain a reserved parking space (only 10 simulations). Without the negotiation, around 25% of trucks have parked in a rest area exceeding its parking capacity or parking in an illegal place. Applying the negotiation process less than 10% of trucks involved have stopped in an illegal place. And, from both applied methods, method 2 reduce even more the amounts of trucks forced to park illegally up to 7%. The second method offers more possibilities to trucks with less pending preferred areas to win the negotiations and that is reflected in the reduction of illegal parking using method 2 to normalize the weights of the vote against method 1.
Reduction of illegal parking is the main objective and it is achieved, but, it is important to know the degree of satisfaction of drivers regarding the parking spaces assigned. Drivers will be completely satisfied, 100% of satisfaction, when he is allocated in his most pre-

ferred area and this value of satisfaction will decrease according to its order in the list of preferences. The satisfaction will be negative if the driver does not receive any reservation and is forced to park illegally. $Satisfaction_j = -100$, when j has to park illegally, and, $Satisfaction_j = \frac{n-i+1}{n} * 100$, where $1 \leq i \leq n$.
Figure 4 shows the average of satisfaction of drivers in the different simulations. Results shows that satisfaction of drivers is enhanced by using the negotiation framework with respect to a framework without negotiation capabilities. Using normalization method 1 the percentage of satisfaction is more than 5%. And, using normalization method 2, the satisfaction of drivers is increased even more, up to 10%. This is due to the fact that there is less illegal parking in the negotiation framework, so trucks are better distributed according to their preferences.

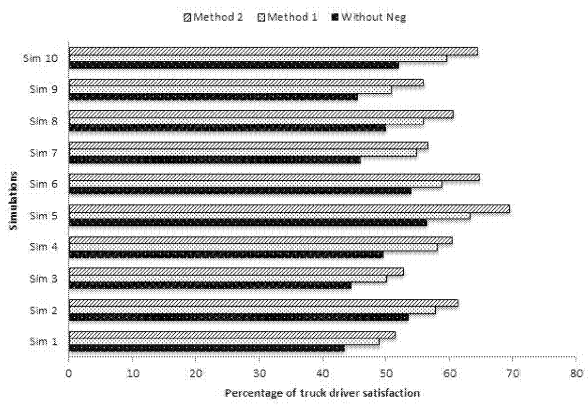

Figure 4: Degree of satisfaction of drivers

CONCLUSIONS

In this paper a Borda based negotiation protocol for coordinating the parking of trucks in rest areas has been improved by defining and evaluating different methods to calculate the value of the votes of trucks in the negotiations.
By using the negotiation protocol the number of trucks parked illegally decreases considerably. The paper shows that the selection of different methods to normalize the votes of trucks can influence considerably in the expected results. Two methods has been defined to normalize the value of votes. The first proposed method represents a good approach, but the second one decreases even more the amount of trucks parked illegally. The reason is that second method increases the possibility of trucks with a lower number of possible areas to park to win a negotiation.
A simple case of study has been presented to show the variation of results in some cases when applying both methods. Also, a simulation has been carried out in a real road network section to evaluate the results.

At the same time, it exists the possibility that improving the global objective (minimising the illegal parking) could decrease the satisfaction of truck drivers. Consequently, a formulation to evaluate the global satisfaction of drivers has been defined. Results show that using a negotiation method satisfaction increases considerably, and that the second method improves also the global satisfaction of drivers in relation to the first proposed method.
Results are very positive, however, there is work to do in order to continue improving the protocol. The solution does not take into account the rest periods of trucks in the rest areas that would modify the number of free spaces along the simulation. At the same time, the protocol considers that trucks are benevolent. Different strategies are being considered to improve the protocol, i.e., VCG (Vickrey-Clarke-Grove) strategies where the best strategy for voter is always saying the truth.

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TRAFFIC NAVIGATION MANAGEMENT SIMULATION

ESTIMATION OF SIGNALS GENERATED BY AMR SENSORS FOR THE SIMULATION OF MAGNETIC MODELS OF VEHICLES

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KEYWORDS
Transportation, Signal Processing, Pattern Recognition, Estimation, Simulation.

ABSTRACT

Identification of traffic vehicles using characterizing magnetic signals has been researched in the recent years. The use of AMR sensors as a substitute of the traditional magnetic loops has provided more reliability to the method. However, a new research challenge arises due to the complexity of vehicle magnetic models that AMR sensors can capture: the relative position of the sensor to the vehicle is very sensitive to the matching process. Although an AMR sensors network can be used to avoid this problem and extract complete vehicle magnetic fingerprints, pairing and matching signals of the same vehicle in different sensing points does not guarantee a complete identification. A low similarity between two individual signals can happen when there is long distance among the network sensors. This paper presents a method to estimate the magnetic signal that a vehicle generates at any sensing point based on the signals measured nearby. This estimation could be used in the future to test and simulate network configurations for effectively re-identify vehicles.

INTRODUCTION

Traffic management is a task that requires as much information as possible from the status of the roads. Both real time and historic trends are equally used with this purpose (Lam & Head 2012). The most valuable information is the detail about the traffic flow and the forecast about its evolution, in particular, Origin-Destination matrices and real-time traffic status (Cascetta and Nguyen, 1988).

This information could be easily obtained if each and every singular vehicle could be traced in its route from origin to destination. Different technologies have been applied to the problem of identifying a vehicle in several points in the road network (Belda 2008). In some cases, technologies have been selected for identifying vehicles in long distances; in some other cases, the target has been reduced to short distances, when other type of technologies are more suitable.

In particular, for short distances identification, the use of magnetic sensors has been one of the options (Abdulhai and Tabib 2003). The main idea after this technology is to obtain differentiating characteristics of a vehicle. A very first approach has been the use of existing infrastructure for getting magnetic information for the vehicle. The magnetic loops can be used to determine the distribution of the ferrous material the vehicle is made of. Although this technology has proved to be good enough to classify vehicles, it has not succeeded in the objective of identifying vehicles, because the magnetic signals do not provide enough discrimination capabilities (Cifman and Krishnamurthy 2007).

An evolution of the magnetic technology has produced the AMR (Anisotropic Magneto Resistive) sensors. They are based on the capabilities of some materials to quickly change their electrical resistance when affected by a magnetic field and reached the industry a few years ago (Honeywell HMC2003). They can detect changes in the magnetic field around them through the measurement of the changes in their electrical resistance. In the field of traffic and transport, AMR sensors have been used to capture the variations of the Earth's Magnetic Field when a vehicle moves over them (or nearby) (Caruso, M. J.; Withanawasam, L. S. 1999). The sensors can obtain a signal which represents the magnetic characterization of the vehicle in 3D (fingerprint), which differentiates it from another one. They have been proved successful for detecting vehicles and for gathering some basic traffic parameters (flow, density, occupancy, speed, etc.) (Kwong et al. 2010). They have also been applied to identify moving vehicles at different and close sensing points. Researchers report a partial (and even high) grade of success (Sanchez et al. 2011), but under particular conditions.

The main drawback for this technology to be used in the vehicle identification problem is the complexity of the magnetic model inherent to the vehicle. The signal captured by an AMR sensors highly depends on its relative position to the passing vehicle (Burns 2009). The sensors network set up and the selection of the adequate sensors signals are crucial to obtain a good identification method through a matching function. This problem has rarely been treated, but simulation is a fair and feasible technique to investigate on, as a way to emulate the magnetic model of a vehicle.

In this paper, we propose an approach to generate inputs for the simulation methodology. As such a simulation would need to obtain or estimate the signals generated by any sensor at any position of a passing vehicle, we propose a signal estimation technique based on some real signals captured from the vehicle. We will present the mathematical model and the scope of application in the estimation procedure. An analysis of the results will also be shown based on the performance of the method in a real case.

OBJECTIVES AND METHODOLOGY

The main objective of the work presented in this paper is to define and test a methodology to estimate the magnetic characterization of a vehicle from the perspective of the data that can be captured by AMR sensors. As already stated, AMR sensors can depict a very detailed magnetic model of a vehicle, in terms of the variation of the Earth's magnetic field generated by its movement. In general, the models of the vehicles are quite complex for two reasons: the ferrous distribution of the material that the vehicle is made of, and the sensitivity of the AMR sensors. Figure 1 shows an example of the variation of the Earth magnetic field captured by an AMR sensor when a vehicle passes over it. In this context, the term complex refers to the variability of the observed magnitude along a transversal path of the vehicle.

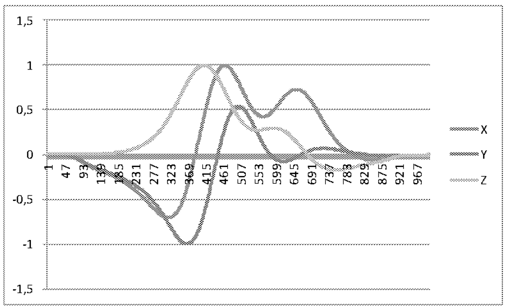


Figure 1: Example of normalized AMR Sensor Signal

The form of a signal obtained by an AMR sensor from a passing vehicle highly depends on the sensor position relative to the vehicle (Ngandjon and Cherkaoui 2011). The evolution of this shape in a transversal path of the vehicle is what makes the identification of a vehicle a difficult task: one only sensor offers very different signals depending on the position of the passing vehicle . That is the reason why nearly all the identification methods try to use only data gathered at a fixed position of the vehicle.

Figure 2 shows a variation of the normalized signals obtained from a vehicle with sensors separated 80 cm. one from each other. The difference on the evolution of the signal shape can be clearly seen. Therefore, when AMR sensors are used to identify vehicles, a set of sensors should be used to get as much information as possible, so that the best signals can be used in the matching process.

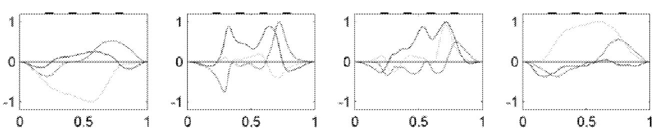


Figure 2: Example of signals captured from an array of 4 AMR sensors for a particular vehicle

The process of identifying a vehicle is made by using one or several signals obtained when the vehicle passes over two arrays of sensors located at different points of the road. The signals of the first array must be matched against those obtained from the second array. The matching methodology is based on the comparison of the fingerprints of several vehicles from the two sensing points (Ndoye et al. 2011). This is achieved by using signal comparison methods, and assigning a similarity value to each possible pair of fingerprints. For a reduced set of vehicles (<= 50) the success rate is high if some restrictions are met (reduced speeds, urban traffic, sensors located in the center of the lanes, vehicles circulating within the lanes).

Removing the restrictions from the matching process means that there is no control on the section of the vehicle where the signals are obtained from, and consequently there is a variation on the captured fingerprints of the same vehicle that can lead to a mismatch. In this case, we propose the hypothesis that the matching process could be improved by setting up a more efficient sensors network configuration. This optimal configuration will state that:

1. Not all the sensors must be used for the matching process as some signals are not relevant for the vehicle magnetic characterization.

2. A minimum number of sensors can gather useful data for an effective matching process.

3. There exists a minimum value of density of sensors at the sensing points to guarantee the previous condition.

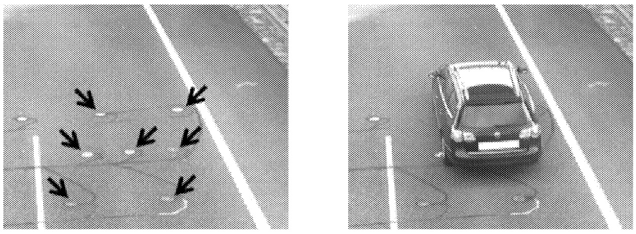
Our hypothesis could be proved with an experiment using a high number of sensors in a very dense distribution, allowing for different types of tests. However, such an experiment could turn out very expensive and unfeasible. In return, we consider that a simulation approximation could be used to validate the hypothesis.

Our objective is to define and validate (through an experiment) a method to estimate the signal that a sensor would gather from a vehicle at any position, by using only a few real AMR sensors. This would permit the simulation of any configuration of sensors in an array, so that a set of matching experiments could be done without the need of using many sensors.

Experiment setup and data acquisition

The estimation method that we propose needs a set of real signals captured from a number of sensors on the road surface. So, an experiment is set up in order to get enough vehicle signals to apply the estimation method. The experiment is oriented towards the construction of a vehicle magnetic model by using some signals obtained at particular positions of the vehicle. They will feed the estimation model, and signals at any position of the vehicle will be generated.

In the experiment, we have set up an array of 7 AMR sensors on a road surface. The sensors have been placed on a lane of a well known Spanish highway (M-12) in Madrid. The horizontal distance between the sensors is of 40 cm. one from each other. Additionally, they are set up in the form of saw-tooth. Figure 3 (a) shows the distribution of the sensors on the highway lane. Then, the target vehicle passes over the sensors 10 times, at different positions inside the lane each time. The aim is to obtain signals of different parts of the vehicle, using only the 7 sensors. Figure 3 (b) shows the vehicle passing once over the sensors.



(a) (b)

Figure 3: (a) Sensors network layout and (b) vehicle passing over the sensors

After passing 10times , a total of 69 signals have been obtained (one signal is lost because the vehicle passes outside the sensing range). Every signal has been recorded and tagged with its relative position to the vehicle (considering the center of the vehicle as the origin of the spatial reference system). The integration of all signals provide an approximation to the vehicle magnetic model.

The dimension of the vehicle is a key factor in this experiment. A Toyota Corolla has been selected as the target vehicle, and the most relevant information of this car for the experiment is that the horizontal distance between wheels is 148 cm., which gives a distance from the center to each wheel of 74 cm. Considering a rough distance of 20 cm around each wheel for signals being affected by it, the distribution of signals obtained per vehicle section is shown in Table 1.

Table 1: Signals obtained per vehicle section

	Outside the wheels	Around the wheels	Between the wheels
Number of signals	27	17	25

Estimation model and validation procedure

The signals we are dealing with respond to physical behaviors of systems in the real world. It is then expected to find a continuous evolution of the measured magnitudes. The estimation model should take this into account, and will consider several adjacent signals for the estimation of the target.

Additionally, the signals are captured in a real situation, with 10 passing vehicles, which makes them different in number of samples and amplitudes. Therefore, a normalization process should be applied to the signals prior to the estimation procedure (Cirilo et al. 2013b). So, signals will be resampled to a size of 100 samples, and the amplitude of signals will be normalized to a maximum value of 1.

The selected estimation model is based on the Gaussian weighting average function. In this model, the standard deviation will affect the weight of the neighbors of the target point. For that reason, the experiment will consider different values for the standard deviation and will evaluate the most suitable one. Equation 1 presents the Gaussian weighting average based function that has been used in this study.

$$w(x, \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad (1)$$

Let $\psi_i(k)$ be the captured signal i, where k represents a particular sample of the signal, i<=69, 1 <= k <= 100. Let δi be the relative position of the signal i to the center of the vehicle. Then the estimation function for a particular signal j and for a standard deviation σ can be formulated by using the Equation 2.

$$\psi_{j,\sigma}(k) = \sum_{i=1, i\neq j}^{69} \psi_i(k)\, w(\delta_i, \delta_j, \sigma) \qquad (2)$$

This procedure is applied for the estimation of the 69 signals obtained during the data acquisition stage, and all of them are normalized to make them comparable to each other.

A validation of the estimation method has been defined. It is based on computing the difference between a real and an estimated signal. The method for comparing signals is based on a matching function consisting in a similarity function (Cirilo et al. 2013a) that takes into account all three components (X-Y-Z) of each signal.

EXPERIMENTAL RESULTS

All the signals (69) captured during the experiment are used to validate the proposed estimation method in two ways. Firstly, every signal is estimated using the other 68 ones. Secondly, every estimated signal is compared to the real one through a similarity measure (Cirilo et al. 2013a).

The function used to estimate a signal is based on all the other captured signals, and considers their relevance for its contribution to the final result in the form of a weight. By using the Gaussian weighting average, the contribution will depend on the distance of the signal to the estimation point, and on the standard deviation used. All signals have been estimated using 5 different values for the standard deviation: {1, 2, 3, 4, 5}. An example of the estimated signal and its corresponding one can be seen in Figure 4.

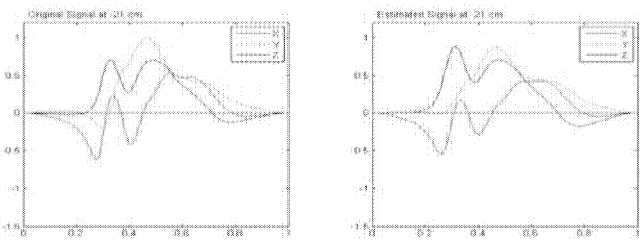


Figure 4: Original (left) vs Estimated (right, σ=5) Signal.

Finally, all estimated signals have been compared to the original ones, for every standard deviation considered. An excerpt of the data obtained from this similarity calculation is shown in Table 2, where the value of the similarity (in the interval [0,1]) is provided for each standard deviation value and the distance of the estimated sensor to the center of the vehicle.

Table 2: Similarity measures between estimated and real signals for different stddev values (excerpt)

	STDDEV				
Distance	1	2	3	4	5
45	0,9244	0,9365	0,9488	0,9576	0,9630
59	0,6025	0,6036	0,6101	0,6161	0,6266
69	0,6627	0,6896	0,6821	0,7076	0,7399
85	0,9086	0,8979	0,8698	0,8489	0,8424
103	0,9192	0,9285	0,9325	0,9335	0,9338

As we can see in Table 2, the similarity values are all in the range [0.45, 0.99] cm. This data has to be analyzed from two perspectives. On the one hand, it has to be checked if there is a relationship between the similarity values and the distance to the center of the vehicle. On the other hand, a comparison among the standard deviation values should be made in order to select the best parameter for the estimation function.

The relationship between the similarity values and the position of the estimated signals can be best perceived with a chart with a representation of the similarity values versus the positions of the sensors. This is shown in Figure 5.

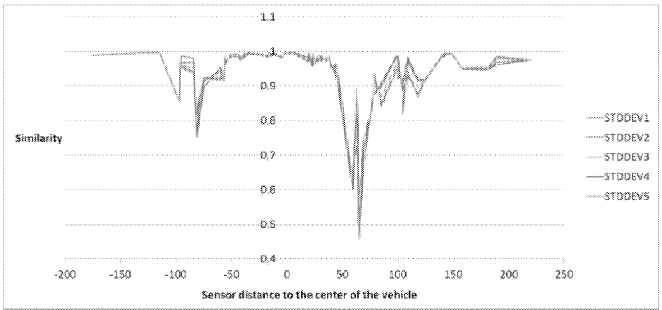


Figure 5: Representation of similarity values for each sensor position, for different stddev values.

The similarity values corresponding to the central section of the vehicle are very high (over 0.98). However, the values corresponding to sections in the [-95, -55] and [55, 95] cm ranges are significantly lower if compared to the rest of values. These two sections correspond to the areas of influence of the vehicle wheels, as they are located at ±74 cm. Then, the vehicle outer section (distances over 95 cm.) has different behaviors at the left or the right hand side, but similarity values are higher than for the wheels sections.

Considering these results, a first observation is that the estimation method works very well for the signals of the center of the vehicle, but signals of the area of influence of the wheels or the vehicle outer area cannot be estimated with the same precision. It is worthy to see how the shapes of the signals are in these areas, and how they evolve with the distance. This can be seen in Figure 6 and Figure 7.

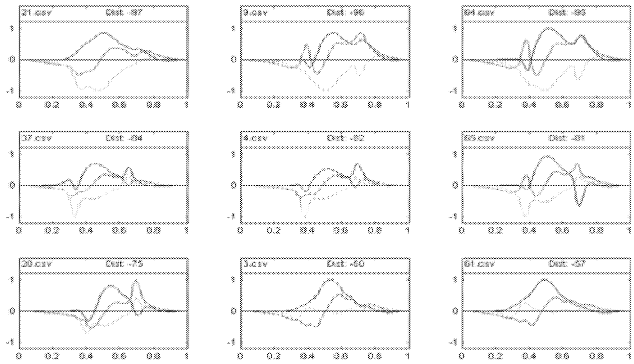


Figure 6: Sensors signals in the area of influence of the vehicle wheels.

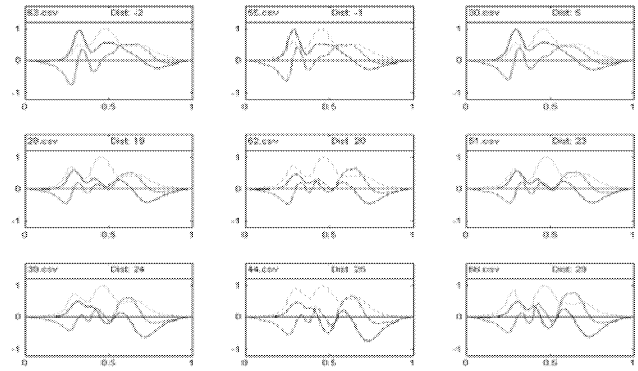


Figure 7: Sensors signals in the middle of the vehicle.

The variation of the signals shapes with the distance is more abrupt around the wheels than in the center of the vehicle. In fact, some of the signals near the wheels look quite different to their next neighbors. In the center of the vehicle, however, the changes on the shapes of the signals are smoother. This can be explained by the ferrous characterization of the vehicle.

Obviously, the wheels and axles sections are heavier than the rest of the vehicle sections in terms of ferrous composition. These parts can be considered as singularities in the vehicle magnetic model. Considering this, an estimation method based on the similarity of the neighbours, like the one proposed in this paper, will perform worse in the sections with singularities. So, the similarity values obtained respond to the expected magnetic characterization of the vehicle.

For the standard deviations, the criteria that has been firstly used to decide the best value for the estimation function is the average of all the similarity values. However, the existence of the singularities should be taken into consideration. A comparison between the total average of similarities values and a subset of values defined by a threshold of similarity values has been made, and is shown in Table 3.

The difference in the values is practically insignificant. However, a value of standard deviation of 5 seems to be the best in the most important situations: a) when all signals are considered (threshold=0.00), and b) when only the best estimations are considered (threshold=0.95). So, a value of σ=5 is chosen for the estimation formula.

Table 3: Average of similarity values for each stddev and for different thresholds.

	STDDEV				
Thershold	1	2	3	4	5
0.95	0,9831	0,9829	0,9836	0,9844	0,9847
0.90	0,9728	0,9738	0,9724	0,9725	0,9722
0.80	0,9653	0,9608	0,9616	0,9599	0,9608
0.00	0,9346	0,9349	0,9334	0,9343	0,9357

CONCLUSIONS AND FUTURE WORK

In this paper, a methodology has been defined for the estimation of signals generated by an AMR sensor applied to vehicle identification problems. The methodology has been based on the application of a Gaussian-weighted average function to the existing vehicle data.

The method has been validated through the deployment of a real experiment, where a parametrization of the estimation function has also been evaluated. The results that we have obtained show a restriction in the vehicle sections that are suitable for the application of the estimation model; in particular, the center of the vehicles signals can be estimated with precision, but the wheels sections signals should not be estimated with this method due to the rapid variation of the signals shapes with the distance. This experiment can be extended and provide a magnetic characterization of the vehicles in general, with more detail on each vehicle section.

Another important conclusion is that, for identification purposes, the signals corresponding to the center of the vehicle should be used, as using wheels section signals will undoubtedly and negatively affect the results of the similarity measures.

This work can further be used to test the performance of sensors configurations for vehicle identification purposes. Considering the variations of the signals shapes in a transversal section of the vehicle, a set of configurations (number and disposition) of sensors can be analyzed through the simulation of signals at different vehicle points. The best vehicle identification method will then be achieved by using the combination of the similarities of the right number of sensors at the right positions.

Finally, this work can also be the basis for a deeper analysis of the magnetic model of a vehicle. It has been shown that a vehicle has several singularities that should be studied in more detail. The vehicles wheels sections, in particular, will be studied in later research projects to learn about their magnetic behavior and to obtain detailed information about vehicles axles.

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INFLUENCE OF PERCENTAGE OF DETECTION ON ORIGIN – DESTINATION MATRICES CALCULATION FROM BLUETOOTH AND WIFI MAC ADDRESS COLLECTION DEVICES.

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KEYWORDS
SUMO simulator, Bluetooth and Wifi traffic sensors, dynamics Origin/Destination traffic matrices.

ABSTRACT

The dynamics Origin/Destination (O/D) matrices are fundamental for the management of road traffic. These matrices describe the vehicle flow between different points inside a road network for a given period of time. Currently the application of Bluetooth (BT) or wireless devices as a source of information to obtain this parameter is being widely studied. This technology does not allow the detection of 100% of the vehicles on the road, only those who have an on-board device using these technologies are detected. This paper analyses the influence of percentage of detection on the error associated with the calculated O/D matrix from BT and WIFI Media Access Control (MAC) address collection devices. For this study, the traffic simulator SUMO will be used, which will provide an initial value for the O/D matrix and will allow us to simulate different technology detection rates.

INTRODUCTION

The usual way to get the O/D matrices has been by off-line processing, using the data provided by magnetic sensors on the road and interviews with users or mobility studies. Mathematic methods were used on this data to estimate the static O/D matrices (Abrahamsson, 1998) (Cascetta & Postorino, 2001).

In recent years new technologies have been applied to obtain the O/D matrix directly. One of the most used is the application of an Optical Character Recognition (OCR) to traffic images in order to identify vehicle number plates. After the identification of the number plate, the vehicle is tracked through the different measuring points, which allows dynamics or time-dependent O/D matrices to be obtained (Sun et al. 2014). Another type of sensor that has also been used to obtain this parameter is the Electronic Toll Collection Tag (Kwon & Varaiya, 2005). For all these cases, a very expensive equipment installation is required on the road, even on on-board equipment, which greatly reduces their applicability.

However, the presence of on-board equipment with BT or WIFI communications (Smartphones, iPad, handsfree) has opened a new source of information in Traffic and Transport Management. This type of technology allows the installation of low cost sensors on the road, which read the MAC address of the BT or WIFI communication device. At each detection point and for each detected device, the following information is registered: its MAC (unique identifier) address, the detection time and the sensor location. Thus the vehicle can be tracked on the sensored network and calculate the dynamics O/D matrices.

The advantage presented by this type of technology is that the installation of equipment in the vehicle is not necessary and the cost of the sensors installed on the road, requirements of electrical power, communications or additional equipment are low (see Figure 1). The disadvantage of this technology is that not all vehicles will be detected and, therefore, there will only be a sample of the total number of vehicles.

Figure 1: Bluetooth and WIFI sensor

This technology has been extensively studied and shown to be valid for calculating travel times, since for its determination only a sample is required (Malinovskiy et al. 2010), (Stevanovic et al. 2014). However, the calculation of the dynamic O/D matrix using Bluetooth or WIFI sensor has a range of additional problems:

- There can be more than one Bluetooth or WIFI device in the vehicle.
- Devices that do not come from vehicles can be captured, mainly in urban areas.
- How to extrapolate the result obtained using a sample to the whole population (Barceló et al. 2010).
- What calculation error we make based on the detection rate of the sensors in relation to the whole population.

In this paper, we analyse how the rate of penetration of BT or WIFI devices has an influence on the error made when calculating the dynamic O/D matrix in a complex road network.

To perform this study we used the SUMO (Simulation of Urban Mobility) (Behrisch et al. 2011) simulator developed by the Institute of Transport Systems of the German Aerospace Center (DLR). SUMO is a microscopic traffic simulator that allowed us to create a testbed, where we have an origin matrix, created from a unique identifier of each vehicle, its start time in the simulation and the segments through which it has circulated in the simulated network. From these data different penetration rates were simulated, the associated O/D matrix was calculated and compared with the real O/D matrix.

The rest of the paper is structured as follows, in next section the related work and our novel contribution is presented. The following sections give a detailed description of the experiment performed and the results obtained.

RELATED WORK

Aspects already evaluated about BT Sensors

Nowadays, the use of reading devices of MAC addresses of on-board equipment with BT or WIFI communications, are being widely studied for its use as traffic sensors, mainly for calculating travel times. There are currently commercial devices that get this traffic parameter in both urban and interurban environments (TrafficNow 2014), (Bitcarrier 2014).

In order to validate the BT technology for its use as traffic sensors in obtaining traffic parameters, different aspects have been studied. Early studies focused on the validity of the technology (Langheinrich & Kasten, 2001) and its scope, demonstrating that BT equipment could be captured within a radius of up to 250 m using devices type I (Murphy et al. 2002).

Once the technology had been validated, studies were focused on how to improve the process of obtaining data, analysing the influence of directionality or polarity of the antenna in the detection. The studies of Porter (Porter et al. 2013) determined that the vertically polarized antennas offered better results.

Another studied aspect was the influence of the antenna gain in the sensor range (Abbott-jard et al 2013). The studies showed that for urban environments or road entry and exit, antennas between 3dBi and 9 dBi of gain should be installed. However, for the main highway or high speed roads the chosen antennas should be between 9 and 20 dBi.

Also an influence analysis of the position of the antenna in the detection has been performed (Brennan et al. 2010). In this study, tests were carried out on a pole where the sensor was placed at intervals of 75cm. The best results were obtained at 2,25m and 3 m high, with the optimum position at 2,5m.

Another aspect that was studied was how placing two sensors in a same point or placing a sensor with two antennas influenced the detection (Malinovskiy et al. 2011) (Wieck, 2011). The data obtained demonstrated that the best results are achieved with the installation of a sensor with two antennas, going from 9,37% of detections and 3,43% of MAC address matching, with one antenna, to 15,35% of detections and to 7,92% of matching in the case of having an equipment with two antennas.

Use of SUMO in similar studies

The SUMO simulator is an microscopic traffic simulator. It is an OpenSource software under GNU license. It has a several tools:

- to import the network to be simulated from different sources (OpenStreetMap, shapefiles, ...)
- to generate abstract networks
- A Graphical Interface of the network representation and of the simulation results
- to define the routes of vehicles from real sensors installed on the road or through a known O/D matrix.

The advantage SUMO offers for its use in this study is twofold, firstly, it allows identifying uniquely each vehicle, as it happens with BT or WIFI sensors. In the simulation a file is generated which contains a unique identifier for each vehicle, a list of segments through which the vehicle has passed since it enters and exists the network and the detection time. From this file the O/D matrix associated to the simulation can be obtained. On the other hand, it allows the modification of the code to adapt the model to the project needs.

The SUMO simulator has been used in recent years in the research of the V2X vehicular communication in the iTETRIS project, in dynamic navigation and choice of routes projects. Another noteworthy experience was the TrafficOnline project (Krajzewicz et al. 2012). In which SUMO was modified to incorporate the behavioural model of GSM telephony as well as the SUMO output so that the travel times of each simulated vehicle would be written on a file.

Novel Contribution

The aim of the study presented in this paper is not to validate the algorithm to be used for the calculation of the matrix O/D developed in the IRTIC (University Research Institute on Robotics and Information and Communication Technologies). This algorithm has already been evaluated and its results presented on another paper (Tornero et al. 2012). For the evaluation of this algorithm the SUMO simulator was also used, with a simple road network on which the algorithm was applied and 100% accuracy was obtained in the dynamic O/D matrix.

To the authors knowledge no researches have been found that analyses the influence of the detection rate of the BT or WIFI technology on the accuracy of the calculation of dynamics O/D matrices. Therefore, this will be the objective of the study presented in this paper.

EXPERIMENT DESCRIPTION

To analyze the error associated to the detection rate of BT or WIFI sensors when calculating the dynamic O/D matrix of a network, it is necessary to have a real O/D matrix.

This matrix could be obtained from a real installation, but it would have a very high cost and it would be almost impossible to vary the detector rates of the BT or WIFI devices. Therefore, the best option is to obtain an O/D matrix from a traffic simulation model. In our case by the use of a simulation model of a real road network using traffic simulator SUMO.

SUMO Simulator

The network on which it has been decided to conduct the study is a real and extensive road network. The metropolitan road network of the city of Bilbao (see Figure 2) with 41 entries and 41 exits has been taken as a basis for the study and its traffic simulation model created in SUMO.

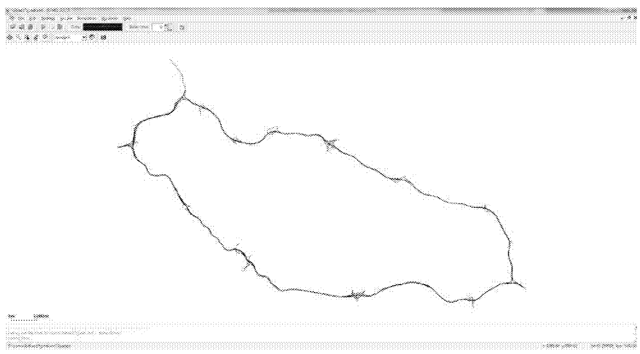

Figure 2: simulated road network

For the creation of the network model in SUMO the network has been extracted from Open Street Map, and the tool netconvert of SUMO has been used to transform it to the format of the SUMO simulator. Once the network was imported in SUMO, the errors coming from the importing were corrected. The main errors were found on road intersections and where the links were joined together.

Once the network had no errors, the traffic demand model was introduced, for this purpose it was decided to enter the actual traffic flow values obtained by traffic sensors. These data are published annually by the Department of Public Works and Transport of the County Council of Bizkaia. Apart from the traffic flows the turning ratios had to be defined at each decision point in the network and the type of vehicles that will appear in the simulation. The simulation interval that was created was an hour long.

After entering this information, the SUMO simulator generates the traffic simulation. The simulation results are written in a file named * .rou.xml. This file contains a list of all vehicles involved in the simulation, sorted by start time in the simulation. For each vehicle the following information is available: type of vehicle, its unique identifier and a list of all the segments of the simulated network of its itinerary. This file was processed to obtain the Real O/D matrix, which we will be taken as a reference for the comparison with the O/D matrices obtained in the study.

To simulate an real installation of BT or WIFI sensors, the SUMO model has been modified to create a new sensor (called D3). This sensor provides the same information as the one generated by BT or WIFI sensors. The result obtained from each sensor is a file where a note is made for each one of the vehicles passing through that sensor, with the unique identifier of the vehicle and the detection time.

This sensor was defined on all inputs and outputs of the road network simulated, by using all files created by D3 sensors and applying the algorithm for calculating O/D matrices, the O/D matrix simulation result was obtained, which corresponds 100% with the one calculated with the input data.

Description of Procedure

Once we confirmed that the O/D matrix that was obtained when applying the calculation algorithm to the data provided by the D3 sensors was identical to the O/D matrix of the simulation model, we studied the error associated to the calculation of the O/D matrix according to the detection rate defined.

In order to be able to simulate the detection rate the output files of the D3 sensors were modified, so that only a percentage of all the simulated vehicles would appear, equal to the percentage of our study. This procedure was performed randomly and repeated N times for all sensors. Therefore obtaining a sample of N O/D matrices for each detection rate.

RESULTS

For the presentation of the results 3 pairs of input-output of the total O/D matrix were chosen, the pair Avanzada - Mungia with 223 vehicles, the pair Santander - Vitoria with 103 vehicles and the pair Santander - San Sebastián along the corridor Txorierri with 33 vehicles. These pairs represent itineraries with high, medium and low volume traffic.

Figure 3, Figure 4 and Figure 5 show the boxplot diagrams for the above mentioned pairs. The X axis shows the detection rate and the Y axis shows the value obtained in the matrix O/D for an N sample of 20 matrices for each percentage.

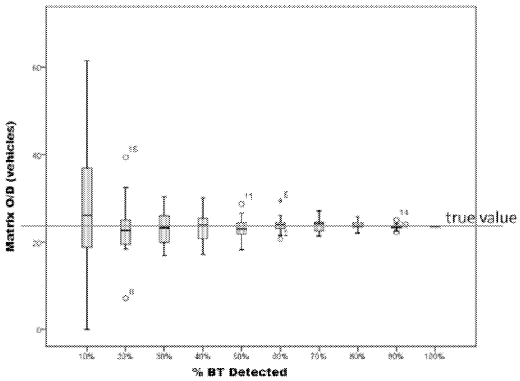

Figure 3: Blox Plot pair O/D Avanzada – Mungia

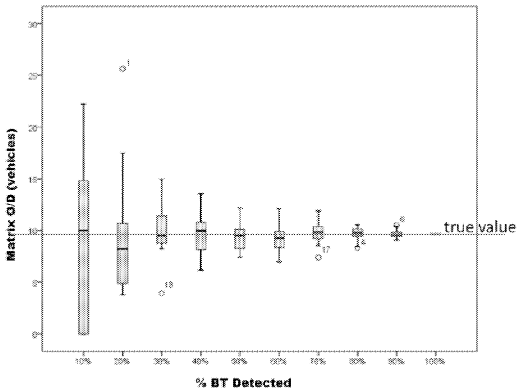

Figure 4: Box Plot pair O/D Santander – Vitoria

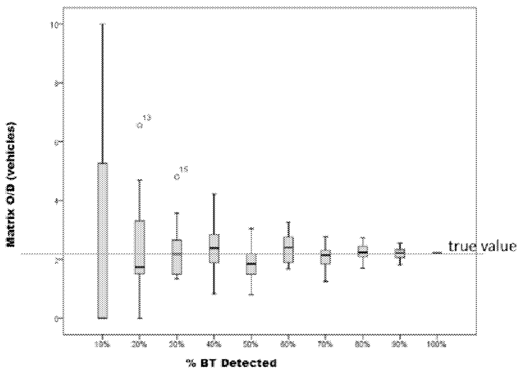

Figure 5: Box Plot pair O/D Santander - San Sebastian by Txorierri

The results demonstrate that for pairs with a medium or high value, the results obtained to the mean can be valid from 20% of detection, where the error of the average is less than 10%. However, when considering pairs with low values, there should be an increase of up to 30% of detection. These results also demonstrate that in order to obtain instant O/D matrices it would be necessary to have detection rates exceeding than 50%.

On the next figures, Figure 6, Figure 7 and Figure 8, we show the coefficient of variation of these samples, it is a standardised measure of dispersion of a probability distribution. This parameter is defined as the ratio of the standard deviation σ to the mean x̄:

$$\mathrm{Cv} = \frac{\sigma}{\bar{x}}$$

, and the standard error of the mean(SEM).

$$\mathrm{SEM} = \frac{\sigma}{\sqrt{N}}$$

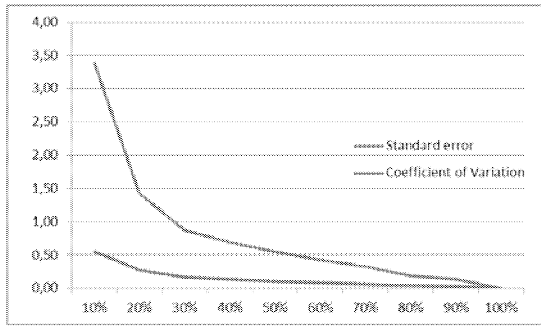

Figure 6: SEM and Cv of the pair O/D Avanzada – Mungia

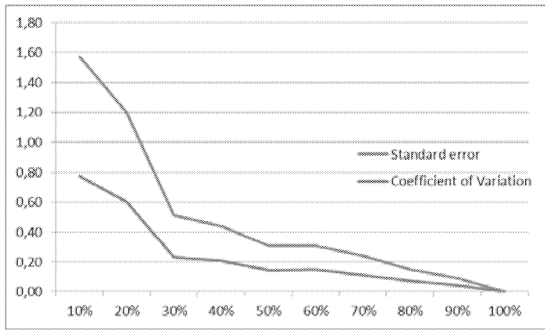

Figure 7: SEM and Cv of the pair O/D Santander – Vitoria

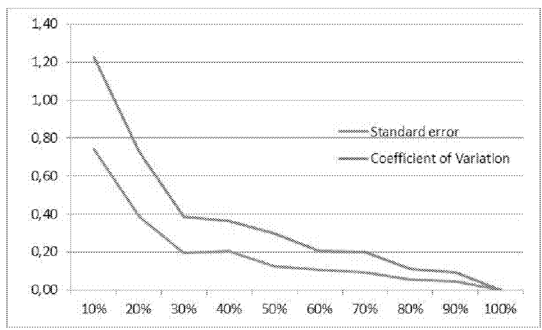

Figure 8: SEM and Cv of the pair O/D Santander – San Sebastian by Txorierri

As shown in the results, for the 30% proposed detection rate, the standard error of the mean is less than 1% and the coefficient of variation is less than 0,3.

CONCLUSIONS

The results demonstrate that the use of BT o WIFI sensors for obtaining dynamics O/D matrices is valid with detection rates higher than 30%. For scenarios in which the distribution between different inputs and outputs were homogeneous, a detection rate of 20% could be considered as valid.

Taking into account that the detection rates are currently between 25% and 38% (CC.com, 2015) and that these rates are expected to carry on increasing in the coming years, we can say that this technology can now be used to obtain O/D matrices.

It has also been shown that the calculation of instantaneous O/D matrices can be associated with a significant error, since the size of the sample could be far too small and the box plot diagrams showed outliers values even with detection rates of 60% and 70%. Therefore, it will be necessary to study in detail the error associated to the instantaneous O/D matrices calculation.

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OBJECTS MOVEMENT PREDICTION FOR SMART ELECTRIC WHEELCHAIR HUMAN AWARE NAVIGATION

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KEYWORDS
Prediction, human-aware navigation, least square fit

ABSTRACT

This paper addresses a problem of navigating a smart electric powered wheelchair using environmental dynamic prediction. The method that allow estimating motion model of objects moving in the wheelchair operational space is presented. The conception of handling the unavailable prediction model uncertainty and inaccuracy is discussed in this study. Exemplary simulations illustrate an adequacy of the method presented..

INTRODUCTION

Technological advancement that can be observed nowadays provides an incentive for robotics development, particularly if we consider the robotics branch which deals with the design and construction of autonomous mobile vehicles. A range of possible applications of robotic mobile devices is very wide, taking military applications on one extreme and homestead applications on the other one. One of the fields the robotics based technologies can be very helpful is medicine. Focusing on the robotics branch which concerns with the design and construction of autonomous vehicles there is a large filed of applications that can improve life quality of persons with mobility impairment By designing and constructing the more and more technologically advanced, comfortable and agile wheelchairs robotics helps people at least partially regain their mobility. Nowadays it is common using by disabled people electric powered manually controlled wheelchairs (EPW) that offers quite new moving quality. The works has been concentrated on both improving the driving system properties (Szafrański and Czyba 2008), controlling the vehicle and determin ing the vehicle spatial orientation (Błachuta et al. 2014). Unfortunately for the people with severe physical or mental disabilities such technological convenience turns out to be insufficient. Therefore there are a lot of researches on wheelchair capabilities improvement by introducing automatic navigation modes (Chung-Hsien 2008; Gao et al. 2012; Oishi et al. 2011). Efficient navigating inside a dynamic workspace is a challenge for autonomous vehicles control systems. Achievement of this task requires proper sensory equipment and algorithms for tracking objects moving in the vehicle surroundings. Sometimes using fast reactive system is enough for agile navigation. In the case of designing navigation strategy for smart EPW frequent changes of control as well as rapid maneuvers are not feasible. The EPW should be navigating with accordance to so called human-aware-navigation rules (Shi et al. 2008, Guzzi et al. 2013, Moussaid et al. 2011). These rules impose some restrictions to the control strategy. In such case good solution is applying environmental state changes prediction in the strategy of control (Skrzypczyk 2009, Gass 2005, Shu-Yun et al. 2011, Shi 2008, Wu 2012). In the fig. 1 an explanation of a prediction based navigation idea is shown. Let us assume a patient driving EPW wants to move in a desired direction. The sensory system of the EPW is able to detect and track the objects (usually persons) moving in its operating space. If the wheelchair is driven by a person, by observing objects' movement, the person can learn objects' behaviour that appear on its way and use this knowledge for more efficient navigation. The same, the navigation system of the EPW is expected to do. The key role in efficient navigation plays environmental changes prediction. This work is the part of research related the smart EPW navigation system creation and deals with the motion problem. Instead of applying the iterative methods of signal filtering the least square method was applied in the approach presented. Such approach allows obtaining relatively long prediction horizon what in turn is a good base for planning a safe, collision-free motion of the EPW.

PROBLEM STATEMENT

Let us assume the EPW is equipped with a sensory system which is able to detect N objects moving in its sensing range and calculate their positions. Moreover the system is provided with a buffer in which information on objects positions collected in M past moments in time can be stored. Assuming it is considered a discrete time system with a sampling period ΔT let us define the set containing objects' observation:

$$P_i = \{p_{i,k}\},\ i = 1,2,..,N, k = \langle n-M, n \rangle \ , \qquad (1)$$

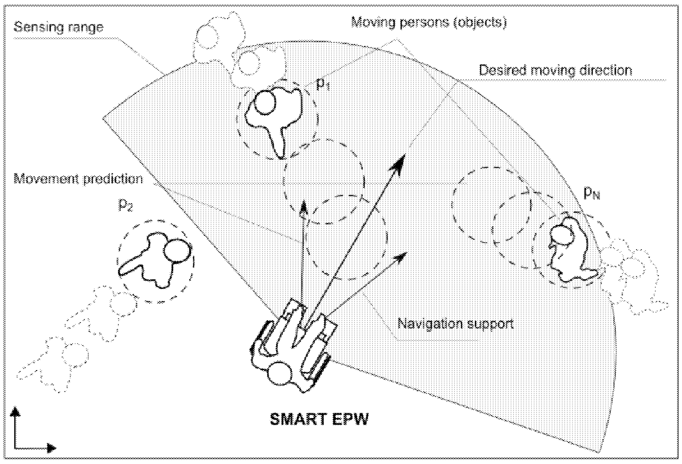

Figure 1: Prediction based navigation in a dynamic environment

where $p_{i,k}$ is a tuple of coordinates $(x_{i,k}, y_{i,k})$ defining location of ith object in kth moment in time. Current moment in time is denoted by n and a number of past observations stored in the buffer is equal to M. Now the prediction problem can be stated as follows: using objects' state observations defined in (1) find an estimation of future states of the objects till the time $H\Delta T$ where H is called the prediction horizon:

$$\hat{P}_i = \{p_{i,h}\}\ i = 1,2,...,N,\ h = n+1, n+2,...,n+H \qquad (2)$$

Motion model

It is assumed that the objects observed by the system move along a curve with constant linear and angular acceleration. In order to describe the object motion model in the discrete moment n the set of motion parameters has to be estimated:

$$\tilde{V}_{i,n} = \{\tilde{v}_{i,n}, \tilde{\omega}_{i,n}, \tilde{\dot{v}}_{i,n}, \tilde{\dot{\omega}}_{i,\mathrm{n}}\} \qquad (3)$$

The estimation (3) is obtained using observations' sequence(1). Hence the goal of the prediction is to estimate the future object's state by applying the motion model (3). So the future state of the object in the time H is determined by:

$$\hat{p}_i(H) = f\left(p_{i,n}, \tilde{V}_{i,n}\right) \ , \qquad (4)$$

where the f denotes an iterative procedure of calculating orientation and position of the object over time assuming the object moves with

PREDICTION METHOD

Preprocessing

None environmental data acquisition method is considered in this study. It is assumed that data captured by sensory system can be uncertain and inaccurate. Regardless of how data were collected and what kind of sensory system was applied – data certainly contain a number of errors and inaccuracies. Therefore a method of filtering the data should be applied. In this study it is made two fold. In the preliminary data processing stage outliers are removed from the input set. In the next stage, appropriate method of dealing with inaccurate prediction (which is the result of uncertain and inaccurate data) while controlling the vehicle is applied.

Removing outliers

Very often while calculating position using range sensory data and active positioning system outliers can appear in the input data set. This is due to inaccuracies and singularity in the measurement system operation. For example, while receiving data from satellites in GPS, the loss of transmission can occur. This results in some data that appears in the input set are not relevant. These data have to be filtered. In this work a vector median filter (VMF) was applied to outliers removing. It is assumed that the set of observations (1) collected by the sensory system is influenced by inaccuracies which should be filtered. After applying the VMF the set containing filtered data, with outliers removed is obtained:

$$\tilde{P}_i = \begin{cases} \tilde{p}_{i,k} = p_{i,k} & \text{for k<h} \wedge \text{k>M-h} \\ \tilde{p}_{i,k} = p_{m_{i,k}} & \text{otherwise} \end{cases} , \qquad (5)$$

where h is a window half-width and $p_{m_{i,k}}$ is a median member calculated according the minimum-distance definition (Yike 2013) :

$$p_{m_{i,k}} = \underset{p_m \in P_i}{\arg\min} \sum_{j=k-h}^{j=k+h} \left\| p_m - p_{i,j} \right\|_{L=2} \qquad (6)$$

Geometrical path fit

The motion model estimation is based on the first and second order differentiating position and heading (orientation). It is assumed the orientation is not measured in the system and is estimated using the current and previous position (fig.2a). In the case data are inaccurate, estimated heading values are subject to large errors. In order to reduce inaccuracies the geometrical model of the object trajectory is computed. Position data included in (5) are replaced by the new ones calculated using the second order polynomial model (fig.2b). Let us define the new set of position data by:

$$\bar{P}_i = \left\{ \bar{p}_{i,n} = \begin{bmatrix} \bar{x}_{i,\mathrm{n}} = f_{i,x}(n, a_{i,0}, a_{i,1}, a_{i,2}) \\ \bar{y}_{i,\mathrm{n}} = f_{i,y}(n, b_{i,0}, b_{i,1}, b_{i,2}) \end{bmatrix} \right\} \qquad (7)$$

$n = n, n-1, ..., n-M,$

where the coefficients of polynomial functions $\{f_{i,x}, f_{i,y}\}$ are calculated using least square fit to the data set (5).
The model obtained estimates the object's movement trend what makes the motion parameters (3) calculated using (7) are closer to their real values.

Motion model estimation

The object position prediction is based on the motion model with assumed constant linear and angular acceleration, which for the *i*th object is defined by (3).

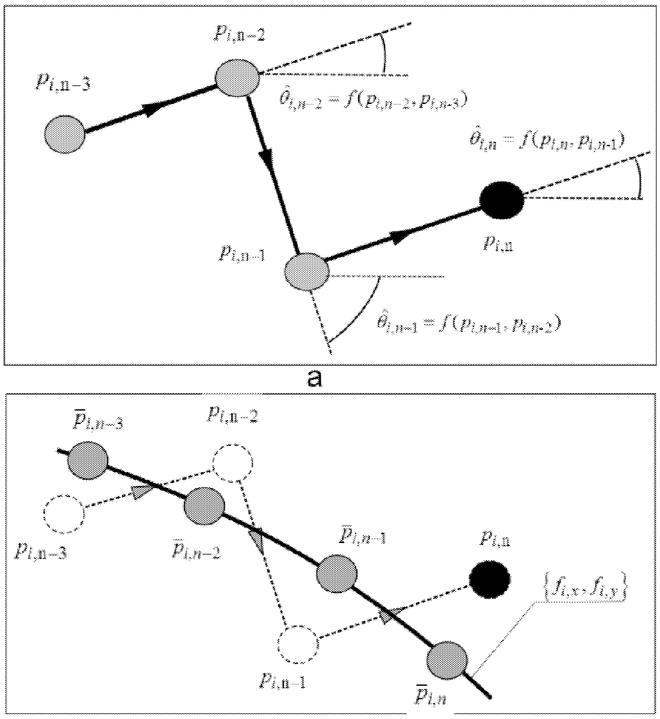

Figure 2: An estimation of object's heading (a) and the object's trajectory model (b)

After preprocessing the data it is possible to find the motion parameters. The linear velocity is found by simple differentiation:

$$v_{i,n} = \frac{\left|\bar{p}_{i,n} - \bar{p}_{i,n-1}\right|}{\Delta T} \qquad (8)$$

Similarly the angular velocity is obtained:

$$\tilde{\omega}_{i,n} = \frac{\tilde{\theta}_{i,n} - \tilde{\theta}_{i-1,n}}{\Delta T} , \qquad (9)$$

where object orientation in the moments n and n-1 are estimated as the functions of the object past positions $\tilde{\theta}_{i,n} = f(\bar{p}_{i,n}, \bar{p}_{i,n-1}), \tilde{\theta}_{i,n-1} = f(\bar{p}_{i,n-1}, \bar{p}_{i,n-2})$. In order to find object accelerations the changes of the velocities over time has to be determined. Let us first transform objects' positions into the distance covered and orientation changes:

$$D_i = \{d_{i,n}, \ldots, d_{n-M-1}\}, d_{i,n} = \left|\bar{p}_{i,n} - \bar{p}_{i,n-1}\right|_{L=2}, \ldots \qquad (10)$$

$$A_i = \{\tilde{\theta}_{n,i} - \tilde{\theta}_{n,i-1}, \tilde{\theta}_{n,i-1} - \tilde{\theta}_{n,i-2}, \ldots, \tilde{\theta}_{n,i-M-2} - \tilde{\theta}_{n,i-M-1}\} \qquad (11)$$

Since it was assumed the accelerations are constant, their values are computed using linear regression method. So the following models are obtained by approximating the data (10) and (11) with the linear function:

$$\bar{d}_{i,n} = \tilde{\dot{v}}_{i,n} n\Delta T + d_{i0} , \qquad (12)$$

where $\tilde{\dot{v}}_{i,n}$ is the linear acceleration estimate calculated using least square fit. Similarly the angular $\tilde{\dot{\omega}}_{i,n}$ acceleration is found:

$$\bar{a}_{i,n} = \tilde{\dot{\omega}}_{i,n} n\Delta T + a_{i0} . \qquad (13)$$

Future state prediction

Using motion parameters (3) calculated according to (8-13) it is possible to simulate the object's motion. Using iterative procedure and equations defining motion, the future object's position can be estimated in the discrete moments *n+1,n+2, …., n+H.* An accuracy of the prediction is strictly related to the parameters' (3) estimation accuracy.

SIMULATION RESULTS

In this section exemplary simulations are presented to illustrate features of the prediction method discussed in this paper. A scenario of the simulations performed is as follows: First, the object's motion is simulated by setting the velocity and acceleration values (3). Next stage of data preparation is introducing random disturbances into the simulated motion path. The figure 3 presents the first experiment. The moving object was tracked by the time equal to 5 sampling periods (measured locations of the object are marked with 'x'). In the moment n=5, the process of prediction is started. Using the procedures described in the previous section the motion model (3) is estimated, and then the future locations of object (marked with '*') for the time n>5 are computed using iterative procedure. The prediction horizon was set to value of 5. The real (simulated without disturbances) motion of the object is drawn by the thin line. It can be noticed that even in the presence of large disturbances short time prediction is accurate. Increasing the prediction range the results are less and less precise. In the next experiment, there was increased the period of tracking the object up to 7. Also the noise value was increased. It can be seen that thanks to increasing number of data the model estimation was better what results in the prediction accuracy improvement. The last example presents the case in which measurements noise had a large value on the level of 70%. As can be seen in the figure 5 even for such a bad quality measurements the object trajectory was estimated properly what results in correct path reconstruction. The experiments briefly discussed in this section are only examples of the prediction method proposed. A large number of simulations performed for many various object's motion scenarios proved a potential of the method discussed. It can reconstruct the properties of the motion even in the case when input data are strongly affected by noise. The possibility of predicting the motion in a relatively long horizon makes easier the EPW motion planning with accordance to the human-aware principles. It must be stressed that the prediction method works only if the motion of observed object is predictable (the object does not change both movement directions and velocity rapidly). In such cases, the prediction horizon should be decreased and the data history taken for prediction should be shortened.

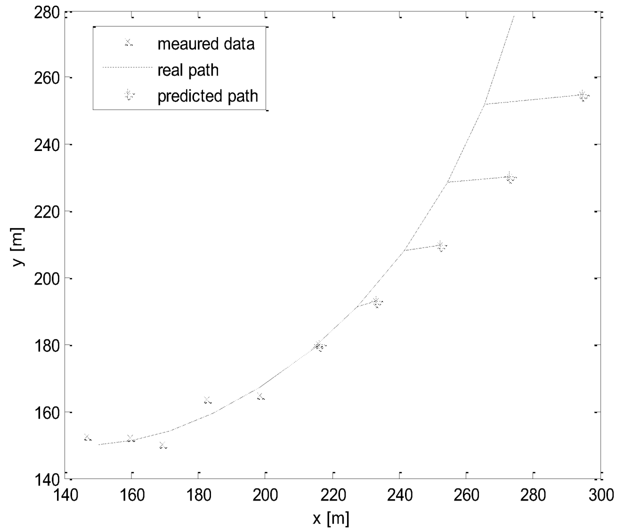

Figure 3: An exemplary motion prediction of an object tracked over 4 past sampling periods, with the prediction horizon 5

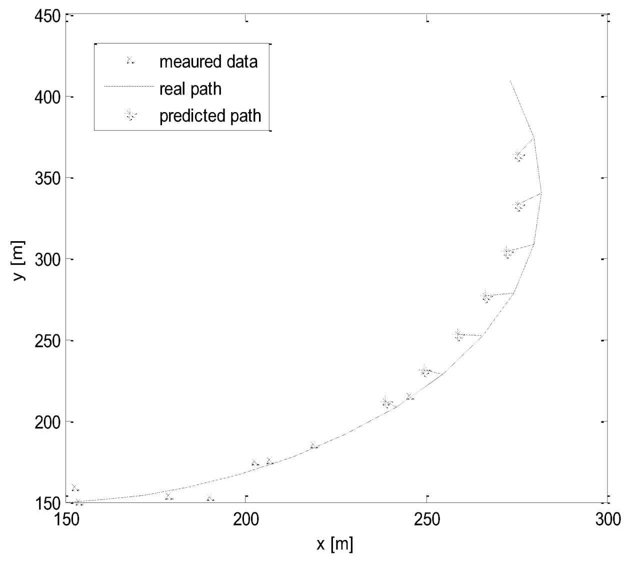

Figure 4: Exemplary motion prediction of an object tracked over 6 past sampling periods, with the prediction horizon 7

CONCLUSIONS

In this paper the method of predicting a motion of moving objects was discussed. Accurate motion prediction is a key issue in a navigation in dynamic environments. The method presented uses the motion model obtained on the basis of object trajectory analysis. The method can be divided into 3 stages: outliers removing and observed trajectory approximation, estimation of the motion parameters and calculating the future object's location using the model estimated in the previous stage. The method of prediction is the part of research focused on creation the human-aware navigation system intended to guide the electric powered wheelchair. The method discussed gives good predictions even for long time horizons and large measurement errors which affect the observed object motion. A large number of simulations performed for various object motion scenarios proved its utility in the context of the application discussed.

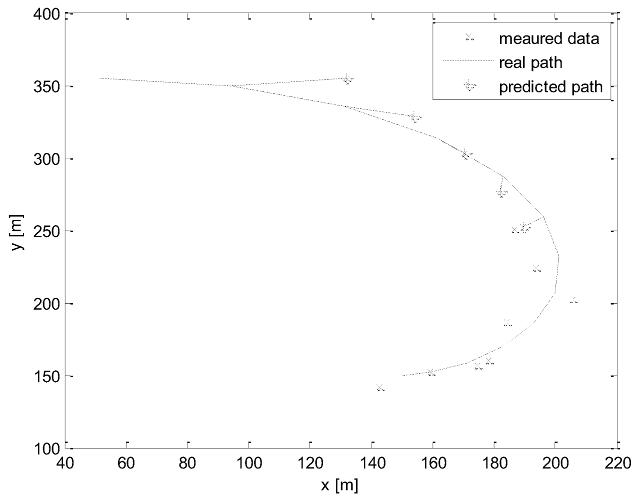

Figure 5: An exemplary motion prediction of an object tracked over 5 past sampling periods, with the prediction horizon 5 in the presence of large measurement noise

Acknowledgements

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BIOGRAPHY

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ELECTRONICS SIMULATION

Analysis of vertical handoff in UMTS network using simulation approach based Opnet

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KEYWORDS
Vertical handoff; UMTS; Mobility; Simulation

ABSTRACT

The procedure by which when a mobile user switches from one network to another is called vertical handover. In this paper, based on a UMTS network we provide and overview of principal types of handover and some simulation results for hard and soft handover using Opnet.

INTRODUCTION

In heterogeneous wireless networks the handover process is divided into two parts: one is the handover decision process and the other is the handover execution process. In the handover decision process both the mobile node and network decide when will be the handover process occur. After the completion of the handover decision process, the handover execution process starts. The handover execution process collects the supplementary network information, such as the address detection time in Mobile IPv6.
The handover process is required when some of the following situations occur.

- The motion of the user equipment (UE) is very fast.
- The UE moves from one cell to another during an ongoing session.
- The UE experiences interference in the link with the current cell.

These are some basic points due to which the network decides that the handover process is required.

PRINCIPAL TYPES OF HANDOVER

Horizontal Handover

Horizontal handover occurs when the mobile station switches from one base station (BS) to another BS within the same technology (e.g., handover between UMTS BSs). The horizontal handover is also called intra-technology handover.

Vertical Handover

Vertical handover means handover between different wireless technologies, such as handover between UMTS and WLAN. It is also called "inter-technologies" handover. In recent years, a lot of research has been done in this field, e.g. on 4G technology based on vertical handover.

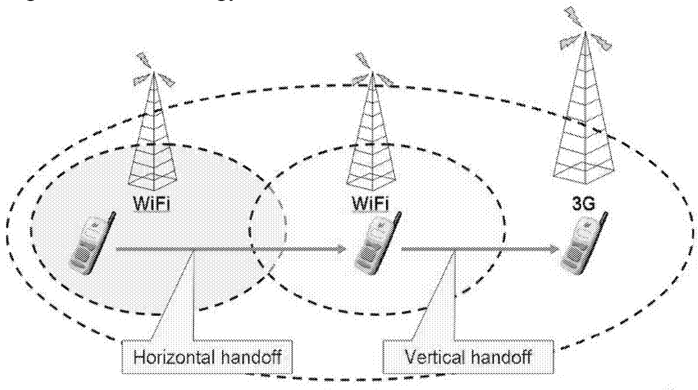

Figure 1. Horizontal and vertival handover.

The vertical handover can be classified into two types: hard and soft handover.

Hard handover
In hard handover, the mobile node has to disconnect first from the current network before connecting to the new network.

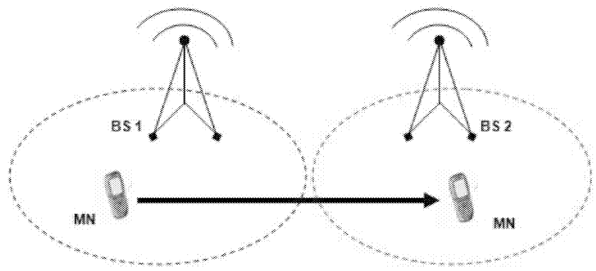

Figure 2. Hard Handover.

Soft Handover
In the case of soft handover , the mobile node can select the new network before the disconnection from the current network. So in soft handover mobile node is connected to two networks at the same time.

[1] The work of this author was supported in part by the Ministry of Economy and Competitiveness of Spain under Grant *TIN2013-47272-C2-1-R*

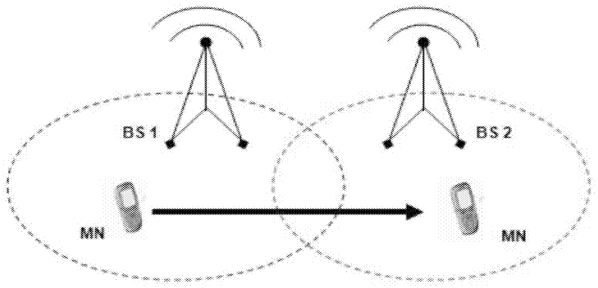

Figure 3. Soft Handover.

SIMULATION OF SOFT AND HARD HANDOVER IN OPNET

For the implementation of our different scenarios we have used the OPNET Modeler 14.5, because of its wide range of possibilities for simulation of wireless networks.
Our work consists in the simulation of two UMTS networks, the first operates with hard handover and the second with soft handover. Each network also includes two mobile users whose mobility has been defined by us. The basic paramerts of the simulations are illustrated in table 1:

Table 1: The parameters of network UMTS

Requirements	Networks UMTS
Duplex Method	FDD
Multiple Access	CDMA
Channel Bandwidth[MHz]	5
Freqency[GHz]	2
Modulation	QPSK/16QAM
DL PHY Peak Data Rate[Mbps]	14.4

The following figure illustrate some of the results that were obtained from our simulation model.

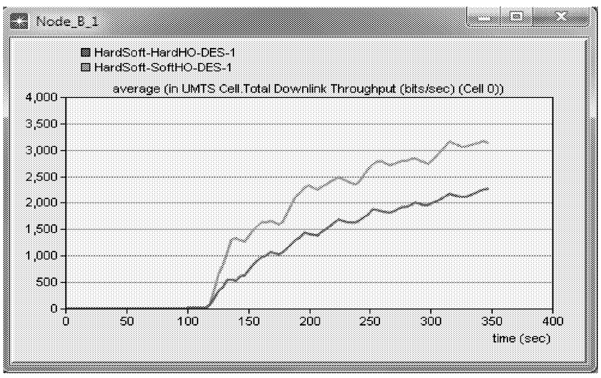

Figure 4. Total downlink throughput.

Figure 4 shows the total downlink throughput, the blue shows the total downlink throughput for hard handover and the red one the total downlink throughput for soft handover. As we move left to right, the total downlink throughput increases in both cases and achieves a maximum value of 3,300 bits/s.

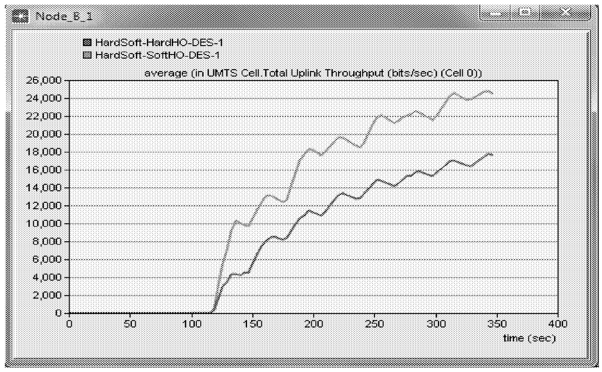

Figure 5. Total uplink throughput.

Figure 5 shows the total uplink throughput of hard and soft handover as a function of time. We can see that the total throughput (both downling and upling) of soft handover is higher than that of hard handover.

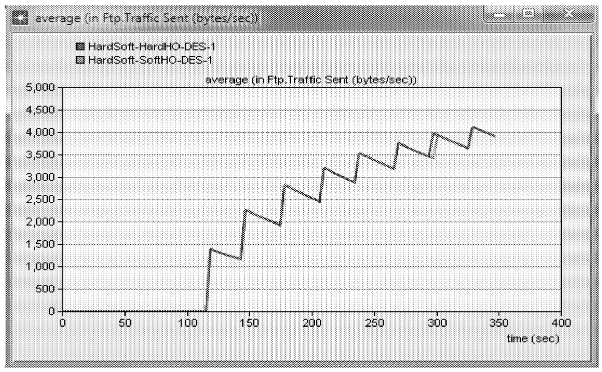

Figure 6. Traffic sent.

Figure 6 shows the traffic sent as a function of time. We can see that the traffic sent in the case of hard handover is maintained between 0 seconds to 130 seconds, after that the curve rises gradually till end of the simulation contrary to soft handover.

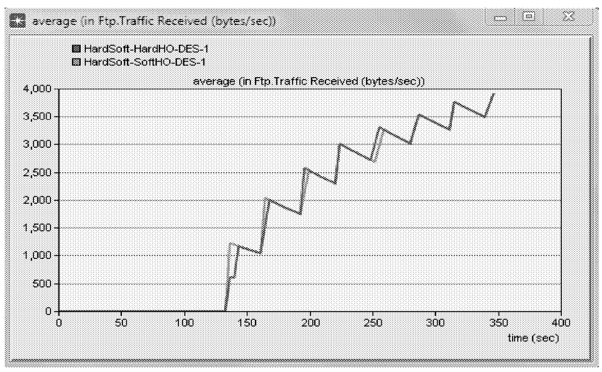

Figure 7. Traffic received.

Figure 7 shows the traffic received for hard and soft handover as a function of time. We can see that the traffic received in the case of hard handover increases and achieves a maximum value of 4,900 bits/s, on the other side the traffic received of soft handover remain in the value of 3,100 bits/s.

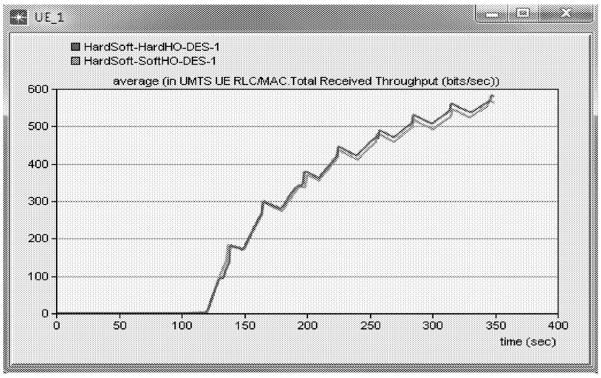

Figure 8. Total received throughput.

Figure 8 shows the total received throughput. The blue curve represent the total received throughput for hard handover and the red one the total received throughput for soft handover. It is clear from the results that there is almost no difference between the total received throughput for hard and soft handover.

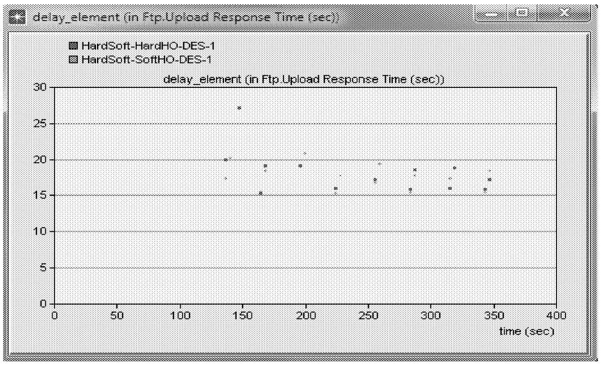

Figure 9. Upload response time.

Besides, from the results shown on Fig.9, we can also conclude that for the soft and the hard handover there is almost no difference between the upload response time. The upload response time represent just the time from sending packet to receiving acknowledgment.

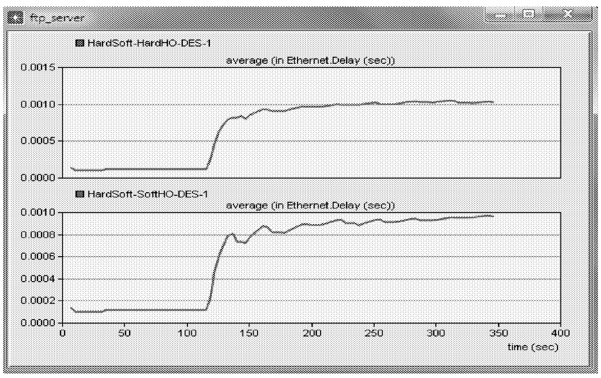

Figure 10. Delay

Figure 10 represent the time needed for a packet to be transmitted from one node to another node in a network. The First graph shows the delay for hard handover and the second graph shows delay for soft handover. We can see that a lower delay is maintained between 5 seconds to 120 seconds, after that the curve rises gradually till end of the simulation.

CONCLUSION

In this paper, we evaluated the performance of hard and soft handover in UMTS network. For both types of handover, we analyzed the traffic sent and received, total received throughput and total downlink throughput, upload response time and delay. The basic conclusion is that, in general, the soft handover shows a better performance than the hard handover. Future work will consider service continuity and assess the energy cost for UMTS/WiMax integration.

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BIOGRAPHY

WAFA BENAATOU is a PhD Student in the third year in telecommunication under the theme "Study and simulation of vertical handovers as UMTS / WiMAX or 802.11b/WiMAX to analyze and compare the performance with the UMTS / 802.11b interconnection model" at the National School of Applied Sciences, University Cadi Ayyad, Marrakech, Morocco. Wafa graduated as master's degree in software quality from Faculty of Sciences -Fes Morocco. Through those experiences, she enhanced her leadership skills, communication and teamwork capabilities, and also she acquired how to manage a team, develop programs and make simulation and to set clear and measurable goals.

ENGINEERING SIMULATION

TUNING AN ELECTROHYDRAULIC ROTARY SERVOMECHANISM BY NUMERICAL SIMULATION AND EXPERIMENT

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KEYWORDS

Numerical simulations, electrohydraulic rotary servomechanism, experimental fine-tuning

ABSTRACT

The stability and the performance test of any servo system with mechanical input like automotive steering systems, lifting equipment, navy rudder, radar antenna etc. needs a rotary servomotor with a fair static and dynamic behavior. The modern testing system are using both electromechanical and electrohydraulic servomotors controlled by different type of real time computers. This paper presents the strategy of finding a good control algorithm for the electro hydraulic rotary servomotors by numerical simulation. The authors built an electrohydraulic servomechanism in order to test the dynamic behavior of the steering system of an articulated forestry tractor, hydraulically driven by radial piston motors inserted in the wheels. SIMULINK was used in order to point out the utility of the numerical simulation in any industrial design process.

INTRODUCTION

The static and dynamic performance of any steering system with mechanical input has to be found with maximum accuracy, in close connection with the real operating conditions. In the framework of a long series of researches aimed at introducing an electrohydraulic remote steering system in parallel with a hydro mechanical one on an articulated steering tractor (Irimia 2014), a rotary electrohydraulic servomechanism was designed and tested (fig. 1). The option for the electrohydraulic solution was chosen in order to test the behavior of the steering system when the oil supply system fails from different causes. This test requires a much bigger torque, which cannot be supplied by common rotary stepping motors. Rotary brush motor servo actuators utilize brush-type DC motors using both Alnico and rare earth magnets. These units have been designed with separate or imbedded analog or digital amplifiers, spur gearing and potentiometers as feedback devices (MOOG 2015). Typical applications include unmanned vehicles, remotely operated vehicles, and light ground vehicles. Communication interfaces including analog, RS232 / 422 / 485, R/C PWM and CAN Bus. Unhappily, for very high-test torques these devices are very expensive. In these cases, the hydraulic version is more suitable. This paper is devoted to the mathematical modeling and numerical simulation of the rotary servo system dynamics by the aid of SIMULINK in order to point out their benefits and the drawbacks. Figures 1…7 define the test bench of the servomechanism.

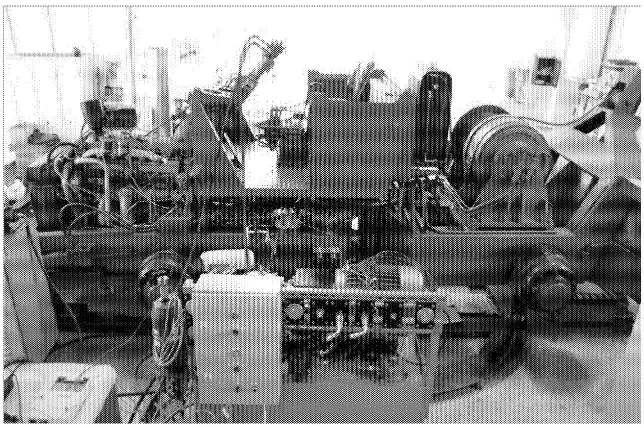

Figure 1: Hydrostatic ASV with remote steering system

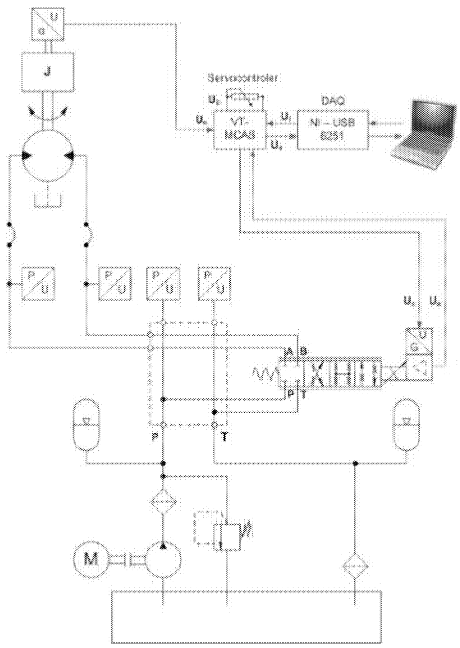

Figure 2: Hydraulic diagram of the rotary servomechanism used for controlling steering system

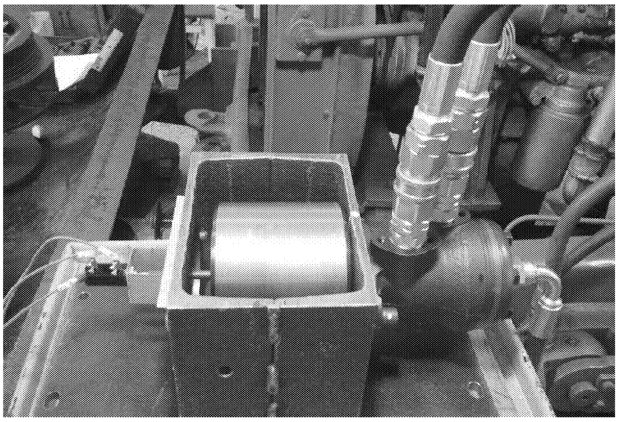

Figure 3: Low speed hydraulic motor OMR 50 with "fly-wheel" and angle feedback transducer

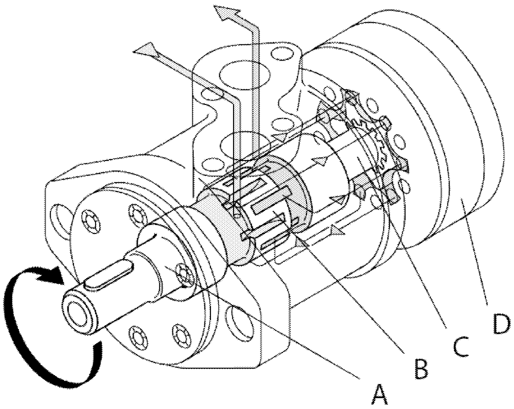

Figure 4: Low speed orbital motor (DANFOSS): A-output shaft; B-rotary spool valve; C-cardan shaft; D - gearwheel set.

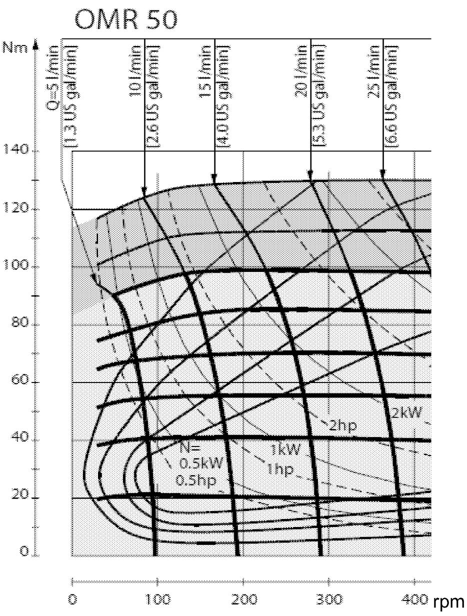

Figure 5: Universal characteristics of OMR 50 Orbit motor

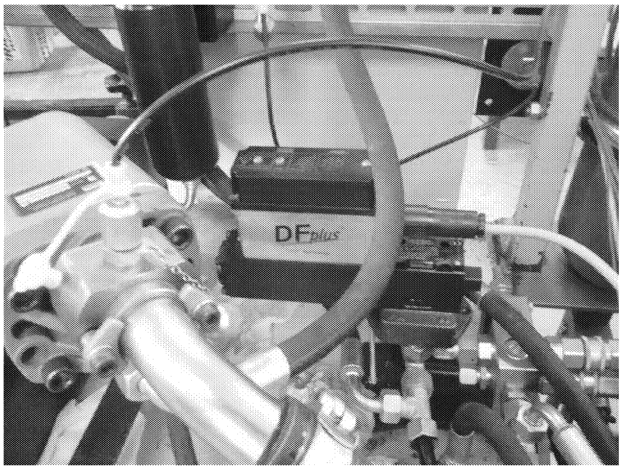

Figure 6: Electrohydraulic control panel with high speed industrial servovalve DFplus (PARKER)

Figure 7: The use of the rotary servomechanism as input device for an articulated steering tractor

MATHEMATICAL MODELING

For small amplitude output signals and small inertia rotary load, one can use a linear mathematical model including the following equations.

a) Hydraulic motor.

Under the above conditions, the classical transfer function [1…4] can be used:

$$H_m(s) = \frac{\theta(s)}{x(s)} = \frac{K_m}{s\left(\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n}s + 1\right)} \tag{1}$$

Here θ represents the motor shaft rotation angle regarding an arbitrary origin ; x – servovalve spool displacement ; ω_n – natural angular speed ; ζ – dumping factor,

$$K_m = \frac{K_{Qx}}{D_m} \tag{2}$$

represents the speed gain of the motor, depending on the displacement D_m and the servovalve flow gain, K_{Qx}. The hydraulic undamped natural frequency,

$$\omega_h = \sqrt{\frac{2\varepsilon_e D_m^2}{V_0 \cdot J}} \qquad (3)$$

depends on the ε_e - the equivalent fluid bulk compressibility modulus, V_0 – the overall oil volume from the motor, and J - the inertia module of the motor. The overall hydraulic dumping ratio of the hydraulic power system can be estimated by the relation

$$\zeta = \frac{K_{lm}}{D_m} \cdot \sqrt{\frac{\varepsilon_e \cdot J}{V_t}} + \frac{f}{4D_m} \cdot \sqrt{\frac{V_t}{J \cdot \varepsilon_e}} \qquad (4)$$

The natural frequency variation with the load is relatively small, but the dumping factor has a strong variation according the operation regime. According the classical research (Merritt 1967), the nominal values of the main variables involved in the motor dynamics are the following: $K_m = 1.15 \cdot 10^5$ rad/m^3, $\omega_n = 100$ rad/s, and $\zeta = 0{,}223$.

b) Servovalve model.

In practical computations for industrial applications, the dynamics of a DDV (Direct Drive Servovalve) spool can be regarded as a first order lag with a time constant T_{SV} of about 4…10ms, for a constant pressure supply of about 14…21MPa (Parker 2014, Mihalescu 2014).

$$H_A(s) = \frac{Q_m(s)}{U(s)} = \frac{K_{SV}}{s \cdot T_{SV} + 1} \qquad (5)$$

For a typical nominal flow of Q_{sv} = 40…60 l/min, the average slope of the servo valve steady state characteristics in the null region is about $K_{SV} = 0.66 \ldots 1.00 \cdot 10^{-4}$ m^3/s/V. The real slope of the servovalve DFplus around the null point (fig. 8) is a little greater than the overall one: about 1.16 m3/s/V (Vasiliu 2012).

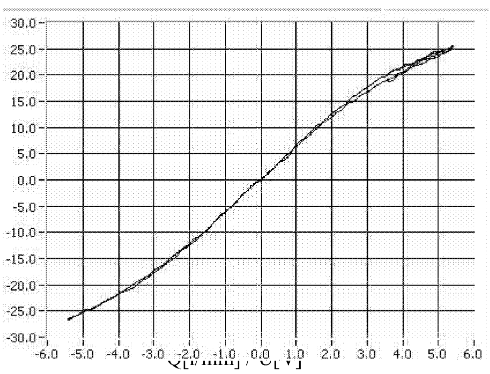

Figure 8: Experimental steady-state characteristics of DFplus DDV

The experimental dynamic behavior of the same DDV (fig. 9) is very good: F (-3dB) = 250Hz (Vasiliu D. 2012).

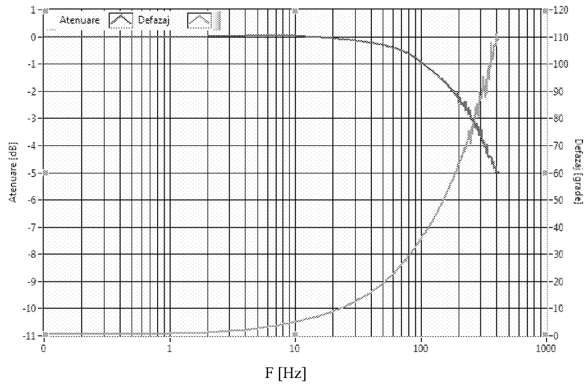

Figure 9: Frequency response of the DFplus DDV

NUMERICAL SIMULATIONS

The above mathematical model was integrated by SIMULINK-MATLAB using the "compressed" network presented in the Figure 10.

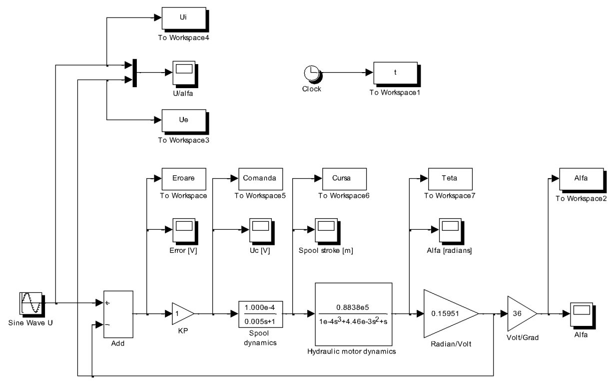

Figure 10: Simulation network of the servomotor dynamics for a sine input

The figures 11…16 present the variation of the main servomotor performance for a sine input signal of 0.125…1.0Hz and p_s=140…210MPa.

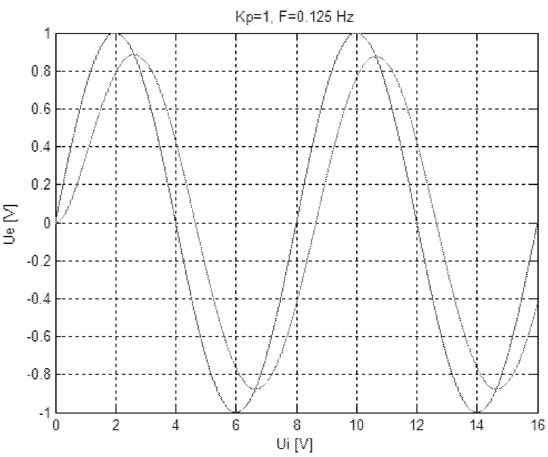

Figure 11: The simulated servomechanism response for a sine input signal with K_P=1 and f=0.125 Hz

The most significant parameter of the mathematical model is the error gain, K_P. It was tested step by step, in order to facilitate the wide use of this type of servomotor in practical applications. A very small steering wheel revolution, used by a driver during a precise turn, can be performed with a small error gain (fig. 1). The static characteristics (fig.12) has a small hysteresis.

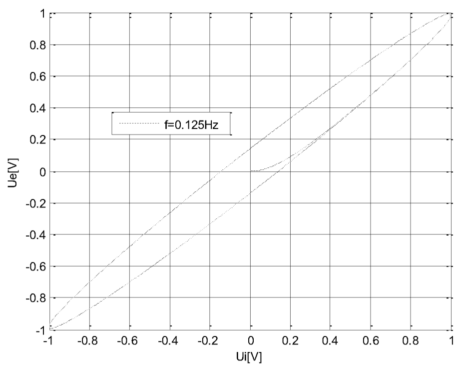

Figure 12: The simulated servomechanism characteristics for a sine input signal with K_P=1 and f=0.125 Hz (1/8 rev/s)

Higher speeds of the steering wheel need the increase of the error gain (figs. 13 and 14).

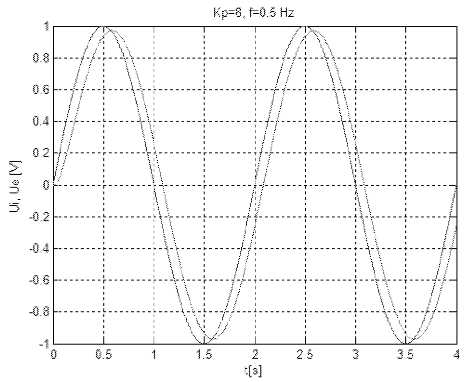

Figure 13: The simulated servomechanism response for a sine input signal with K_P=8 and f=0.5 Hz

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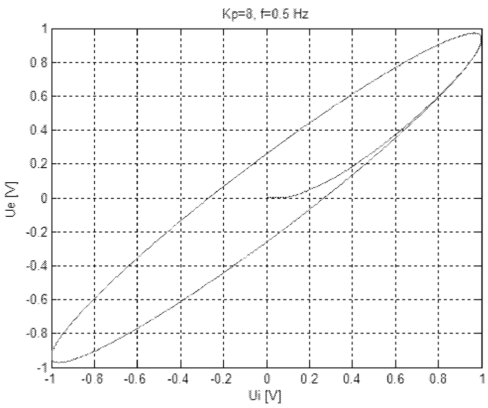

Figure 14: The simulated characteristics for a sine input signal with K_P=8 and f=0.5Hz

The highest steering wheel speed accepted by the tractor strucure is about 1rev/s. Even in that case, the turning accuracy of the hydraulic motor shaft is good enough for a forestry tractor working in harsh ground conditions.

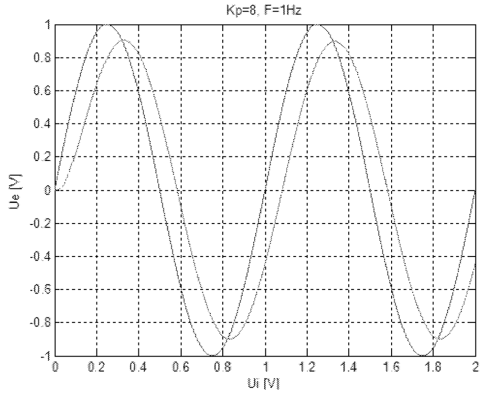

Figure 15: The simulated servomechanism response for a sine input signal with K_P=8 and f=1 Hz

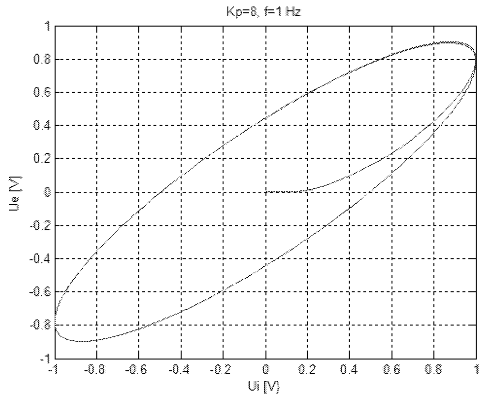

Figure 16: The simulated characteristics for a sine input signal with K_P=8 and f=1.0Hz

EXPERIMENTAL RESULTS

The simulations performed using SIMULINK have shown a good enough dynamics for the considered application. The theoretical results are found in good agreement with the theoretical ones (figs. 18 and 19) if we consider the volumetric efficiency of the hydraulic motor. For very small angular speed, this component of the overall efficiency is about 90%.

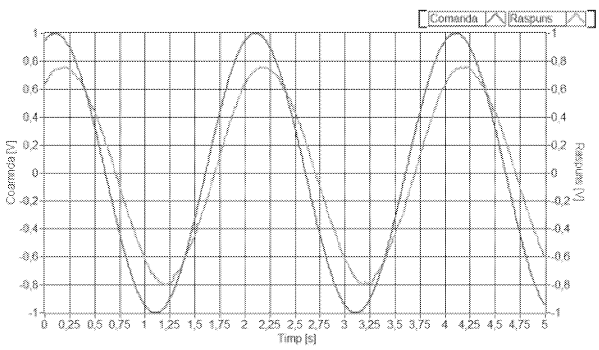

Figure 18: The real servomechanism response for a sine input signal of 0.5 Hz

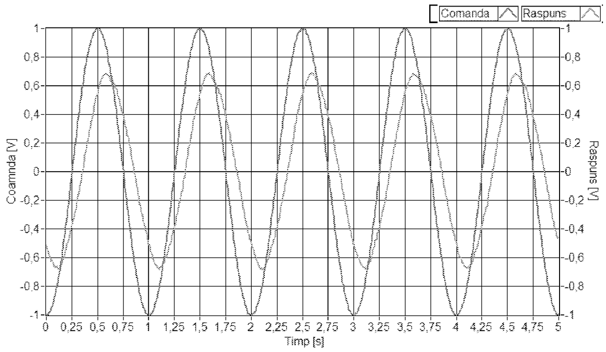

Figure 17: The servomechanism response for a sine input signal of 1Hz

CONCLUSIONS

The numerical results supplied by the numerical simulations can be very useful in the preliminary phase of the design of any control system. The simple case considered by the authors was completed by the dynamic study of the entire new electrohydraulic steering system (Irimia 2014). The overall results were competed by the integration of the new steering system in a modern autonomous system with GPS feedback. Because of the system complexity, the numerical simulations were performed by LMS Imagine. Lab Amesim language (LMS INTERNATIONAL 2014).

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AN APPROACH OF STATIC MODELLING OF SEWAGE NETWORKS BASED ON THE HYDRAULIC FORMULAS

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Mathematical modelling of sewage networks, hydraulic parameters of network canals.

ABSTRACT
The hydraulic calculations are carried out using nomograms, which are the charts connecting diameters, flow rates, hydraulic slopes and average flow velocities. In traditional planning of sewage networks the appropriate hydraulic values are read from the nomogram chart tables. In the paper another way of executing of hydraulic calculations is presented. The numerical solutions of nonlinear equations describing the phenomena of sewage flows are used. The presented method enables the quick analysis of sewage net parameters and opens the possibility of sewage network computer simulation. Basing on this method two algorithms to analyse and planning communal sewage networks have been presented.

INTRODUCTION

Modelling and planning of municipal sewage networks is a complex task because of the complexity of the equations describing the sewage flows in the canals. The basic hydraulic parameters describing a sewage net are sewage flows and sewage filling heights in the canals that result from the canal diameters and canal slopes. The standard approach of planning the sewage nets consists in using the nomogramms which are the diagrams showing the relations between canal diameters, sewage flows, canal hydraulic slopes and flow velocities. The values of these variables are picked off from the diagrams that are results of the former calculation of the standard hydraulic formulas for computing the sewage network canals which are Chezy, Colebrooke-White and Manning formulas [1], [3], [4]. A more advanced approach of planning the sewage networks bases on the use of professional programs for calculating the network hydraulic models like SWMM5 developed by EPA (*US Environmental Protection Agency*) [7] what requires a rather high knowledge in informatics from the program users. The first approach with the diagrams is mechanical and the second one is very complicated.

In the paper an indirect approach to calculate the hydraulic parameters of sewage networks is presented and it consists in relative simple numerical solution of the nonlinear equations resulted from the basic hydraulic rules and formulas. The method applied in the algorithm proposed for modelling and planning the sewage networks enables to analyse fast the network parameters what makes it similar to the nomogramms approach and on the other side it enables to understand easy the mutual relations between the different hydraulic parameters of the network canals what makes it similar to the approach using the complex hydraulic models.

The results received by means of the approach proposed have been compared with the results obtained with professional software MOSKAN [11] that is based on the hydraulic model SWMM [13] similar to MIKE URBAN software distributed by DHI [14]. MOSKAN software has been developed at the Systems Research Institute and successfully tested in a waterworks in Poland. The parameter values of the sewage net calculated while using both tools are practically the same what means that our indirect approach proposed is not less exact and simpler and faster than professional MOSKAN and it is exacter and more handy than the classical approach.

BASIC PROBLEMS

For the considered algorithms of wastewater networks calculation the following basic assumptions are made: ● only housekeeping or combined sewage nets are considered, divided into branches and segments by nodes, ● the nodes are the points of connection of several network segments or branches or the points of changing of network parameters as well as of location of sewage inflows to the network (sink basins, rain inlets, connecting basins). In the connecting nodes the flow balance equations and the condition of levels consistence are satisfied, ● it is assumed that the segments parameters such as shape, canal dimension, bottom slope or roughness are constant. Because of these assumptions all relations concern the steady state problem, ● the nets considered are of gravitational type. Designing and analysis of sewage networks are connected with the following tasks:

1. Making hydraulic analysis of the network for known section crosses and for known canal slopes. In this case the calculation of filling heights of the canals as well as the calculation of flow velocities depending on the sewage flow rates must be done. These calculations are done for the respective net segments using the earlier received flow values. The method presented consists in numerical solution of nonlinear equations describing the basic relations in a network. These equations are resulted from the standard hydraulic rules and formulas. The method applied in the calculation algorithm enables to analyse fast the network parameters, i.e. the canal fillings and flow velocities, and it makes possible to simulate the sewage network in a very simple way. By changing the sewage inflows in the selected network nodes one can get immediately and easy new filling values and sewage flows in the canals connected with the related nodes.
2. The network planning means the situation when to existing sewage net some new canals have to be attached or when the operated network must be reconstructed because in some of its canals the sewage fillings are too high and there is a threat of sewage outlet. The latter problem is then to solve by the calculation of new canal diameters or slopes for the related canals. There is assumed that the forecasted sewage inflows into the network are known.

Basing on the network description and the actions formulated above an algorithm to model sewage nets by means of classical algebraic hydraulic formulas is proposed in the following.

ALGORITHMS OF CALCULATION OF WASTEWATER NETWORKS

The algorithm of wastewater networks modelling

The algorithm presented below is used for analysis of work of sewage net. The algorithm requires the following data for its calculation:

♦ type of the network– housekeeping sewage net or combined sewage net

♦ structure of the network – i.e. number of nodes NW, number of segments N, set of nodes $W=\{j=1,\ldots., NW\}$, set of segments $U=\{i=1,\ldots., N\}$

♦ maximal sewage inflow q_i into the network and the corresponding input node number

♦ set of diameters $\{d_i\}$, set of slopes for segments J_i, $i=1,\ldots, N$, roughness coefficients n_i

The task of the algorithm is to determine the following values (for given values of rate inflows):
● filling heights in each wastewater network segment, ● flow velocity for each network segment.

The calculation scheme presented below is for the canals with circular section. The most important part of algorithm is the calculation of the filling heights H_i (or canal filling degree $x=H_i/d_i$) and the flow velocities v_i for each wastewater network segment (for given values of rate inflows q_i in particular sewage net nodes). Now the problem is to solve the nonlinear algebraic equations which are derived from the basic relations and hydraulic formulas.

1. From the Manning formula and taking into account the canal geometry one can obtain the equations describing the dependance between the canal filling $x=H/d$ and the sewage flow Q. The equations are in the form [1, 2, 3]:

From the balance equations result for the i-th network segment the following formulas:

$$Q = q_i + \sum_{j<i} Q_j \qquad (1)$$

For $x \le 0,5$ $\quad \beta \cdot F_1(x) - Q = 0 \qquad$ (2a)

$$F_1(x) = \frac{(\varphi_1(x) - \sin(\varphi_1(x)))^{\frac{5}{3}}}{\varphi_1(x)^{\frac{2}{3}}} \qquad (2b)$$

$$\varphi_1(x) = 2 \cdot \arccos(1 - 2 \cdot x) \qquad (2c)$$

For $x > 0,5$ $\quad \beta \cdot F_2(x) - Q = 0 \qquad$ (3a)

$$F_2(x) = 2 \cdot \frac{(\pi - 0,5 \cdot \varphi_2(x) + 0,5 \cdot \sin(\varphi_2(x)))^{\frac{5}{3}}}{(\pi - 0,5 \cdot \varphi_2(x))^{\frac{2}{3}}} \qquad (3b)$$

$$\varphi_2(x) = 2 \cdot \arccos(2 \cdot x - 1) \qquad (3c)$$

$$\beta = 0,5 \cdot \frac{1}{n} \cdot (d)^{\frac{8}{3}} \cdot \left(\frac{1}{4}\right)^{\frac{5}{3}} \cdot J^{\frac{1}{2}} \qquad (4)$$

where: H – filling height, φ – central angle, d – inside canal diameter, J – canal slope, n – roughness coefficient, Q –inflow rate, H/d - canal filling degree.

The β parameter in (4) depends on canal diameter d and on canal slope J and for the fixed diameter values and canal slopes it is constant. Solving equations (2a–3b) we obtain canal filling degree H/d as a function of flow rate Q. Equations (2a–3b) for calculating the canal filling degree are nonlinear and the standard numerical methods for solving nonlinear algebraic equations can be here applied. For fixed network parameters like canal diameter d and canal slope J, equation $\beta\cdot F(x)–Q=0$ has solutions depending on sewage flow Q. Equation $\beta\cdot F(x)–Q=0$ has the following roots:

a. For $x\in(0; 0.5>$ there is only one root and the following inequality must be fulfilled: $0< Q \le \pi\cdot\beta$. This inequality defines a values range for sewage flows Q for fixed canal diameters d and canal slopes J.

b. For $x\in(0.5; 1>$ equation $\beta\cdot F(x)–Q=0$ has the following roots:
♦ one root for $x\in(0.5; 1)$ and $\pi\cdot\beta < Q < 2\pi\cdot\beta$; ♦ two roots for $x\in(0.5; 1>$ and $2\pi\cdot\beta \le Q < \beta\cdot 6.7586936$, whereas for $Q=2\pi\cdot\beta$ there are $x_1=1$ and $x_2=0.81963$.

For the fixed network parameters such as a canal diameter d and canal slope J the above relations let to decide what are the solutions for the given flow Q and whether the value of Q is not greater than the upper limit $\beta\cdot 6.7586936$, what means the lack of solutions. In such the case a change of one or of both of the fixed network parameters d and J must be considered. The result of the above relations is that the flow value Q depends on the parameter β. In Fig.1 the relation between the solution of equation $\beta\cdot F(x)–Q=0$ and flow Q for $n=0.013$ and $0<Q<2\pi\cdot\beta$ for different values d and $J=1/d$ are designed.

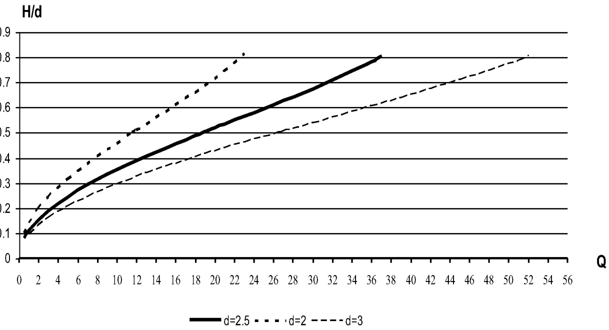

Figure 1. Relation between the solution of $\beta\cdot F(x)–Q=0$ and flow Q for different d.

2. For canal filling degree H/d calculated above the hydraulic radius R should be determined according to the formula:

For $x\le 0,5$:

$$R = \frac{1}{4} d \left(1 - \frac{\sin\varphi}{\varphi}\right) \qquad (5a)$$

$$\varphi(x) = 2 \cdot \arccos\left(1 - 2 \cdot \frac{H}{d}\right) \qquad (5b)$$

For $x>0,5$:

$$R = \frac{\pi d - 0,5 \cdot d \cdot \varphi + 0,5 \cdot d \cdot \sin(\varphi)}{4 \cdot (\pi - 0,5 \cdot \varphi)} \qquad (3b) \quad (6a)$$

$$\varphi(x) = 2 \cdot \arccos\left(2 \cdot \frac{H}{d} - 1\right) \qquad (6b)$$

3. The flow velocity should be calculated from:

$$v = \frac{1}{n} R^{\frac{2}{3}} \cdot J^{\frac{1}{2}} \qquad (7)$$

Knowing the network geometry, i.e. slopes, shapes and diameters of canals as well as the wastewater inflows Q_i, one can calculate filling heights and flow velocities for each network canal. The calculations are carried out for each network segment beginning from the farthest one and going step by step to the nearest segment regarding the wastewater treatment plant. The algorithm scheme is shown in Fig. 2.

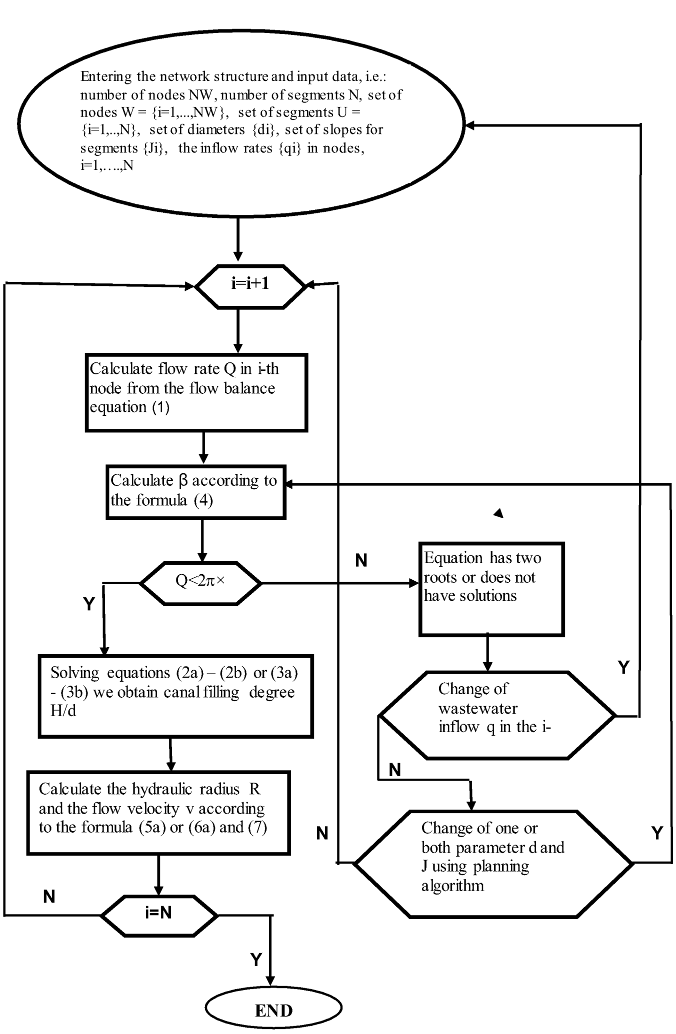

Figure 2. Scheme of the algorithm for calculation of canal filling degree and of flow velocity.

The planning algorithm for given flow values Q

The conclusion is that the value of flow Q depends on the parameter β which depends on the canal diameter d and on the bottom slope J. The equation describing the dependence of the filling degree from the flow has one solution in the interval $(0; 2\pi\cdot\beta)$ and this is the cause that this interval is relevant. The calculation procedure shown below concerns the following cases: • flow Q exceeds the upper boundary of values domain for $\beta\cdot6.7586936$; then a change of values for given canal diameters d and slopes J has to be considered; • new segments must be added to the existing network; then the diameters and slopes must be defined for the new canals under the assumption that the sewage inflows Q into the canals have been forecasted and they are known. In both cases while calculating diameters and slopes for the new canals for given flows Q the inequality $2\pi\cdot\beta - Q>0$ has to be considered. The fulfilling of the inequality guarantees the existence of only 1 solution of the equation describing the dependence the filling degree x from the canal flow Q. The calculation procedure consists of the following steps which are realized for the forecasted and fixed flow values Q:

Step 1. Determination of canal slope value J. The value can be determined according to the existing technical standards or calculated regarding the relations for minimal slopes which are known from literature [4, 5, 6, 12].

Step 2. Solution of the following equation:

$$\frac{\pi}{n}\cdot\left(\frac{1}{4}\right)^{\frac{5}{3}}\cdot J^{\frac{1}{2}}\cdot d^{\frac{8}{3}} - Q = 0 \tag{8}$$

a) For $J = \frac{a}{d}$:

$$\frac{\pi}{n}\cdot\left(\frac{1}{4}\right)^{\frac{5}{3}}\cdot a^{\frac{1}{2}}\cdot d^{\frac{13}{6}} - Q = 0 \tag{9a}$$

b) For J ensuring canal self-purification:

$$\frac{2\pi}{n}\cdot\left(\frac{1}{4}\right)^{\frac{5}{3}}\cdot\left(\frac{\tau_{\min}}{1,1106\cdot\rho}\right)^{\frac{1}{2}}\cdot d^{\frac{13}{6}} - Q = 0 \tag{9b}$$

c) For the limiting slope J:

$$\frac{\pi}{n}\cdot\left(\frac{1}{4}\right)^{\frac{5}{3}}\cdot\left(3,778\cdot10^{-3}\right)^{\frac{1}{2}}\cdot d^{\frac{5}{2}} - Q = 0 \tag{9c}$$

If a solution d_* of equation (8) exists then inequality $\varsigma\cdot d^{\frac{8}{3}} - Q > 0$ is valid for all values $d > d_*$. Now an appropriate method to calculate the canal slope J must be selected and depending on this method the diameter is to determine by the solution of equations (9a) or (9b) or (9c). Then a value d greater than will be taken into account and one shall pass to **Step 1** and the canal slope must be calculated again. If a solution of equation (8) does not exists then one shall return to **Step 1**, change value J and solve once again equation (8).

MODELLING AND PLANNING OF AN EXEMPLARY WATEWATER NETWORK

The algorithms presented for modellinsg and planning the sewage networks have been tested on an exemplary housekeeping network consisting in general of 27 nodes connected by 26 segments (Fig. 3). The net consits of 15 input nodes (W_6, W_7, W_8, W_{10}, W_{11}, W_{14}, W_{15}, W_{16}, W_{19}, W_{20}, W_{21}, W_{23} , W_{25}, W_{26}, W_{27}) and of 1 output node W_1. Other nodes constitute the connections between different segments of the network. The arrows in Fig. 3 show the sewage flow direction.

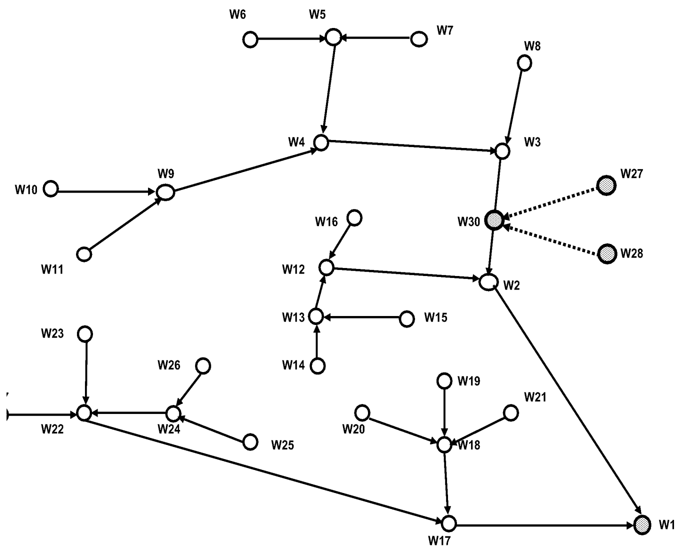

Figure 3. Structure of the sewage net investigated.

The sewage flow rates values for the input nodes are given. The flow rates in the connection nodes should be calculated according to the balance equation. For the respective segments the diameters d=0,2 and the canal slopes J=0,5‰ are given. For such a structure of the net the fillings H/d and the velocities of flows v in respective segments are calculated.

Table 1. The results of hydraulic computations for the exemplary net shown in Fig. 3.

Upper node	Lower node	Segment	input flows in node	flows in segments *Q* [dm3/s]
W6	W5	1	0,56	0,56
W7	W5	2	0,31	0,31
W5	W4	3	0,27	1,14
W10	W9	4	0,36	0,36
W11	W9	5	1,13	1,13
W9	W4	6	0,64	2,13
W4	W3	7	0,64	3,91
W8	W3	8	0,11	0,11
W3	W2	9	0,1	4,12
W14	W13	10	0,11	0,11
W15	W13	11	0,32	0,32
W13	W12	12	0,23	0,66
W16	W12	13	0,24	0,24
W12	W2	14	1,86	2,76
W2	W1	15	0,73	7,61
W23	W22	16	0,56	0,56
W27	W22	17	0,4	0,4
W25	W24	18	0,81	0,81
W26	W24	19	0,83	0,83
W24	W22	20	0,09	1,73
W22	W17	21	1,53	4,22
W19	W18	22	0,83	0,83
W20	W18	23	0,3	0,3
W21	W18	24	0,19	0,19
W18	W17	25	0,22	1,54
W17	W1	26	0,57	6,33
W1	Sewage plant			13,94

Segment	*H/d* [%]	*v* [m/s]	*H/d* [%] MOSKAN	*v* [m/s] MOSKAN
1	10,72	0,309	11	0,29
2	8,09	0,259	8	0,26
3	15,08	0,383	15	0,38
4	8,69	0,271	9	0,27
5	15,02	0,382	14,6	0,39
6	20,48	0,460	20	0,46
7	27,78	0,549	28	0,55
8	4,98	0,189	5	0,19
9	28,53	0,557	29	0,56
10	4,98	0,189	5	0,19
11	8,22	0,261	8	0,26
12	11,59	0,325	12	0,33
13	7,17	0,240	7	0,24
14	23,29	0,497	23	0,49
15	39,42	0,661	39	0,66
16	10,72	0,309	11	0,29
17	9,13	0,280	9	0,27
18	12,79	0,346	13	0,36
19	12,94	0,348	13	0,38
20	18,48	0,433	18	0,43
21	28,89	0,561	29	0,56
22	12,94	0,348	12	0,38
23	7,97	0,256	7	0,26
24	6,42	0,223	6	0,22
25	17,46	0,419	18	0,49
26	35,70	0,629	36	0,63

The network investigated was also calculated by means of MOSKAN system worked out in IBS PAN [9]. This system is based on hydraulic model SWMM5 developed by EPA [13]. The results obtained from the modelling run are presented in Table 1. These results won with our algorithm are comparable with the results that have been reached by means of the ICT system MOSKAN and the insignificant differences result from the values rounding which is used in MOSKAN.

The conclusion is that for these values of sewage rate flows and for the given values of geometric parameters (diameters and canal slopes), the heights of filling are lower than the half of canal diameters. So there is a possibility of increasing of the input flows in some sewage nodes.

Planning of the network parameters, i.e. of canal diameters *d* and of canal slopes *J*, has been realized for 2 computing cases.

The first case concerns the situation when the sewage inflows in 5 network nodes W_{23}, W_{25}, W_{26}, W_{24}, W_{27} have been raised. This increase resulted in raising of the canal fillings in the network canals connected with the related nodes what shows Table 2.

Table 2. Calculation results for the network with sewage inflows changed.

Upper node	Lower node	Segment	input flows in node	flows in segments *Q* [dm3/s]
W23	W22	16	4,56	4,56
W27	W22	17	4,4	4,4
W25	W24	18	4,81	4,81
W26	W24	19	3,53	3,53
W24	W22	20	3,69	12,03
W22	W17	21	1,53	22,52
W17	W1	26	0,57	24,63

Segment	*H/d* [%]	*v* [m/s]	*H/d* [%] MOSKAN	*v* [m/s] MOSKAN
16	30,06	0,574	30	0,58
17	29,51	0,568	30	0,57
18	30,90	0,582	31	0,58
19	26,37	0,533	26	0,53
20	51,10	0,745	51	0,75
21	79,47	0,841	79	0,84
26	89,27	0,832	89	0,83

The analysis of the results from Table 2 shows that for two network segments 21 and 26 the canal filling degrees are too large and they exceed the given allowable value of 75% of the filling high. In this situation some new canal diameters and new canal slopes have to be calculated what has been done using the planning algorithm proposed in 3.2.

Three cases of calculation of bottom slope *J* have been applied and they are:

a. *J* is the inverse of diameter *d*

b. J is the minimal slope securing the self-purification process in the sewage

c. J is the limit slope.

The values of d have been obtained by the optional calculation of J from equations (9a) or (9b) or (9c). For the new values of d and J the new filling degrees H/d and flow velocities v can be computed. The results obtained from the planning run are presented Table 3.

The analysis of the results from Table 3 shows that for the given flow values the least filling degree is obtained for the bottom slope being the least slope securing the canal self-purification process. For the bottom slope being the inverse of diameter d the filling degree H/d is the greatest one and exceeds 50%.

Table 3. Results of planning computations for the first example

			Case *a* of calculation		
Upper node	**Lower node**	***Q***	***d* [m]**	***J* [‰]**	***H/d* [%]**
W22	W17	22.52	0.5	2	55.76
W17	W1	24.63	0.5	2	59.01

		Case *b* of calculation			**Case *c* of calculation**		
Upper node	**Lower node**	***d* [m]**	**J [‰]**	***H/d* [%]**	***d* [m]**	***J* [‰]**	***H/d* [%]**
W22	W17	0.8	6.2	30.25	0.7	4.4	38.23
W17	W1	0.8	6.2	35.43	0.7	4.4	40.13

In the second case new canals are to be added to the existing sewage network. In Fig. 3 the added segments are drawn with the discontinues lines and the new nodes added are W28, W29 and W30. The extension of the network caused the change of the sewage flows Q and of canal fillings H/d in the canals located below the node W30 what is shown in Table 4.

Table 4. The results of computations.

Upper node	**Lower node**	**Seg ment**	**input flows in node**	**flows in segments Q[dm3/s]**	**H/d [%]**
W3	W30	9	0.1	4.12	28.53
W30	W2	29	0.0	6.08	34.94
W2	W1	15	0.73	9.57	44.76

For these new segments the values of canal diameters and canal slopes have been cakculated. To do it the planning algorithm proposed in 3.2 including 3 variants of determining canal slopes J and related canal diameters d has been applied. For the new values of d and J the new filling degrees H/d and flow velocities v can be computed. The results obtained from the planning run are presented Table 5.

The analysis of the results from Table 5 shows that for all 3 variants of calculating the canal slopes J and canal diameters d the filling heights in the new canals are less than 16%. The least filling degree is obtained for the bottom slope being the least slope securing the canal self-purification process. For the whole network the values J=0,5‰ and d=0.2 have been assumed and the same values can be taken for the new canals 27 and 28.

The calculation results for modelling and planning runs obtained while using the algorithms proposed as well as the MOSKAN software are very similar and practically comparable. The differences existing are caused by the rounding of numbers used in MOSKAN. It means that the algorithms presented are more reliable and dependable than these classical ones that use the nomograms and not less reliable than the complicated approach that uses SWMM algorithm for sewage networks hydraulic modelling.

Table 5. Results of planning computations for the new nodes W28 and W29.

			Case *a* of calculation		
Upper node	**Lower node**	***Q***	***d* [m]**	***J* [‰]**	***H/d* [%]**
W28	W30	1.13	0.2	5	15.02
W29	W30	0.83	0.2	5	12.94

		Case *b* of calculation			**Case *c* of calculation**		
Upper node	**Lower node**	***d* [m]**	***J* [‰]**	***H/d* [%]**	***d* [m]**	***J* [‰]**	***H/d* [%]**
W28	W30	0.3	5.6	5.07	0.25	6	10.80
W29	W30	0.3	5.6	4.39	0.25	6	9.33

CONCLUSIONS

In the paper a new practical approach for computing sanitary sewage networks is proposed that differs from the approaches commonly used in the today's practice of sewage nets operation. The standard and mostly applied method of sewage networks calculation uses the nomograms which enable to calculate in pure mechanical way the basic parameters of the designed nets such as diameters and canal slopes on the base of estimated sewage inflow values. The nomogram schemes have to be drawn before the process of network designing is started and their drawing occurs on the base of appropriate hydraulic equations and relations. The received results of sewage network calculation are approximate and depend on the quality of the schemes.

The modern approach in this field consists of applying advanced computer programs like SWMM [7, 8, 13], MIKE URBAN [14] or MOSKAN [9] which use in their computations hydraulic models of sewage networks. This approach requires an advanced computer knowledge from the program users and although the programs mentioned are already commonly in use on the universities then there is lack of their applications in the waterworks. The next obstacle in using this software in operational practice in the waterworks for designing the sewage networks is the necessity of having their right calibrated hydraulic models [10]. To calibrate the models a GIS system to generate the numerical map of the network and a properly dense monitoring system to collect the measurements data have to be installed on the sewage net what means expensive investments.

The most of Polish waterworks are municipal enterprises and they have not enough money for buying these costly systems. It seems that the approach for designing the sanitary sewage networks presented in the paper being an indirect method between the standard and modern ones can be currently an ideal tool for computing such networks for it owns the advantages of these both approaches and it has not their drawbacks. It uses the analytical relations concerning the hydraulics and geometry of sewage networks and it transform them to nonlinear equations from which depending on the requirements the of canal fillings and sewage speeds or canal diameters and slopes can be directly calculated. The analysis of the equations performed enables the determination of the available maximal sewage inflows going to the network nodes. In this way the calculations can be done quickly and exactly avoiding the using of the complicated hydraulic model of the sewage net.

In the presented calculation example the results received by means of the approach proposed have been compared with the results obtained with professional software MOSKAN [11] that is based on the hydraulic model SWMM [13] similar to MIKE URBAN software developed by DHI [14]. The parameter values of the sewage net calculated are the same for both cases. It means that the indirect approach presented is not less exact than the modern approach and at the same time it is much more simple and fast than this modern one and it is more exact and handy than the classical approach.

The computational example presented is rather simple but the approach proposed and the computer program developed for it can be used unproblematic also for modeling and designing more complex municipal sewage systems.

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Driving Simulator Development
Phase I – From State of Art to State of Work

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KEYWORDS
Driving simulator, vehicle dynamics, motion control, hexapod

ABSTRACT

The human-vehicle interaction, vehicle dynamics, increasing safety and functional behavior represent part of the research directions in the new innovation technologies for the automotive industry. Being able to develop different scenarios, very difficult to be reproduced in the real life, the driving simulator offers multiple possibilities to study the behavior of a vehicle and also of a driver. Several testing approaches can be developed using a driving simulator.
This paper aims to highlight the importance on safety security for vehicles that a driving simulator is having, but going in from a major research boundary regarding the driving simulator behavior.

INTRODUCTION

The human-vehicle interactions, as well as driver's behavior during different maneuvers represent long debated subjects in the automotive engineering domain. Driving simulators have an extraordinary important role both in industry and academia, because they allow research that would not be possible to study within real world scenarios.
Due to their various applications such as entertainment, scientific research and special trainings (ex: Formula 1), the driving simulators are targeted by most of the vehicle manufacturers.
The driving simulators can be classified by several criteria. Taking into account their fidelity level for the simulation of real world, their classification include: low-level fidelity driving simulators, mid-level fidelity driving simulators and high-level fidelity driving simulators (Slob, 2008).
The driving simulator that will be studied in this paper is a high-fidelity simulator used in scientific research. It has six degrees of freedom (6 DOF) and it is a motion based driving simulator.

AIMS AND OBJECTIVES

The purpose of the experiments is to perform a parametric evaluation of the simulator's inputs and outputs regarding the motion delays from which design recommendations could be made to optimize the control performance and minimize operators' discomfort.
The main objective is to introduce the key sub-systems within a typical driving simulator. The aim is to highlight the key characteristics of these sub-systems and the influences that they can have on the perception of self-motion (Howard and Templeton, 1966) within a virtual driving environment.
The optimal configuration of each system remains a significant cause for debate and still is a major challenge when considering the ability of simulators to extract realistic driver behavior. If any differences are observed between real and virtual conditions, a major difficulty is it to explain what factors specifically cause these differences.
An important limit represents how the resources that are provided and the simulators characteristics (hardware and software) can be best optimized to re-create optimal perceptions. In order to properly get an appropriate solution to eliminate or to minimize this limit, the key subsystems of the driving simulator and the complex movement that can be simulated by the hexapod have to be perceived as such.
While operating the driving simulator, the perception of motion is influenced by three main sensory systems: visual, vestibular and auditory. These three main sensory systems are present in the driving simulator and they are designed in order to give a real „feeling" to the driver.

KEY SYSTEMS OF A RESEARCH DRIVING SIMULATOR

The key sub-systems of the research driving simulator and how they interact with one another are presented in figure 1.
Originating from the driver making control inputs from the vehicle cab, each sub-system plays a vital role in forming the perception of the virtual driving environment.

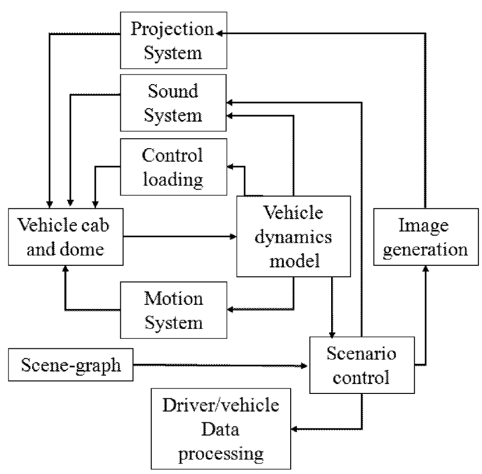


Figure 1: Key sub-systems of the research driving simulator

Vehicle cabin

The primary elements for simulation are the driver and the vehicle cabin. The dashboard instrumentation is commonly fully operational to show the indications of driving speed, engine speed, fuel level and other information concerning the vehicle's operation. Taking into account the organizational work, for the driving simulator to benefits from the motion system, the whole cab may reside within a simulation dome or the vehicle cab can be located directly on the motion platform. This is normally a stiff but lightweight construction, but one disadvantage can be that it resonates at the usual frequencies of operation of the motion system, which can modify further experiments results by showing low or high frequencies peaks.

Vehicle instrumentation and safety

An actual medium size class vehicle has been modified, where the motor, the drivetrain and the running gear have been removed. The rear part of the car was removed also (figure 2).

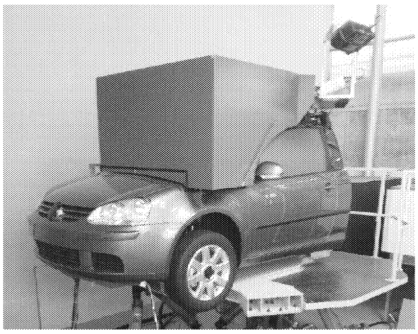


Figure 2: The vehicle cabin

The brake and the accelerator pedals, the gear selector and the other controls that need to reproduce the feeling characteristics in consistence with task requirements have been kept. The secondary vehicle controls such as radio, climate control and turning signals are only instrumented if the studies require them. The interior compartment and the driver workspace are relatively complete, with some modifications regarding the safe operation of the driving simulator.

The safety features include an emergency button, the `STOP` button, placed inside the cabin, next to the gearbox lever (figure 3 a). Another safety feature is that the gearbox lever is locked and it cannot be operated (figure 3 b).

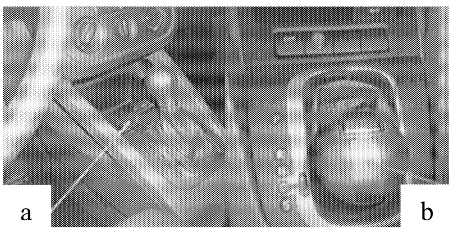


Figure 3: The safety features

The upper platform

All around the vehicle, an upper platform is connected to the hexapod being used for the access inside the vehicle, on both sides, and also as an inspection alley for the protection system (figure 4).

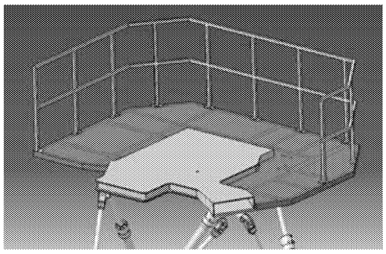


Figure 4: The upper platform

Vehicle dynamics model

Vehicle dynamics are critical and difficult to be investigated to the steering wheel, accelerator, brake etc. from the driver's perspective and simulate the dynamic behavior of a real-life vehicle.

The quest of numerous vehicle dynamics engineers has led them to modern computerized methods that simplify the development of complicated vehicle models, as well as the design of highly developed programs for the reconstruction of the physical behavior of individual vehicle systems. This, in turn, has created a very good correspondence between the real world measurements and those results produced with a vehicle simulation program.

Vehicle dynamics simulation

The IPG Driver was the simulation solution in order to perfectly reproduce the actions and reactions of a real driver. The most successful driver model for sophisticated closed loop driving tasks is easy to configure. Embedded in a powerful maneuvers control the IPG Driver can follow general driving instructions. It can trigger testing, measuring and diagnosis events during the maneuver. This allows the test engineer to reconstruct any driving maneuvers using familiar maneuvers and action commands. The simulation is therefore very similar to the test drive in terms of method. In the simulation as in the test drive, the user concentrates on test content and not, as is often the case with model-based approaches, on the generation of appropriate signals.

In this simulation, IPG Driver enables to add the control actions of a human driver to the complete vehicle simulations. These actions include the steering, the braking, the throttle position, the gear shifting and the clutch operation.

The most important features of the IPG Driver include the automatic adaptation to the present vehicle by identifying the dynamic behavior of the vehicle and the ability to learn, which gives you the possibility to use the knowledge in later simulations (IPG Documentation - IPGDriver User Manual 6.4).

The inputs for the driver model include the behavior on the road, the vehicle motions (position, speed and acceleration), the steering wheel torque (if available).

The outputs of the driver model include the dependencies on the structure of the vehicle model, the steering wheel angle or the steering wheel torque, the 'standardized' accelerator pedal position, the force on the brake pedal, the position of the clutch pedal and the selected gear number.

Scene graph

The scene-graph holds the data that defines the virtual world in a hierarchical database structure. Initially, the 3-D model of the roadway describes only static roadside objects, e.g. roadways,

buildings, trees, signposts. It includes low-level descriptions of object geometry and their appearance, as well as higher-level, spatial information of their location within the virtual environment.
Additional data defining attributes of particular objects, e.g. road friction, can be included in the scene-graph. Its function is to provide an efficient structure of the graphical data that supports optimal performance in terms of speed of rendering the image generation process falling later in the simulation loop (Foley and van Dam, 1990).

The virtual vehicle environment
A virtual vehicle is a computer modeled representation of an actual vehicle, its behavior being reproduced in order to match the real world counterpart.
Using CarMaker, the virtual vehicle consists of mathematical models that contain the equations of motion, kinematics, etc. along with other mathematical formulas that define the vehicle multibody system.
The model is parameterized with data that relate directly to the vehicle to be studied.
Following this approach, CarMaker allows to test any vehicle with a validated parameter set, and to easily switch between virtual vehicles by changing the parameter data that are used in the vehicle model. The virtual vehicle contains all components of a real vehicle, including powertrain, tires, chassis, braking system etc. The controllers can easily be integrated as hardware or as software models, part of the virtual vehicle, developing hardware in the loop or software in the loop testing system (*, IPG Documentation-CarMarker User`s Guide Version 4.5).

The scenario control
The scenario control refers to the process of `choreographing` particular traffic scenarios or events within the virtual driving environment, by modifying the scene-graphs and adding the real-time agents based on their own behavior, including pedestrian, vehicles, traffic signs, traffic lights etc. The roadway description represent the fundamental scenario control; the Logical Road Network - LRN (van Wolffelaar, 1996).
The scenario control uses the LRN to provide information in order to support the behavior and interaction of the real-time agents. For example, intelligent virtual traffic effectively uses the LRN to "perceive" the road as a human driver in order to make intelligent decisions such as intersection right of way and overtaking.

Image generation
Image generation describes the computational process of visually rendering the virtual environment from the driver`s point of view. The process acts on the complete hierarchical visual scene-graph, taking into account both the initial static objects in the 3-D model of the roadway and those moving agents appended to the scene-graph by the scenario control module. The image generation module is described by the viewer's position from the vehicle dynamics module, and also using standard libraries to render a perspective view of the complete scene-graph. These libraries efficiently manage the computational drawing process in order to maximize the frame rate and complexity of the visual scene. Visual effects such as weather conditions and lighting conditions can be added along with features such as multiple visual display channels to create a wide overview.

The projection system
The projection system physically displays the virtual driving scene rendered by the image generation module. This can take place over a single visual channel or over a number of projected images. The images are blended and color-balanced, to create a wide `field of view`. Projection screens for narrow field of views (less than 50-60°) tend to be flat surfaces, having the advantage to be easily modified.
The visual cues are mostly there for the driver's cognitive driving needs. The driver from the observed virtual scenery gathers the primarily information for shape and color, distance and self movement from the visual system.

The motion system
The motion system is designed to artificially retake the dynamic cues of both longitudinal (braking and ride) and lateral (cornering and stability) vehicle accelerations (Nordmark and Lidström).
For experiments with ordinary vehicle drivers, the motion is only one important topic out of many others (i.e. visual system, sound, realistic car cabin) to deceive a realistic driving feeling.
The driving simulator is equipped with a hexapod that generates movement through the hydraulic system. The cylinders of the hexapod are also hydraulic driven which makes the whole system profit from the advantages of a hydraulic system: multi-functional control, motion can be almost instantly reversed, safety in hazardous environments etc.

Motion reference point (MRP)
The motion reference point (MRP) denotes the point in space at which the platform translations and rotations are centered (Nahon and Reid, 1990). For the hexapod system, although the location of the MRP can vary, it is usually located with respect to the geometry of the motion platform. Most commonly, it is defined as the centroid of the two triangles formed at the upper joint rotation points (figure 5).

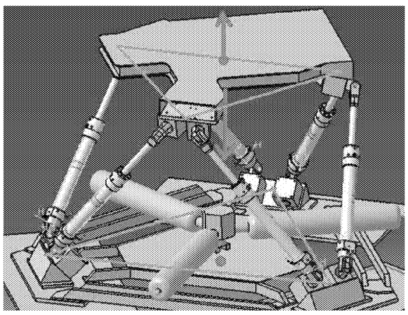
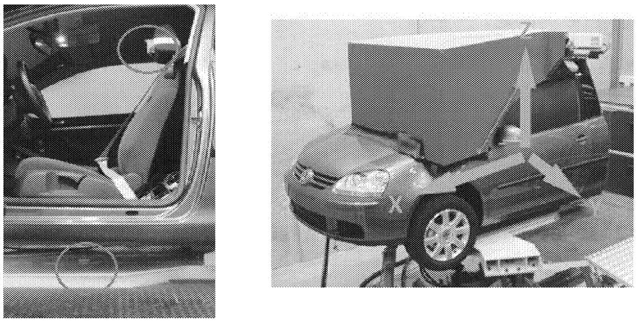


Figure 5: The motion reference point

DEFINING THE STATIC BEHAVIOR OF THE DRIVING SIMULATOR

The static limits for the moving platform represent a major task for understanding the driving simulator behavior. Using XSens sensors placed exactly on the motion reference point (figure 6) allows investigating the static behavior and also determining the rotations around axles, on X and Y, the actuators displacement, the roll and pitch angles (Table 1) for the maximum inclination of the platform.



A b

Figure 6: a-XSens sensors position, b-Experiment axis

The XSens System is a wireless inertial measurement unit that incorporates 3D accelerometers, gyroscopes, magnetometers (3D compass) and a barometer (pressure sensor). The XSens system processor can handle sampling, buffering, calibration and strap down integration of the inertial data. It can provide 3D linear accelerations, angular velocities and atmospheric pressure data. The purpose is to collect the linear accelerations and the angular velocities from the system (Harlapur 2014).

Table 1: The static behavior presented in data for maximum inclination of the platform

Rot	Acc	A1, mm	A2, mm	A3, mm	A4, mm	A5, mm	A6, mm	R, ^{0}	P, ^{0}
Xcw	a_{y+}	602	58	161	459	315	602	17	1,7
Xccw	a_{y-}	52	611	612	312	459	156	-17,2	0,5
Ycw	a_{x-}	299	299	158	602	604	164	0,3	-15
Yccw	a_{x+}	464	463	533	91	92	53	0,7	16
N	-	328	335	336	339	332	330	0	0
U	-	605	612	612	602	604	602	0	0
D	-	30	30	30	30	30	30	0	0

Legend: Rot-rotation around axis, Xcw-X clockwise, Xccw-X counterclockwise, Ycw-Y clockwise, Yccw-Y counterclockwise, N-neutral (start position), U-up (maximum position), D-down (safe position), Acc-acceleration, A1…6-actuators from 1 to 6, R-roll angle, P-pitch angle

DEFINING THE DYNAMIC BEHAVIOR OF THE DRIVING SIMULATOR

The experiment is focused on assessing the relationship between the input-output delays and the analyzed parameters, the variables that can be easily changed manually in the simulator's software.

The variable that can be changed is the tilt/translation ratio of the hexapod. In order to analyze this ratio and to see the delay, the longitudinal and lateral accelerations, pitch and roll angles were investigated. The longitudinal acceleration and the pitch angle can be analyzed using a simple vehicle virtual environment: a straight line where the vehicle can run from 0 to 100 km/h with 3 different longitudinal accelerations as inputs: 2, 3 and 5 m/s^2 and a straight line where the car can decelerate from 60 km/h to 0 km/h using a longitudinal deceleration of 2, 4 and 6 m/s^2.

Three different scenarios were used to analyze the lateral acceleration and the pitch angle, based on different inputs.

The first scenario consists in a straight line and a curve with a radius of 50m. The vehicle will run on the curve with two different speeds: 40 km/h and 50 km/h.

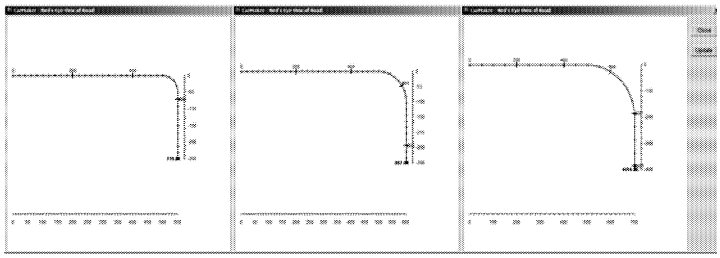


Figure 7: Acceleration scenarios

The second scenario consists in a straight line and a curve with the radius of 100m where the vehicle will run on the curve with the precise speed of 80 km/h.

The third scenario is also a straight line and a curve with a radius of 200m. The vehicle will run with the speed of 80 km/h (figure 7).

Choosing a larger selection of different vehicle speeds allows for determining more information about the delays occurred for different input velocities. In addition, the reference regarding the velocity value is a factor that can affect the delay.

TESTING INSTRUMENTATION

Experiment apparatus

The analyzed parameters were sorted in two main categories: inputs and outputs. The inputs were received from the driving simulator's software: CarMaker. The outputs were measured by using an external apparatus that wasn't related to the driving simulator. In order to be able to measure and record different accelerations and velocities the XSens system was used.

Two different sensors were used from the system, being positioned as following: one sensor was placed on the platform, underneath the vehicle mock-up and one of the sensors was placed on the driver seat at the head level (figure 6a), where the driver can perceive the actual accelerations and velocities through the vestibular system.

Collected and analyzed data

As described above, three different scenarios were used to measure different outputs and ratios between inputs and outputs. The main purpose of the measurements is to find a better ratio between the inputs and outputs that can analyze and understand where the delay comes. In addition, the calibration of the motion system represents a goal to be achieved.

There are many factors that can result in a delay, but for simplification the focus will only be on the delay caused by the tilt/translation ratio. The delays caused by the hydraulic system or by the mechanical parts and connections will be excluded (Kemeny and Panerai).

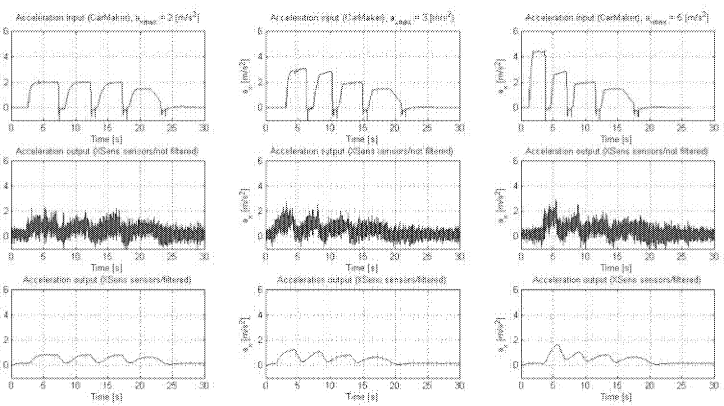
The tilt/translation ratio which is already set up in the simulator is 40/60. Different scenarios using the same ratio will be analyzed. To simplify the experiment, the function is assumed to be linear.

All of the data collected was analyzed and processed in Matlab. The output signals were also filtered in Matlab because the noise from the hydraulic and mechanical systems can affect the actual signal.

RESULTS

Example of data analyzed: acceleration scenario

As already mentioned above, the scenario was built to allow the vehicle to travel from 0 to 100 km/h in a straight line. The signals resulted from the experiment are shown in figure 8.



a b c

Figure 8: Acceleration scenarios

The scenario was evaluated at 3 different accelerations: 2 (figure 8-a), 3 (figure 8-b) and 5 m/s^2 (figure 8-c). The data collected include the longitudinal accelerations and the pitch angle values.

The acceleration signal had to be filtered because of the surrounding noise.

CONCLUSIONS

In order to improve the driving simulator's behavior, its actual behavior has to be understood.

First of all, taking into account all the key sub-systems of the driving simulator and the importance of each of them, the static limits for the platform, the cylinder opening lengths, were determined.

Also a 3D model of the driving simulator, simulating different moving scenarios has been made.

The understanding of the behavior was useful for being able to find the best positions for the acceleration sensors. The position of the motion reference point is allows to place the sensors on the motion reference axis.

In order to conduct the experiments, different acceleration and deceleration scenarios were designed.

Furthermore, a transfer function should be established between the inputs and the outputs.

The measurements should be done again but for different tilt/translation ratios and the results should be compared. The selected transfer functions resulted from the different ratios and the adequate ratios in order to give the driving simulator a more realistic feeling were set.

Due to the lack of time, the project could not be continued with a further analysis, but this could be the main step that can offer a basic understanding on the driving simulator's behavior that can lead to ideas on how to optimize the simulator.

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BIOGRAPHIES

ALEXANDRA TUCA received her bachelor degree in Automotive Engineering in 2014 at University POLITEHNICA of Bucharest, Romania. She prepared the diploma project in collaboration with Technische Hochschule Ingolstadt, doing a traineeship in the laboratory for Driving simulation. During the same year, showing her interest in the topic of "Driving simulators development", she also presented a paper at a student congress called "The necessity of biomimetics in the development of driving simulators", being one of the awarded papers at the congress. Currently, Alexandra is attending the master program "International Automotive Engineering" at the Technische Hochschule Ingolstadt, Germany. She also joined the academic staff as a research assistant since October 2014 in the Faculty of Mechanical Engineering from Technische Hochschule Ingolstadt, with a main focus on "Development of traction control systems and sensors for electric go-karts".

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THOMAS BRANDMEIER received the Doctorate degree in electrical engineering from the Technical University of Karlsruhe, Karlsruhe, Germany, in 1992. He is the Scientific Director of the Center of Automotive Research on Integrated Safety Systems and Measurement Area (CARISSMA). He is a Consultant with the German Council of Science and Humanities (Wissenschaftsrat) and the Federal Ministry of Education and Research. He also holds a professorship for fundamentals of electrical engineering and vehicle communication systems. His main research interests include vehicle mechatronics, automotive electronics, and vehicle safety.

LARGE BODY SIMULATION

LATERAL DIFFUSION IN FINITE DIFFERENCE SCHEMES FOR AVALANCHE SIMULATION

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KEYWORDS
Granular Material, Partial Differential Equation, Finite Difference Scheme, Avalanche Simulation

ABSTRACT

Modelling and simulation of granular materials is an active research field with applications in many industry sectors. Topics of interest range from microscopic problems, such as grain segregation to macroscopic phenomena, such as avalanches. The BCRE model (from the authors' names, Bouchaud, Cates, Ravi Prakash and Edwards) is a model that describes the evolution of an avalanche as a thin layer of rolling material over a basis of static grains. The model uses a system of two partial differential equations to compute simulations of the avalanche process. Depending on the numerical scheme used to solve the equations, there are some phenomena appearing in real avalanches which are not properly reproduced in the simulation. In this paper we focus on the lateral expansion of an avalanche that slides down a slope. We analyse two different finite difference schemes that can be used to solve the equations and prove that only one of them can simulate some expansion processes observed in real avalanches. We perform several simulations to show the properties deduced from our analysis.

INTRODUCTION

Granular materials are present in many natural processes, like avalanches of sand or snow. The study of granular systems can play an important role in different industries such as mining, chemical industry or geotechnics. In sectors where manipulation of granular materials is done with heavy machinery it is common that Virtual Reality simulators are used in order to train the operators (García-Fernández et al. (2011)). Our research is motivated by the use of granular systems in Virtual Reality applications that involve granular systems, such as earthmoving scenarios or industrial environments that involve bulk materials (coal, fertilizers or grains). In these simulators, a proper simulation and visualization of avalanches and their evolution is necessary.

We address the problem of finding an appropriate numerical scheme to solve models of avalanches based on partial differential equations. We compare two finite difference schemes and prove that one of them can simulate the observed shape of real avalanches, while the other one does not propagate according to such observations. In this section we give an introduction to the problem of avalanche modelling and describe the BCRE model of avalanche evolution. In the next section we present our analysis to compare two finite difference schemes used to develop simulations of avalanches. Finally, we present some numerical tests to illustrate our results.

Avalanches in Granular Materials

Granular materials have a property known as the *critical slope angle*. When the slope of the granular system exceeds this angle, a layer of grains starts flowing over the surface of the system, causing an avalanche. The existence of this critical angle is a macroscopic feature resulting from internal friction, and it depends on the properties of the granular material, such as grain size distribution, grain shapes, roughness of surface or material moisture. Most models assume that, during an avalanche, there is a static layer, made of immobile grains, and a rolling layer, made of grains that are sliding down the slope. The interested reader can find further information about the properties of avalanches in granular systems in the works by Savage and Hutter (1991), Duran (1999), Prigozhin and Zaltzman (2001), Aradian et al. (2002), Prigozhin and Zaltzman (2003).

Bouchaud et al. (Bouchaud et al. (1994)) proposed an analytical model for an avalanche, the so called BCRE model (from the authors' names, Bouchaud, Cates, Ravi Prakash and Edwards), which is based on a phenomenological description of the process. The BCRE model consists of two equations that describe the evolution of the static layer, $u(x,t)$, and the rolling layer, $v(x,t)$:

$$\begin{aligned} v_t &= \nabla\left(v\nabla u\right) - (1-|\nabla u|)v + f \\ u_t &= (1-|\nabla u|)v \end{aligned} \qquad (1)$$

The equation (1) has been normalized so that the model parameters have value 1 (see the work by Hadeler and Kuttler (1999) for more details). The first equation shows two terms, a transport term $\nabla\left(v\nabla u\right)$ and a term that accounts for material exchange between layers, $(1-|\nabla u|)v$. The term f represents a source of granular material, which allows the introduction of material in the system. This model has been revisited by several authors (Alamino and Prado (2002), Shen (2007), Shen and Zhang (2010), Colombo et al. (2012), Cattani et al. (2012)). The formulation used in this paper is a two dimensional version of the model proposed by Hadeler and Kuttler (1999).

According to empirical studies, an avalanche caused at a point in a slope extends forming a characteristic shape. The works by Daerr and Douady (1999) and Daerr (2001) describe two main behaviours. When there is an avalanche formed by a thin rolling layer, it will grow laterally on its way down, forming a triangular shape, whereas avalanches with a thick rolling layer also propagate upwards, eventually causing the whole slope to slide. In both cases, the avalanche not only propagates down the slope but also extends sideways.

In our work we want to simulate avalanches in a slope of granular matter using a discretisation of the system of equations (1). Falcone and Vita (2006) propose a finite difference scheme for the BCRE model and derive a condition for consistency and convergence. However, when using this numerical scheme to simulate an avalanche generated at an isolated point in a slope, it can be observed that avalanche evolution does not show lateral diffusion or uphill avalanche propagation, as described before. As an alternative to this finite difference scheme, we propose the use of the Lax-Friedrichs scheme (Strikwerda (2004)).

In the next section we compare the lateral diffusion of an avalanche when simulated with the scheme proposed by Falcone and Vita (2006) (the FV scheme from now on) and with the standard Lax-Friedrichs finite difference scheme. More precisely, the evolution of a point that is next to the avalanche area is obtained, showing that the FV scheme will not propagate sideways or upwards.

LATERAL AVALANCHE DIFFUSION IN FINITE DIFFERENCE SCHEMES

The goal of the analysis presented in this section is to quantify the lateral and uphill expansion of an avalanche in a slope. We shall focus on a system with an active avalanche, and will analyse the evolution of a point of the finite difference grid that is next to the avalanche, but not affected by it.

We shall consider a regular grid aligned with the X and Y axes, that discretises the spatial domain of the problem. The grid spacing will be denoted as h and the time step for the numerical time integration will be denoted as Δt. The nodes of the grid will be denoted by indexes (i, j). The value of the discretised solution of (1) at grid point (i, j) and time $t_n = t_0 + n\Delta t$ will be denoted as $(u^n_{i,j}, v^n_{i,j})$.

Let's consider a grid point (i, j) that has no active avalanche at time t_n. As the thickness of the avalanche is given by $v(x, t)$ in (1), this is equivalent to $v^n_{i,j} = 0$. And let's consider that this point is in the border of an active avalanche, so that only one of the adjacent nodes has active avalanche. Without loss of generality we shall assume that it is node $(i-1, j)$, having

$$v^n_{i-1,j} > 0; \qquad v^n_{i+1,j} = v^n_{i,j+1} = v^n_{i,j-1} = 0. \tag{2}$$

Moreover, we shall consider that no rolling material is being added at point (i, j) by an external source, thus $f_{i,j} = 0$. Figure 1 shows the situation that is described. In the figure, nodes with double circle represent locations with avalanche, while the ones with only one circle correspond to locations with no avalanche.

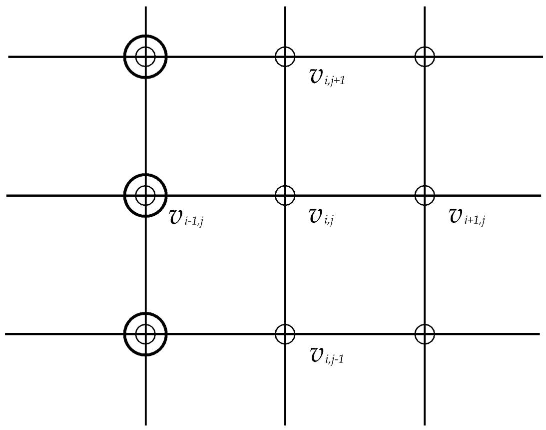

Figure 1: The scenario considered in the analysis. A regular grid is used to discretise the domain. Nodes with double circle indicate the existence of material in the rolling layer. The point of interest is the node (i, j), which is not affected by the avalanche but is next to a node affected by it.

We are interested in the situation when point (i, j) is located uphill or at the same level than the point with an active avalanche $(i-1, j)$. Thus, we shall consider that, at point (i, j), the slope does not go down in the direction from grid point (i, j) to grid point $(i+1, j)$. That is to say that the gradient of the static layer, $Du_{i,j}(x, t)$, has a positive or null first coordinate,

$$Du_{ij}(x, t) = (a, b);\ a \geq 0, b \in \mathbb{R}. \tag{3}$$

Next we show that using the FV finite difference scheme the avalanche has no effect on point (i, j) whereas in the Lax-Friedrichs finite difference scheme point (i, j) changes its value.

Analysis of the FV Finite Difference Scheme

The explicit finite difference scheme proposed by Falcone and Vita (2006) to integrate the BCRE model can be written as

$$v_{i,j}^{n+1} = v_{i,j}^n + \Delta t\Big[v_{i,j}^n D^2 u_{i,j}^n + \\ + \overline{D} v_{i,j}^n \cdot Du_{i,j}^n - \left(1 - \left|Du_{i,j}^n\right|\right) v_{i,j}^n\Big], \quad (4)$$

$$u_{i,j}^{n+1} = u_{i,j}^n + \Delta t\left(1 - \left|Du_{i,j}^n\right|\right) v_{i,j}^n,$$

where the involved differences are as follows. For any quantity A taking values on the grid, the lateral differences are defined as

$$D_x^- A_{i,j} = \frac{A_{i,j} - A_{i-1,j}}{h}; \qquad D_x^+ A_{i,j} = \frac{A_{i+1,j} - A_{i,j}}{h}; \quad (5)$$
$$D_y^- A_{i,j} = \frac{A_{i,j} - A_{i,j-1}}{h}; \qquad D_y^+ A_{i,j} = \frac{A_{i,j+1} - A_{i,j}}{h}.$$

According to Falcone and Vita (2006), the gradient $Du_{i,j}$ is computed choosing the lateral differences that maximize $|Du_{i,j}|$. The gradient of v, denoted by $\overline{D}v_{i,j}$, is approximated by the uphill finite differences with respect to $Du_{i,j}$, defined as

$$\overline{D}_x v_{i,j} \equiv \begin{cases} D_x^+ v_i & \text{if } D_x u_i > 0, D_x^+ u_i > 0, \\ D_x^- v_i & \text{if } D_x u_i < 0, D_x^- u_i < 0, \\ 0 & \text{otherwise.} \end{cases} \quad (6)$$

The definition for $\overline{D}_y v_{i,j}$ is analogous. Finally, $D^2 u_{i,j}$ is approximated using the standard central difference of order two

$$D^2 u_{i,j} = \frac{u_{i,j-1} + u_{i,j+1} - 4u_{i,j} + u_{i-1,j} + u_{i+1,j}}{h^2}.$$

Using the previous definitions, the value of $v_{i,j}^{n+1}$ can now be computed from (4). The first term, involving the second order difference is zero, since $v_{i,j}^n = 0$, and the last term is also null for the same reason, leaving

$$v_{i,j}^{n+1} = \Delta t\left[\overline{D} v_{i,j}^n \cdot Du_{i,j}^n\right]. \quad (7)$$

The x component of the gradient $\overline{D}v_{i,j}^n$ is given by (6). According to the condition (3) the gradient of u accomplishes $D_x u_{i,j}^n = a > 0$ and

$$\overline{D_x} v_{i,j}^n \equiv \begin{cases} D_x^+ v_{i,j}^n & \text{if } D_x^+ u_{i,j}^n > 0 \\ 0 & \text{otherwise.} \end{cases}$$

Now, by equation (2), $v_{i,j}^n = v_{i+1,j}^n = 0$ and $D^+ v_{i,j}^n = 0$, leading to

$$\overline{D_x} v_{i,j}^n = 0.$$

Moreover, the y component of $\overline{D}v_{i,j}^n$ is also zero since, again by (2), $v_{i,j-1}^n = v_{i,j}^n = v_{i,j+1}^n = 0$ and

$$D_y^+ v_{i,j}^n = D_y^- v_{i,j}^n = 0. \quad (8)$$

Plugging (8) into (7) it is finally seen that

$$v_{i,j}^{n+1} = 0. \quad (9)$$

Analysis of the Lax-Friedrichs Finite Difference Scheme

The equation for the rolling layer $v(x,t)$ in (1) can be discretised using the Lax-Friedrichs finite difference scheme (Strikwerda (2004)) leading to:

$$v_{i,j}^{n+1} = \overline{v_{i,j}^n} + \Delta t\left[v_{i,j}^n D^2 u_{i,j}^n + Dv_{i,j}^n \cdot Du_{i,j}^n - \\ -(1 - \left|Du_{i,j}^n\right|) v_{i,j}^n\right] \quad (10)$$

In this case, the gradients are computed by central differences

$$D_x v_{i,j}^n = \frac{v_{i+1,j}^n - v_{i-1,j}^n}{2h}; \quad D_y v_{i,j}^n = \frac{v_{i,j+1}^n - v_{i,j-1}^n}{2h}, \quad (11)$$

and the value of v_{ij}^n is approximated by

$$\overline{v_{i,j}^n} = \frac{v_{i+1,j}^n + v_{i-1,j}^n + v_{i,j+1}^n + v_{i,j-1}^n}{4} \quad (12)$$

From equation (10), and taking into account that $v_{i,j}^n = 0$, we can derive the increment of the rolling layer as

$$v_{i,j}^{n+1} = \overline{v_{i,j}^n} + \Delta t\left[Dv_{i,j}^n \cdot Du_{i,j}^n\right] \quad (13)$$

Using the hypotheses that only $v_{i-1,j}^n \neq 0$, expressed by equation (2), and that $D_x u_{ij}^n = a$, by equation (3), we can develop the dot product in equation (13). Using the central differences (11),

$$\begin{aligned} Dv_{i,j}^n \cdot Du_{i,j}^n &= \frac{\left(v_{i+1,j}^n - v_{i-1,j}^n\right)\left(u_{i+1,j}^n - u_{i-1,j}^n\right)}{4h^2} + \\ &\quad + \frac{\left(v_{i,j+1}^n - v_{i,j-1}^n\right)\left(u_{i,j+1}^n - u_{i,j-1}^n\right)}{4h^2} \\ &= -\frac{v_{i-1,j}^n}{2h}\left(\frac{u_{i+1,j}^n - u_{i-1,j}^n}{2h}\right) \\ &= -\frac{v_{i-1,j}^n}{2h} a. \end{aligned} \quad (14)$$

Applying again that only $v_{i-1,j}^n \neq 0$, the approximation to $v_{i,j}^n$ given by (12) results in

$$\overline{v_{i,j}^n} = \frac{v_{i-1,j}^n}{4}. \quad (15)$$

Finally, substituting (14) and (15) into (13), we have that using the Lax-Friedrichs finite difference scheme the value of the rolling layer at point (i,j) will be

$$\begin{aligned} v_{i,j}^{n+1} &= \overline{v_{i,j}^n} + \Delta t\left[Dv_{i,j}^n \cdot Du_{i,j}^n\right] = \\ &= v_{i-1,j}^n\left(\frac{1}{4} - a\frac{\Delta t}{2h}\right), \end{aligned} \quad (16)$$

producing a change in the value of $v_{i,j}^n$ in any situation. The only case when (16) vanishes is in the particular situation when $a = \frac{h}{2\Delta t}$. This situation, however, is unlikely to last in time, since the evolution of the avalanche will cause that the situation disappears in very few time steps.

Discussion

In the last two subsections we have proved that, under the assumptions (2) and (3), the finite difference scheme proposed in the work by Falcone and Vita (2006) only propagates an avalanche provoked at a point in the downhill direction of the simulated granular system. Under the same conditions, but using the Lax-Friedrichs finite difference scheme, avalanches expand in all directions, showing an evolution that is more coherent with empirical studies.

Thus, the FV scheme is adequate for situations of massive avalanches, where the lateral avalanche expansion is not relevant, as shown by Falcone and Vita (2006) in their work. Moreover the FV scheme is known to be convergent and stable under certain conditions. However, in situations where the avalanche starts as a more local process and we are interested in the geometry of the avalanche as it evolves, the averaging term in the Lax-Friedrichs scheme leads to better qualitative results.

To the best of our knowledge, there is no convergence and stability analysis for the Lax-Friedrichs scheme applied to this problem. In our numerical tests, described next, we have used the same criteria for both numerical schema, and stability has been achieved in the two methods.

NUMERICAL TESTS

We have simulated an avalanche on a static slope with 45 degrees of inclination. We provoke the avalanche in a bounded region, discretised as a square of 3×3 grid cells, by increasing the amount of material in the rolling layer. The whole system is discretised by a grid of 80×80 cells. Figure 2 shows the evolution of the avalanche, using the finite difference scheme proposed by Falcone and Vita (2006). In the figure, the slope points in the down direction. The figure shows the region occupied by the avalanche after 2.8 seconds (left) and the intermediate states after every 0.2 seconds of simulation time. As predicted, the material flows down the slope, but it does not slide laterally, perpendicular to the main slope, and does not expand uphill.

Figure 3 shows the evolution of the avalanche simulated with the Lax-Friedrichs finite difference scheme. The figure shows a similar representation as the depicted in the previous figure. In this simulation, the avalanche slides down the slope and expands laterally. Moreover, it can be observed that the avalanche also propagates upwards. This reproduces real avalanche behaviour, in which grains located uphill progressively tumble down because of loss of support, as it is described in Daerr and Douady (1999).

Recalling the motivation of this work, we have implemented a graphical simulation, in order to show the application of the results in the context of a Virtual Reality environment. In Figure 4 we show an OpenGL visualization of the model using both numerical finite difference schemes. The visualization is done by means of texture advection as described by Rodriguez-Cerro et al. (2015) on a triangle mesh that is built upon the discretisation of the BCRE model.

Since computation time is relevant in the models used in Virtual Reality simulations, it is noteworthy that the

Figure 2: Avalanche propagation using the FV finite difference scheme. Left image shows the silhouette of avalanche after 2.8 seconds from the start. Right image shows the expansion of the avalanche in intervals of 0.2 seconds. The black spot indicates the point where the avalanche was generated.

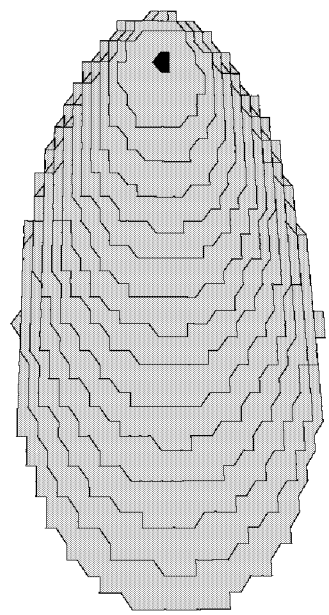

Figure 3: Avalanche propagation using the Lax-Friedrich scheme. The image shows the silhouette of avalanche after 2.8 seconds from the start. The lines indicated the expansion of the avalanche in intervals of 0.20 seconds.

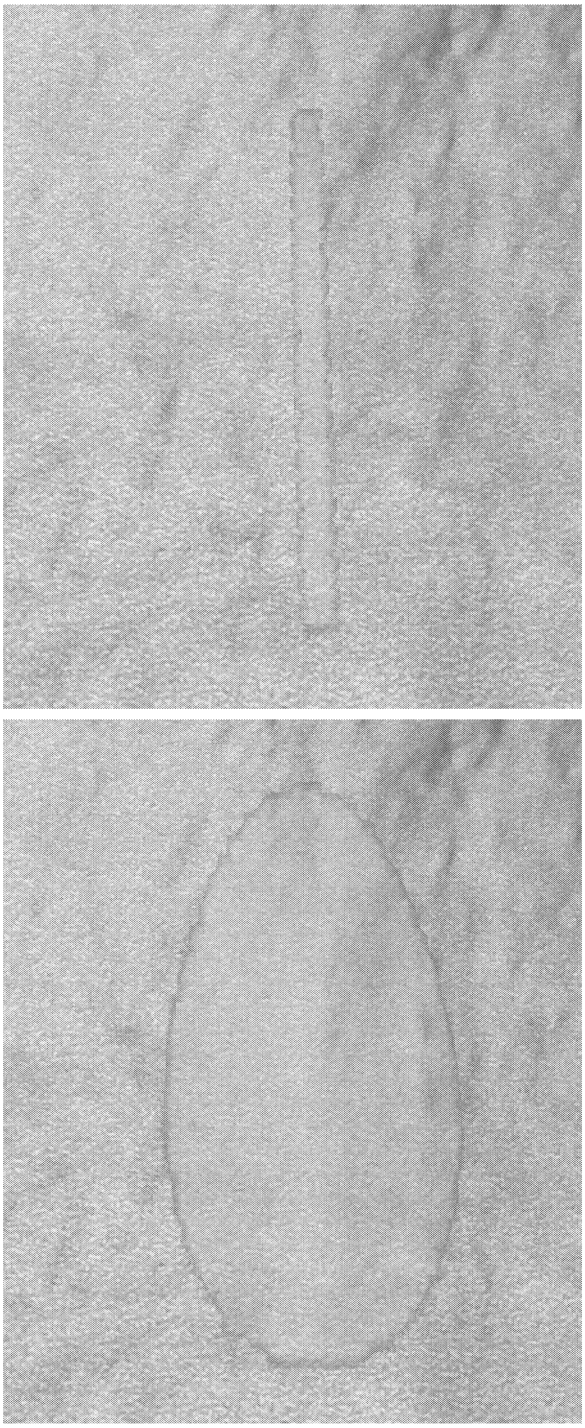

Figure 4: An OpenGL visualization of an avalanche simulated using the FV finite difference scheme (top) and the Lax-Friedrichs finite difference scheme (bottom).

two finite difference schemes are explicit schemes and require a number of computations of the same order of magnitude.

CONCLUSION AND FUTURE WORK

We have addressed the simulation of avalanches in a slope of granular matter using two finite difference discretisations of the BCRE model. We have proved that the scheme proposed by Falcone and Vita (2006) does not propagate laterally and upwards on the slope. This behaviour is not consistent with the behaviour of avalanches observed by empirical studies (Daerr and Douady (1999)). We have also demonstrated that the Lax-Friedrich finite difference scheme, applied to the BCRE model, produces the formation of avalanches that have a shape more consistent with the aforementioned empirical observations. An analysis of stability and convergence of the Lax-Friedrichs scheme has yet to be done for this particular problem.

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WATER DISTRIBUTION NETWORK OPTIMIZATION USING GENETIC ALGORITHMS

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KEYWORDS
Water supply system, genetic algorithms, multiobjective optimization, pump switching

ABSTRACT

This paper presents the description of the IT solutions which have been applied in a computer simulation system for optimal pump switching. The Genetic Algorithm (GA) was used to solve the altered multi-objective optimization model. Nowadays, genetic algorithms (GA) have becomes one of the preferred water system designed optimization technique for many researchers (Cheung 2003; Prasad et al. 2004; Zheng 2013; Jin Xi et al. 2008; Kurek and Ostfeld 2013). The main reason is that GA (Golberg 1989) have the ability to deal with complex nonlinear optimization problems. The GA is integrated with the hydraulic simulation programme called WDS (Water Distribution System). The description of the implementation of the WDS software is provided in (Fajdek et al. 2014; Stachura et al. 2012). The WDS software can be used to design new networks, analyse existing networks, perform hydraulic simulation of the networks etc. In (Fajdek et al. 2014) the WDS system performance was presented using simple example of rehabilitation process applied to the hypothetical network. In this paper, a new algorithm for pump scheduling was presented and applied to the real water distribution system of Głubczyce city. Pump scheduling is one of the most important tasks of the operation of a water distribution system. Moreover, it is much more complex problem than rehabilitation process. The main goal was to schedule N pumps in water distribution system over a time period, in our case 24 hours. In proposed solution we had to use a more complex solutions in both math and programming than in the solution applied to rehabilitation process (Fajdek et al. 2014). Developed algorithm which is the part of WDS software for complex management of communal waterworks is under development at the Warsaw University of Technology, Institute of Automatic Control and Robotics, in cooperation with the Systems Research Institute of Polish Academy of Sciences.

INTRODUCTION

Currently, Polish water distribution systems are mostly controlled on the basis of decisions made by a master operator, with the use of information on a network status, including the failures reported by company employees or water consumers. By using these information, an operator determines the number and type of working pumps, thus controlling the pressure in the system and assuring the proper network operating conditions. This approach is effective when a network load is stable and predictable over time, and an operator has experience in network control. If the above mentioned conditions are not fulfilled, this approach may result in increased network failure rate, particularly in the case of too high pressure in the network nodes, excessive consumption of electricity in the water pumping stations or unsatisfactory fulfillment of the water consumers' needs.

Problem of water distribution network control is mainly related to determining pumps working time patterns and sequences of filling and draining expansion tanks. With the use of a mathematical model of the network and water consumption models, the working patterns of pumps for different days of the week at different seasons can be determined.

The operation of water networks is very complex problem. Moreover the operation of water distribution systems affects the water quality. It forces managers to accomplish a more reliable control of the operations that includes monitoring and optimization. Improvement in a system performance can be achieved through optimal operation of the water network. One of the main problems in the water distribution system operation is an effective control of pumps in the pump stations. In this way the pump scheduling is one of the most important tasks while operating a water distribution system.

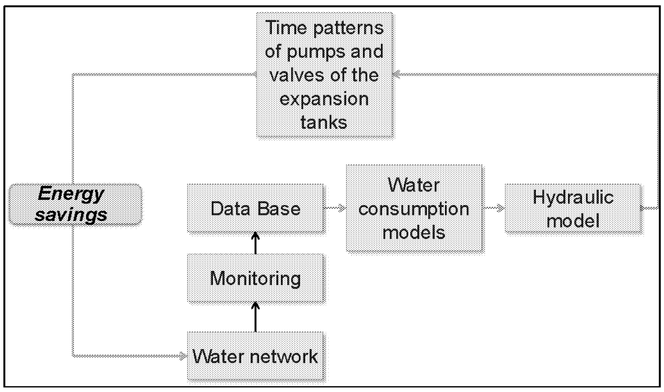

Figure 1. General scheme of application of a hydraulic model and of consumption patterns to determine a network control scenario.

There are also a lot of benefits coming from the reducing energy use at water networks. First of all energy efficiency saves money. We can achieve this by improving energy efficiency, which means using less energy to provide the same level of service and water quality. Also by reducing energy consumption we have a direct impact on reducing the greenhouse emissions and criteria air pollutants. Moreover energy efficiency can reduce air and water pollution from the power plants that supply electricity to water facilities, resulting in human health benefits.

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The pump scheduling is, in fact, a dynamic optimization problem. In these type of tasks and in particular in these ones described by algebraic and differential equations, in the presence of constraints on the states, there is in principle no universal numerical procedures, which could guarantee the high accuracy of the solutions with simultaneous nonrestrictive requirements for initial approximation of the solution (i.e. for the starting point of the optimization dynamic solver). Methods for solving nonconvex dynamic optimization problems based on an internal point or methods of active constraints are the natural choice for the solving pump scheduling task. Moreover, primal and dual interior point algorithms using an approach based on SQP (Sequential Quadratic Programming) and on effective procedures for solving quadratic tasks using the specific structure of rare Jacobian matrix and the Hessian of Lagrange function are commonly used in the field.

Some researchers are adapting (Pytlak 1999) procedures for solving the inner square method to the nonconvex tasks. As a result the applied procedures are being solved by external solver, e.g. ipopt, KNITRO or LOQO. However most of the modern optimization packages requires an explicit mathematical description of the controlled object. Furthermore, this description should be linear and at least twice differentiable (C^2 class). It is very time consuming to develop such description in the case of water distribution systems (Alvisi and Franchini 2014).

The hydraulic model of a network involves static nonlinear flow equations. Hazen-Williams approximation is commonly used for all pipe sections. A number of specific constraints define, for the purpose of optimization, the operation of PRVs and other active system components. In fact, modeling of such components as PRVs has to be, for the purpose of optimization, different from the description of those components as used for simulation (Błaszczyk et al. 2012). Optimization solvers require them to be represented by a set of constraints (Bragalli et al. 2012).

Moreover, the final description results in simplifications (Bragalli et al. 2012), which might affect the optimization quality.

On the other hand, the problem of efficient operation of pumps in water networks has been the subject to research over the last several years. As has been summarized in (Lopez 2008), several techniques have been proposed: linear (Jowitt and Germanopoulos 1992), non-linear (Chase and Ormsbee 1993; Yu et al. 1994), dynamic programming (Lansey and Awumah 1994; Nitivattananon et al. 1996), heuristic (Ormsbee and Reddy 1995; Leon et al. 2000) and meta-heuristics algorithms (Savic et al. 1997; van Zyl et al. 2004; Studziński and Kurowski 2014). Because of the large scale of the problem only algorithms based on meta-heuristics (evolutionary algorithms) have shown promised results and it seems that they could be used in the real-world water distribution networks. Despite the promising results of the research there is a very limited acceptance of optimal control models in engineering practice. A very important reason for the lack of the acceptance and of the models application was the unavailability of suitable and user-friendly computer systems for that purpose. There is some commercially available software for presented purpose but these are the systems dedicated to the particular and specified solutions. Moreover the systems that are distributed by renowned international companies are too expensive especially for Polish communal companies and their functionality there is usually limited. Implementation of such systems usually entails the need to hire highly qualified specialists from abroad. Moreover, managers of water utilities face numerous difficulties on account of the fact that the expert scientific knowledge needed is often not readily accessible and it is not available in a user friendly manner. Present study attempts to develop a decision support system that will perform, inter alia, the task of optimal control of pumps in water distribution systems.

MATHEMATICAL DESCRIPTION OF THE WATER DISTRIBUTION SYSTEM

The main task of a water supply system is to provide a sufficient amount of water at the appropriate pressure to all users of the system. Hence, each waterworks consists of three main components: pumps, storage tanks and distribution network. Most systems require pumps that allow to raise the water to the desired height and to cover energy losses due to friction. The pipes can be fitted with devices to control the flow or relief the valves.

Flows in a water supply system are calculated in accordance with the principle of conservation of mass and energy. The mass conservation law shows that the entire mass stored in the system is equal to the difference between inlet and outlet of flows. In the pressurized water distribution network, it is not possible to store water in pipes, although the levels in the tanks may change over time. For this reason, the input and output flow for each node in the network and the water supply pipe have to be balanced.

Assume we have a pipe network with N junction nodes and NF fixed grade nodes (tanks and reservoirs). Let the flow-headloss relation in a pipe between nodes i and j be given as:

$$H_i - H_j = h_{ij} = rQ_{ij}^n + mQ_{ij}^2 \tag{1}$$

where H is nodal head, h is headloss, r is resistance coefficient, Q is flow rate, n is flow exponent, and m is minor loss coefficient.

The value of the resistance coefficient will depend on which friction headloss formula is being used (see below). For pumps, the headloss (negative of the head gain) can be represented by a power law of the form

$$h_{ij} = -\omega^2 \cdot \left(h_0 - r \cdot \left(\frac{Q_{ij}}{\omega}\right)^n\right) \tag{2}$$

where h_0 is the shutoff head for the pump, ω is a relative speed setting, and r and n are the pump curve coefficients.

The second set of equations that must be satisfied is flow continuity around all nodes:

$$\sum_j Q_{ij} - D_i = 0 \quad dla \quad i = 1, \ldots, N \tag{3}$$

where D_i is the flow demand at node i and by convention, flow into a node is positive. For a set of known heads at the fixed grade nodes, we seek a solution for all heads H_i and flows Q_{ij} that satisfy Eqs.(1) and (2).

ALGORITHM DESCRIPTION

Designed algorithm for optimal pump switching is implemented in an iterative form (Fig. 2). The main goal of the algorithm is to schedule *N* pumps in the water distribution system over a time period, in our case 24 hours. During the operation of pumps some selected constraints must be satisfied while the objective cost function is minimized.

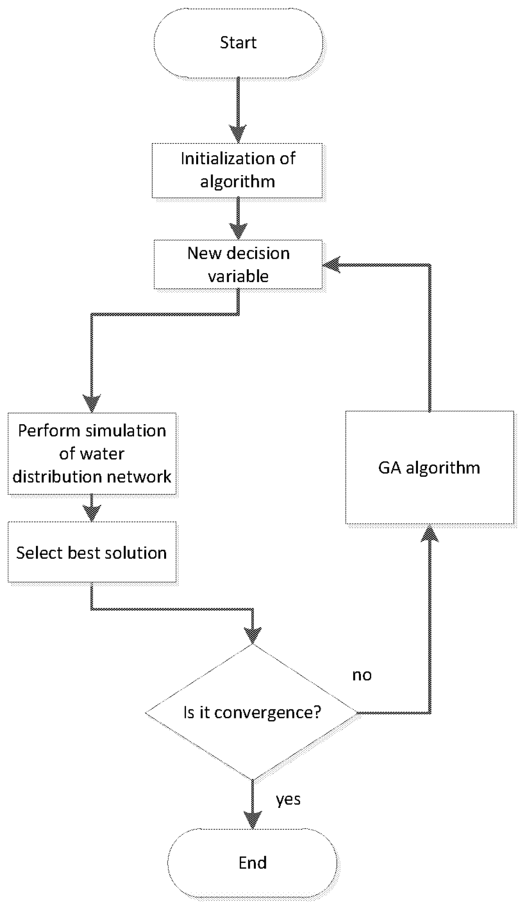

Figure 2. Flowchart of the Algorithm.

With the entered start and end time of simulation of a water distribution system as $t_{ni}, i = 1, \ldots, T_s$ at the interval the optimization task can be expressed as follows:

$$\text{minimize } \sum_{n=1}^{T_s} (E + D) \tag{4}$$

subject to:

$$L_{min_n} \le L_n(t) \le L_{max_n} \tag{5}$$

$$P_{min_k} \le P_k(t) \le P_{max_k} \tag{6}$$

$$S_l \le S_{max_l} \tag{7}$$

$$SP_{min_l} \le SP_l(t) \le SP_{max_l} \tag{8}$$

where: *E* – energy consumption cost, *D* – demand charge, $L_n(t)$ represents the level at *n* tank at time *t* and L_{min_n} and L_{max_n} are respectively minimum and maximum value of the level at *n* tank at time *t*, $P_k(t)$ represents the pressure at *k* node at time *t* and P_{min_k} and P_{max_k} are respectively minimum and maximum value of the pressure at *k* node at time *t*, S_l represents the number of pump switchings for pump *l* and S_{max_l} denotes maximum number of pump *l* switchings.

It is worth to notice that in order to reduce maintenance costs, an additional constraint on the number of pump switches is used. Additionally constranints of pumping cost minimization problem were formulated. These constraints include hydraulic constraints, representing minimum and maximum limits on the tank storage levels (Eq. 5), and minimum pressures requirements at the demand nodes (Eq. 6). Moreover, the minimum and maximum values of each pump normalized speed were defined (Eq.8).

Also for each pump the control setting is a value from 0 to 1 which is the normalized speed of the pump at a specific time *t* of simulation (Fig. 3).

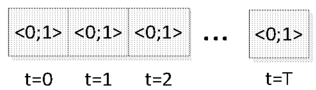

Figure 3. Representation of chromosome for a pump switching task

Each of the pump speed can be set as a real value from 0 to 1, where 0 denotes that pump is off and 1 denotes that pump operates in maximum speed. The genetic algorithm (GA) technique was used to obtain optimal solution for the pump scheduling problem. The GA are a method of search, often applied to optimization or learning (Golberg 1989).

The objective function (Eq. 4) includes costs of the energy, which varies over time: the energy consumption is charged basing on a tariff whose value varies over time. The energy consumed at considered period of the day is charged according to predetermined per unit cost and the remaining energy is charged according to current spot market price (rate). Hence, to compute power consumption at the pumping stations it is necessary to use aggregated pumping station efficiency curves. As a result the presented objective function (which looks simple) is, in fact, complex, non-convex and highly nonlinear.

EXAMPLE WATER DISTRIBUTION SYSTEM DESCRIPTION

The study of the Głubczyce town water network was performed using the developed control algorithm.

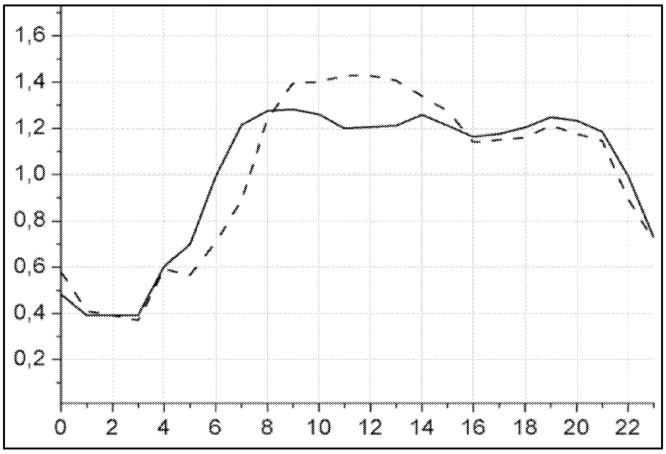

Figure 4. Demand pattern for the Głubczyce city.

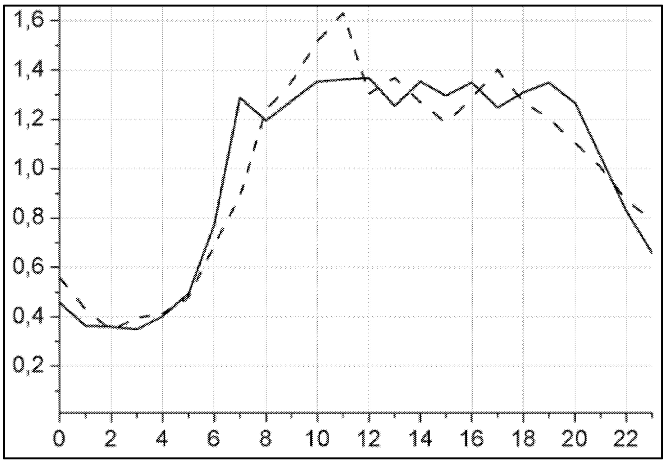

Figure. 5. Demand pattern for the Gadzinowice village (Głubczyce district).

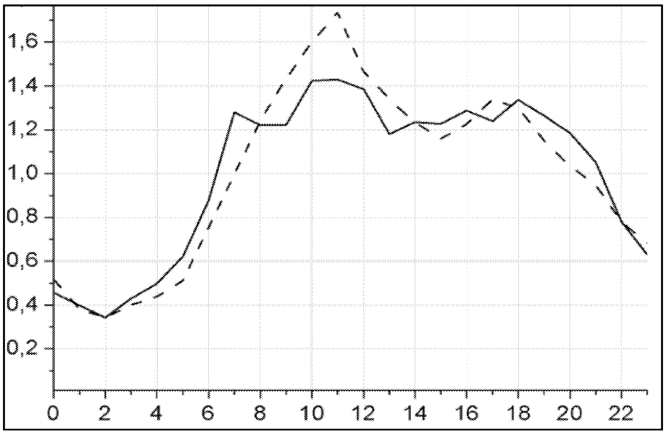

Figure 6. Demand pattern for the adjacent towns.

Głubczyce is a part of Opole local government voivodships, near the border with the Czech Republic It is situated on the Głubczyce Plateau on the Psina River. The Głupczyce water distribution system supplies with water 13 286 inhabitants. Curves of the water consumption in the city and in the adjacent towns are similar and shown in Figures 4, 5, 6.

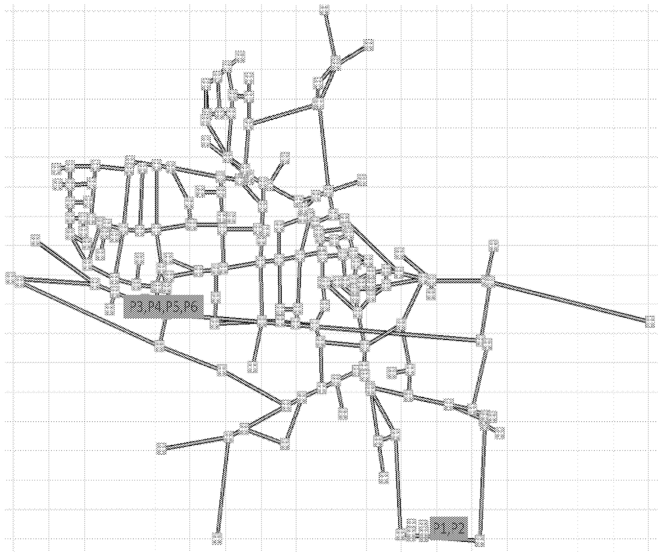

Figure 7. The Głubczyce Water Distribution Network.

In Fig. 7 the water distribution system of the Glubczyce water network is presented with *P1, P2, P3, P4, P5, P6* marked as the pump locations.

For the exemplary network given the following parameters were chosen for the GA algorithm:

- population size: 100
- crossover probability: 0,7
- mutation probability: 0,01
- generation size: 2.000.

As a result of the optimization procedure the sequences of pump speeds were obtained for the pumps marked as P3, P4, P5, P6 and P7.

Basing on the knowledge of experts working in the Głubczyce water network we decided not to take into account the pumps marked as P1 and P2. These pumps are designed for other purposes in the Głubczyce water distribution system.

The presented approach computes the optimal pump relative speeds for each pump based on the specified control time span, in such the way that the overall energy cost is minimized. In Figures 8, 9, 10, 11 the comparison between obtained values and those used during real operation of the water distribution system are shown. The results obtained from 10 different optimizations runs of the algorithm presented are very similar in respect to the value of the objective function. Moreover for all optimization runs, the GA results in lower cost with respect to this one generated during the real operation of the water distribution system. The best obtained improvement was equal to 23.6% of the energy costs. Of course it is not possible to obtain such the high value in a real network. Main reason for that is that the water distribution network model is not ideal. The quality of the water distribution system hydraulic model using in the calculation plays a very important role in terms of quality of the results of the developed optimization algorithm. Before applying the proposed algorithm a calibration process of the hydraulic model of the water distribution system investigated should be performed.

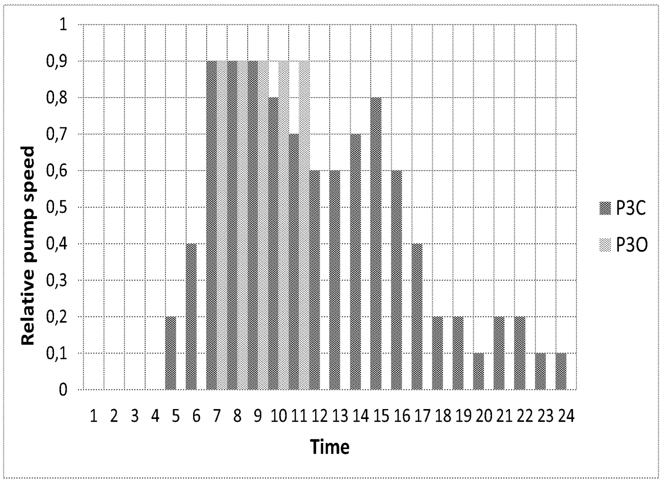

Figure 8. Control sequence for pump P3.

The quality of the obtained results is very similar to those ones obtained by other algorithms known from the literature (Lopez et al. 2008; Ormsbee and Reddy 1995; Savic and Walters 1997; Lansey and Awumah 1994; Kurek and Ostfeld 2013; Chase and Ormsbee 1993). The solutions presented in the literature describe mainly the results got only from simulation tests done with academic data. There are very few solutions implemented directly into a real water distribution system. In this paper the main emphasis is made on presenting solutions in the form of a comprehensive ICT system that could be used for the management of a real water supply network. In our opinion the algorithm presented is already mature to implement it into practice. Moreover the presented approach is now being implemented in the sub-region of the central and western province of the Polish Silesia.

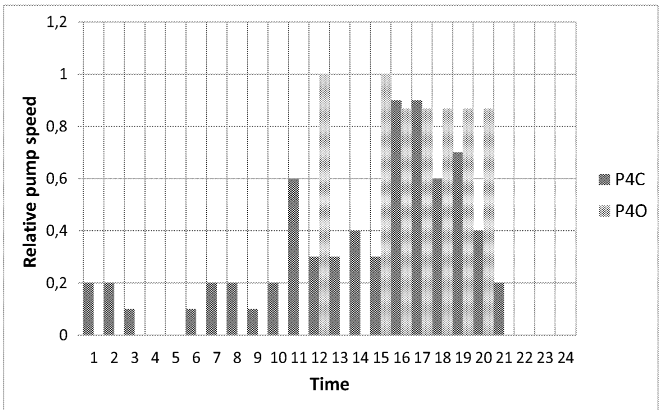

Figure 9. Control sequence for pump P4.

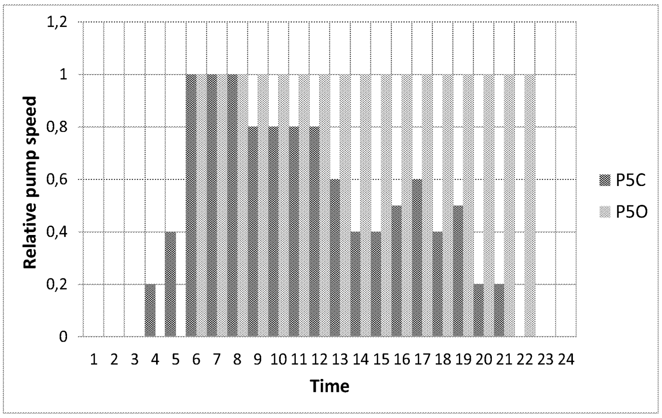

Figure 10. Control sequence for pump P5.

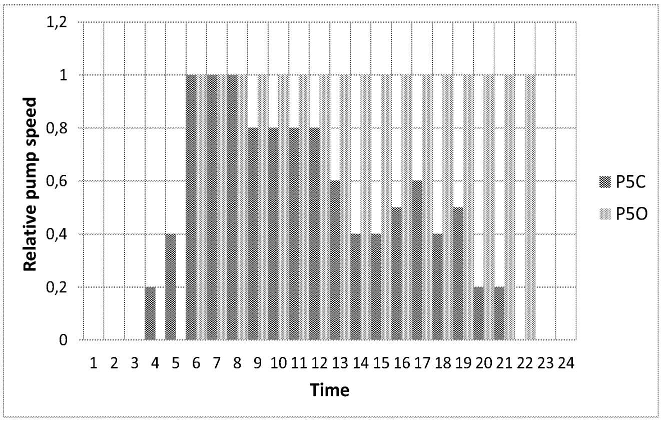

Figure 11. Control sequence for pump P6.

CONCLUSION

The paper presents the description of the IT solutions which have been applied in a computer simulation system for pump control of a water distribution system. An algorithm for solving pumping cost minimization problems was shortly described. The GA algorithm was used to solve the presented optimization problem. The case study was conducted using the Głubczyce water distribution system. The obtained results confirm the effectiveness of the algorithm. The implementation of the presented ICT system in the waterworks shall cut down the operational costs of the water net, boost its reliability and ensure a high and homogeneous quality of the water. The integrated ICT system shall also improve and make easier the job of the water net operators and planners and of the management staffs of the waterworks. The implementation of the ICT system shall be especially important and useful for city agglomerations running the complex and wide spread water networks. However it requires having a high quality hydraulic model of the water distribution system investigated. In the near future the proposed algorithm will be tested and implemented in the sub-region of the central and western province of Silesia in Poland.

ACKNOWLEDGEMENT

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A NUMERICAL ANALYSIS OF SUPERCRITICAL CO_2 INJECTION INTO GEOLOGICAL FORMATIONS

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KEYWORDS

Modelling Carbon Sequestration, CO_2 Storage Capacity, CO_2 Storage Efficiency, Simulation of CO_2 Sequestration, Injecting CO_2 into Saline Aquifers.

ABSTRACT

One of the most promising means of reducing carbon contents in the ambience and tackling the global warming threat is injecting carbon dioxide into deep saline aquifers (DSAs). Selecting a site to store CO_2 depends on many controlling parameters including permeability, heterogeneity, hydrostatic conditions, injection scenarios and domain grid resolution. In this research study, we aim to investigate the influence of different injection scenarios and flow conditions on the storage capacity and efficiency of CO_2 in geological formations. This is carried out through a series of numerical simulations employed on 3-D hypothetical homogeneous and heterogeneous aquifers utilizing STOMP-CO_2 simulation code. The results of this work are expected to play a key role in providing insight knowledge for assessing the feasibility of various geological formations for CO_2 storage.

1. INTRODUCTION

Injecting CO_2 into deep saline aquifers (DSAs) is one of the most viable means of tackling the global warming arising concern, which has become a critical warning to the universe. This is owing to that these aquifers offer more extensive storage potential than other geological formations and that technology is immediately applicable due to the experience gained from oil and gas exploration and waste disposal methodologies (IPCC, 2005). Consequently, many research studies have been conducted to assess their storage capacity and efficiency to inject and sequester CO_2 safely. In spite of the high uncertainty because of the lack of geological data, these assessments propose considerable value to understand the deployment of CO_2 sequestration in saline aquifers across the globe.

The suitability of any potential storage site CO_2 is assessed based on its geological characteristics including; capacity and injectivity, hydrostatic conditions, the integrity of the cap rock, porosity and permeability.

Theoretically, the storage capacity of an aquifer is the substantial limit of CO_2 that can be admitted into it. However this limit is not practically achievable due to various geological factors and engineering barriers, therefore a new term called effective storage capacity has been a subject of many researches using different calculation methods. A detailed comparison study by (Goodman et al. 2013) has been conducted to evaluate the impact of a variety of approaches and methodologies on estimating CO_2 sequestration in geological formations. They include; the method employed by Carbon Sequestration Leadership Forum (CSLF) (Bachu et al. 2007), an analytical methodology by (Zhou et al. 2008), and the widely used method by U. S. Department of Energy (US-DOE) which has been adopted in this research work. It assumes infinitive-boundary conditions and determines the CO_2 mass storage capacity and efficiency for an aquifer by;

$$G_{CO_2} = A_t h_g \emptyset_t \rho_{CO_2} E_{aq} \tag{1}$$

Where A_t is the total cross-sectional area of the domain, h_g defines the gross thickness of the formation, $\emptyset_t$ is the total porosity of the rock, ρ_{CO_2} and E_{aq} represent CO_2 density and storage efficiency of the aquifer respectively.

A recent method developed by (Szulczewski et al. 2012) considers both residual and solubility trapping mechanisms in addition to the CO_2 migration capacity. Unlike the US-DOE methods, it counts the net thickness of the aquifer to calculate the pores volume.

For the open-boundary systems, the total mass of CO_2 (C_t) in an aquifer can be determined by;

$$C_t = \rho_g L_t W H \emptyset (1 - S_{wc}) \frac{2}{\varepsilon_T} \tag{2}$$

where ρ_g is the density of CO_2, L_t is the migration length, W is the width of the well, H is the net thickness of the aquifer, $\emptyset$ is the porosity of the rock, S_{wc} defines the connate water saturation and $\frac{2}{\varepsilon_T}$ represent the storage efficiency factor.

For the pressure-limited systems, the CO_2 mass is calculated by;

$$C_p = \rho_g H W \sqrt{\frac{k_{aq} c T}{\mu_w}} \frac{P_{fraq} - (p_o + \overline{\rho_w} g D)}{4 \tilde{p}_{max}} \tag{3}$$

Where k_{aq} is the permeability of the aquifer, c is the compressibility, T is the temperature, μ_w is the brine viscosity, P_{fraq} is the fracture pressure of the rock.

p_o is the hydrostatic pressure, $\overline{\rho_w}$ is the average density of brine, g is the gravitational acceleration, D is the depth to the top of the aquifer and $\tilde{p}_{max}$ represents the maximum dimensionless pressure, which can be determined by numerically solving the partial differential equation (PDE) for the pressure-limited flow system.

2. MODEL SETUP

To assess the storage capacity and efficiency in open storage aquifers, a cylindrical computational domain extending from 0.3 m to 6000 m laterally and 96 m vertically, was stipulated with two types of grid resolution namely, coarse and fine grids. For the coarse-grid the domain was discretized with 88 and 24 nodes in the horizontal and vertical directions respectively elements. For the fine resolution, the grid spacing was increased by 100% in both directions. Supercritical CO_2 ($ScrCO_2$) to be injected into the centre of the domain at a constant rate of 32.0 Kg/s (about 1 MMT/year) which represents a typical benchmark value, via number of cells at the lower section of the reservoir.

The simulation parameters used for this work are based on the geological settings for Sleipner Vest Field which is located in Norwegian part of the North Sea at an approximate depth of 110 m. All petrophysical parameters are listed in Table 1.

Table 1, Lithostratigraphic Division and Petrophysical Parameters from Sleipner Vest Field, after (White et al. 2013).

Parameter	Units	Sands	Shales
Thickness	(m)	30	3
Porosity	-	0.35	0.1025
Horizontal permeability	(m^2)	$3.0e^{-13}$	$0.1e^{-13}$
Vertical permeability	(m^2)	$3.0e^{-13}$	$0.1e^{-13}$
Density	(kg/m^3)	2650	
Pore Compressibility	(Pa^{-1})	$4.5e^{-10}$	
Aquifer pressure	(MPa)	11.2	
Pressure gradient	(KPa/m)	10.012	
Aquifer temperature	(°C)	37	
Salinity	Wt%	0.032	
Aquifer depth	(m)	800-1100	
Water depth	(m)	110	

The CO_2 properties adopted in our simulation code have been arranged in a data table developed from the equation of state by (Span and Wagner 1996). The phase equilibria calculations in STOMP-CO_2 code are conducted via a couple of formulations by (Spycher et al. 2003) and (Spycher and Pruess 2010) that are based on Redlich-Kwong equation of state with fitted experimental data for water-CO_2 flow systems. Details of these equations can be found in the STOMP-CO_2 guide by (White et al. 2013).

Aqueous saturation (S_w) is calculated by (Van Genuchten 1980) formulation that correlates the capillary pressure (P_c) to the effective saturation (S_e);

$$S_e = \frac{S_w - S_{wr}}{1 - S_{wr}} = [1 + (\alpha . P_c)^n]^m \quad \text{for } P_c > 0 \qquad (4)$$

Where S_{wr} is the water residual saturation and α, n and m are the Van Gunechten parameters that describe the characteristics of the porous media. Formulations factors used in the equations above are listed in Table.2.

Table 2, Functions Parameters of the simulated aquifer, after (White et al. 2013*, Holtz 2002**).

Description	Symbol	Value	Units
Irreducible aqueous saturation*	S_{lr}	0.2	-
Irreducible gas saturation*	S_{gr}	0.05	-
Van Genuchten parameter for (Sand)*	α	2.735	m^{-1}
Van Genuchten parameter for (Shale)*	α	0.158	m^{-1}
Saturation function parameters*	m	0.4	-
	n	1.667	-
Pore index parameter	λ	0.667	-
Max. residual gas sat. for aquifer**	S_{grm}	0.208	-
Max. residual gas sat. for aquitard**	S_{grm}	0.448	-

During the injection period (drainage process), there is no gas entrapment therefore the injected CO_2 can be either existed as free or trapped gas. STOMP-CO_2 code deploys a model developed by (Kaluarachchi and Parker 1992) to compute the potential effective trapped gas by;

$$\hat{S}_{gt}^{potential} = \left[\frac{1 - \hat{S}_l^{min}}{1 - R\left(\hat{S}_l^{min}\right)}\right] \qquad (5)$$

Where $\hat{S}_l^{min}$ is the minimum aqueous saturation and R is the Land's parameter (Land 1968) which relates to the maximum trapped gas saturation;

$$R = \frac{1}{\hat{S}_{gt}^{max}} - 1 \qquad (6)$$

The aqueous and gas relative permeabilities are computed by (Mualem 1976) correlation in combination with (Van Genuchten 1980) formulation according to the following Equations (7) and (8) respectively;

$$k_{rl} = (\bar{S}_l)^{1/2}\left[1 - \left(1 - \left(1 - (\bar{S}_l)^{1/m}\right)^m\right)\right]^2 \qquad (7)$$

$$k_{rg} = \left(1 - \bar{\bar{S}}_l\right)^{1/2}\left[1 - \left(1 - \left(1 - \left(\bar{\bar{S}}_l\right)^{1/m}\right)^m\right)\right]^2 \qquad (8)$$

Where m is the pore distribution index, $\bar{S}_l$ is the effective aqueous saturation which is calculated from Eq.(4) and $\bar{\bar{S}}_l$ represents the apparent aqueous saturation which is defined as the sum of the effective aqueous and entrapped CO_2 saturations (White and Oostrom et al. 2004).

3. INITIAL AND BOUNDARY CONDITIONS

The simulated domains adopted in this study are assumed to be isotropic and isothermal under hydrostatic pressure gradient of 10.012 KPa/m with an open boundary condition. The domains are symmetrical with no heterogeneity in the azimuthal direction. The aquifer is considered to be fully saturated with brine prior to injecting $ScrCO_2$ with initial conditions illustrated in Table 1. No flux boundary condition is considered for the aqueous wetting phase (brine) at the injection well border as a West boundary whilst the East boundary was set to be infinite with zero flux for CO_2. Zero flux is also considered at the top and bottom confining layers with the ignorance of gravity and inertial effects.

The injection rate for our system was set according the fracture pressure (P_{frac}) using the simplified model adopted by (Szulczewski, MacMinn et al. 2011) which calculates the pressure-limited storage capacity by;

$$M_p = 2\rho_{CO_2} HW \sqrt{\frac{kC}{\mu_b T}} \frac{P_{frac}}{\hat{p}_{max}} \quad (9)$$

Where all variable defined in Eq.(3) above.

For infinitive aquifer, the value of the maximum dimensionless pressure ($\hat{p}_{max}$) in Eq.(9) is about 0.87 (Szulczewski, MacMinn et al. 2011). All parameters in Eq.(9) are known except the fracture pressure of the rock which can be defined as the effective vertical stress for deep aquifers and determined by Eq.(10) (Szulczewski 2009);

$$\sigma_v' = (\rho_b - \rho_w)Z \quad (10)$$

Where ρ_b , ρ_w represent bulk and brine densities respectively and Z is the depth of the aquifer.

From equations (9-10) we set the value of the injection rate for our model at 32 Kg/s. According to Eq. (9), this rate results pressure build-up values less than 1.5 magnitudes of the hydrostatic pressure that are far away from the average default values of the sustainable pressure.

4. METHODOLOGY

Generally CO_2 sequestration efficiency in saline aquifers can be assessed by using the equation developed by USDOE (Wang et al. 2013);

$$E_{aq} = {G_{CO_2}}\Big/{A_t h_g \emptyset_{tot} \rho} \quad (11)$$

Where G_{CO_2} is the mass of CO_2, A_t, h_g *and* $\emptyset_{tot}$ represent the area, thickness and average porosity of the aquifer respectively. ρ, is the density of CO_2.

In this study case we used an archetype of actual field heterogeneity in a domain that consists of three stratums of sands intermingled with two layers of low permeability shales. Six simulation cases (presented in Table 3.) were setup to demonstrate different models of the computational domain.

Table 3. Simulation Cases and Conditions

Case No.	Domain	Hetero-geneity	Grid	Nodes (r,θ,z)	Injection scheme
1	Homo-geneous	N/A	coarse	88,1,24	30 yrs continuous
2	Hetero-geneous	uniform	coarse	88,1,24	30 yrs continuous
3	Hetero-geneous	non-uniform	coarse	88,1,24	30 yrs continuous
4	Hetero-geneous	non-uniform	coarse	88,1,24	batch* 10-5-10-5-10
5	Homo-geneous	N/A	coarse	88,1,24	batch* 10-5-10-5-10
6	Homo-geneous	N/A	Fine +100%	176,1,48	30 yrs continuous

* Batch injection schemes refer to the years of (injection – stop – injection – stop – injection).

The first injection scheme involved 30 years of continuous injection and in the second scenario the injection period was divided into three stages of 10 years separated by two stopping periods of 5 years in between. In all cases, the total simulation time was 5000 years including injection and stopping times.

Because of the density difference driving forces between the injected CO_2 and the existing brine, initially the former percolates upward to be trapped under the upper impermeable layer. During this time, part of the gas dissolves in the brine forming an aqueous phase rich of CO_2 which is heavier than the ambient liquid and hence sinks down to settle at the bottom of the aquifer. As soon as the injection stops the replaced water (brine) invades the domain to reinstate the CO_2 leaving some traces of it behind in some small-sized pores in a process called residual or capillary trapping. These amounts of CO_2 are determined by the simulation code for different cases and utilized to calculate the capacity and efficiency factor of the simulated aquifer;

Total integrated CO_2 = Integrated aqueous CO_2 (CO_2^{aq}) + Integrated gas CO_2 (CO_2^{g}) (12)

CO_2^{g} = Trapped gas (CO_2^{gt})+ Free gas (CO_2^{gf}) (13)

$$E_{aq}^{perm} = \frac{CO_2^{aq} + (CO_2^{gt})}{A_t h_g \emptyset_{tot} \rho} \quad (14)$$

Where all parameters were explained in Eqs.11.

In our work the focus is on the storage efficiency of the aquifer in terms of the permanent sequestration of the injected CO_2 which in our case of study, occurs mainly through solubility and residual trapping due to the insignificant influence of the mineral trapping mechanism before few thousands of years (De Silva and Ranjith 2012).

5. RESULTS AND DISCUSSIONS

To asses our numerical simulation validity we plotted the results versus the similarity variable (r^2/t) that relates the variable dependence on both lateral distance and simulation time for four time steps at a radial distance of 500 m, (O'Sullivan 1981, Doughty, Pruess 1992). Fig. 1 presents changes in the average capillary pressure values with the similarity variable. The plot shows excellent agreement for all time steps, which reflects the high accuracy of our simulation results.

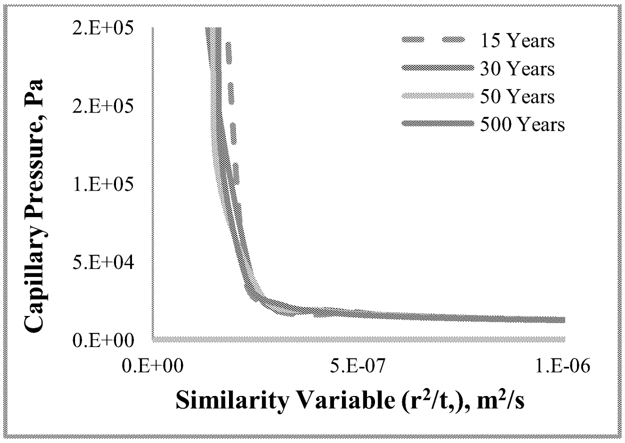

Figure1. Capillary Pressure Development as a function of the Similarity Variable at 500 m radial distance.

5.1. Impact of Heterogeneity

To investigate the impact of heterogeneity on the propagation of CO_2 profiles, saturation-capillary pressure relationships and storage efficiency, three numerical cases (1, 2 and 3) with their employed conditions illustrated in Table 3. have been developed in this study.

Permeability of geological formations is strongly related to their porosity any heterogeneity, which is a key role in controlling water-CO_2, flow in sequestration sites. Heterogeneity is found to have significant impact on capillary pressure-saturation relationships as illustrated in Fig.2, which demonstrates significantly higher values of capillary pressure for both heterogeneous domains.

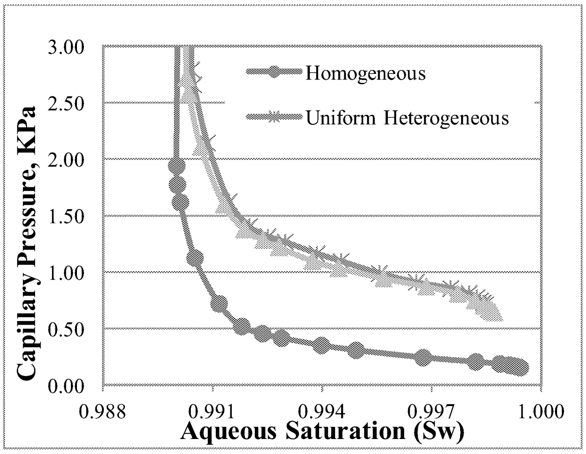

Figure 2. Effect of Heterogeneity on Saturation-Capillary Pressure relationships.

This influence is evidently reflected on the amount of trapped CO_2 because higher values were achieved in heterogeneous formations. This is owing to the existence of intermingled layers of shale that restrict the injected gas from moving between layers of the domain which results in less contact with brine and consequently less subjectivity of gas entrapment in more small-sized pores.

Fig.3 demonstrates no effect of heterogeneity on CO_2 solubility before 800 years of simulation. After this time, it is observed that more CO_2 dissolved in the homogeneous domain compared to both types of heterogeneous ones by about 15% at 2000 years of simulation.

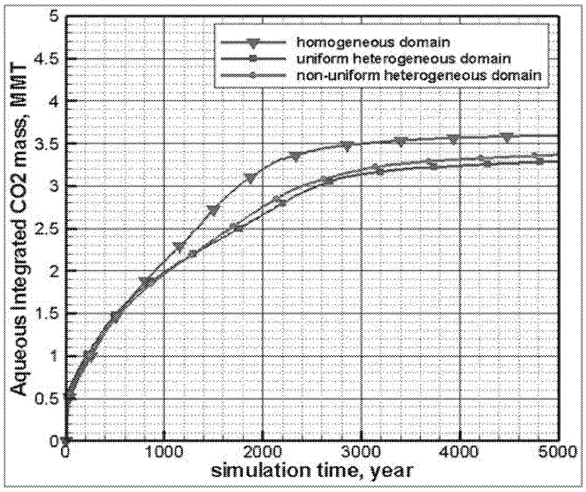

Figure 3. Effect of Heterogeneity on CO_2 Solubility.

5.2. Impact of Cyclic Injection

To inspect the effect of cyclic injection of CO_2 on the characteristics of sequestration in saline aquifers, four schemes of injection were employed in cases 1, 3, 4 and 5 (shown in Table 3) using continuous and cyclic injection scenarios in different porous domains. Injected CO_2 distribution contours after 100 years of simulation in Fig.4 display almost equal maps of carbon dioxide distribution in the homogeneous domain for both continuous and cyclic injection of 30 years. However, the impact of injection scenario is more obvious in the heterogeneous domain map in Fig.5(c-d) where more gas is exposed to be dissolved or trapped in the lower and middle segments of the domain for cyclic injection.

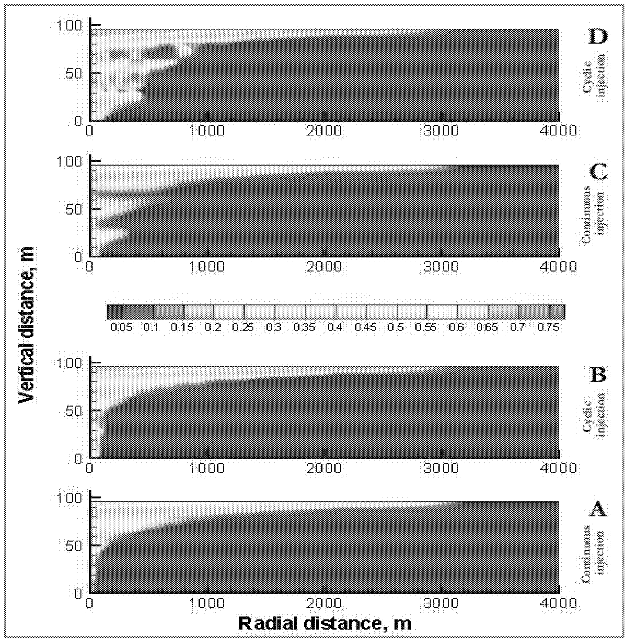

Figure 4. CO_2 plume evolution in Cyclic and Continuous schemes of injcetion.

Additionally, results reveal no effect on the amount of CO_2 dissolution in homogeneous domain as demonstrated in Fig.5 however less dissolved CO_2 was achieved in the case of cyclic injection into heterogeneous domain after 2000 years.

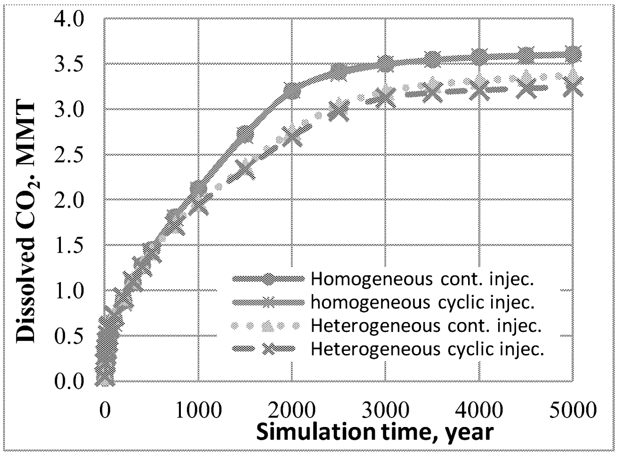

Figure 5. Effect of Injection scheme on CO_2 Solubility.

Similarly, for trapped CO_2, no sensitive impact of cyclic injection was observed for homogeneous media in spite of a slight difference shown in Fig.6 after 3500 years of simulation. Residual trapping of CO_2 in heterogeneous media was found to be more sensitive to injection method because simulation results revealed that more CO_2 was trapped in cyclic injection case compared to continuous one specifically after 300 years as illustrated in Fig.6.

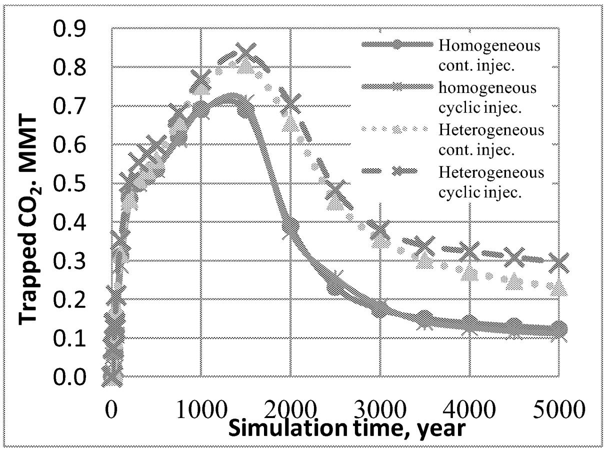

Figure 6. Effect of Injection scheme on Residual Trapping of CO_2.

According to the attained results, injection scheme appears to have no influence on the storage efficiency of CO_2 in geological formations. However, more research work is required to investigate the optimization of the cyclic injection in terms of injection and stopping intervals in long-term sequestration projects.

6. CONCLUSIONS

A set of numerical simulation cases were developed and conducted using STOMP-CO_2 simulation code to investigate the influence of various types of heterogeneity, injection schemes and grid resolution on CO_2-water flow system behaviour and storage efficiency in saline aquifers. The conclusions of the results can be summarized as follows;

1- Heterogeneity has significant impact on saturation-capillary pressure relationships because results demonstrated greater values of capillary pressure at any specific saturations in heterogeneous domains compared to homogeneous ones. Consequently, this amplifies the residual trapping of the injected gas in heterogeneous geological formations.

2- The presence of intermingled layers of shales in sand rocks increases the storage efficiency to a limited extent because it promotes more CO_2 dissolution in the existed brine by restricting the vertical migration of the injected gas and maintaining more contact with the hosted brine.

3- Using cyclic injection scheme appeared to have no sensitive influence on the storage efficiency of CO_2 in geological formations in medium terms of sequestration however; this finding requires more research work to investigate the impact of CO_2 injection methodology in closed aquifers for longer terms of sequestration.

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LATE PAPER

Generic Product Creation System

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KEYWORDS

Holistic Product Creation System, Strategic Planning, Product Engineering, goals, guiding principles, methods, tools

ABSTRACT

Contemporary Holistic Production Systems improve competitiveness and increase profitability of a company by providing joint alignment of entrepreneurial activities across all levels of management in the short, middle and long term point of view. The core action focus of Holistic Production Systems lies in optimizing material and information flows within order processing in production. Enablers for competitive and profitable production are to be found in Product Creation, particularly Strategic Planning and Product Engineering. However, the action field of Product Creation is hardly covered by any Holistic Production System.

Therefore, a corresponding Generic Product Creation System (GPCS) has been developed and prepared for enterprise specific configuration. The degree of novelty of this contribution lies in transferring the core ideas of Holistic Production Systems to the action field of Product Creation while specifying and paying tribute to specific conditions and elements of Product Creation, such as the subordinate role of material flows.

1 INTRODUCTION

In order to improve competitiveness and increase profitability of a producing company, common guidelines for management and operations have to be set and followed. Entrepreneurial activities at all management and operational levels must be consequently and holistically aligned towards short, middle and long term goals.

In terms of order processing in production, this goal has been pursued using Lean Production Systems since the 1990s in Germany (VDI 2870). Lean Production Systems originate from the Toyota Production System (Ohno 1988). Their core focus lies on optimizing material and information flows in manufacturing and assembly. Main goals lie in improving customer orientation, avoiding waste and improving structures and processes continuously (VDI 2870).

Cause and effect chains of competitiveness and profit orientation, however start much earlier, i.e. with strategic orientation of a company, product engineering and production planning. These tasks are described within the field of action of Product Creation (Chapter 2). Product Creation activities therefore also are to be initiated and aligned holistically towards entrepreneurial goals. In order to provide a generic framework for such joint orientation, a corresponding approach to Lean Production Systems is chosen and a Generic Product Creation System (GPCS) has been developed, which will be proposed in Chapter 3. For this, specific conditions of Product Creation Processes have been taken into account. As an example, order fulfillment within Product Creation is mainly characterized by information flows. Material flows only play a subordinate role, e.g. representing result status using physical prototypes. As another important restriction, a continuous evolution from original mechanical engineering towards mechatronic systems engineering takes place. The Generic Product Creation System therefore must take the multidisciplinarity in product engineering into account.

In order to implement the Generic Product Creation System in a company, the generic structure and elements must be configured and prioritized according to specific restrictions of the company, the regarded branch of industry, product segment and application where necessary.

2 ACTION FIELD OF PRODUCT CREATION

The action field of Product Creation comprises Strategic Planning and Innovation Management, Systems Engineering, Production Management and Virtual Engineering (figure 1). Based on the strategic orientation of a company, the most promising ideas for product innovations are detected in Strategic Planning and Innovation Management. As market-driven inputs, future customer requirements of existing markets (market pull) as well as possibly developable new markets (blue ocean strategy) are anticipated. A product innovation will only be successful at the market, if the envisioned market segment has sufficient volume and purchasing power. As a prerequisite from a technological point of view, new basic developments in product and production technologies are needed (technology push). As a result of strategic planning and innovation management, selected promising product ideas are assigned to product engineering.

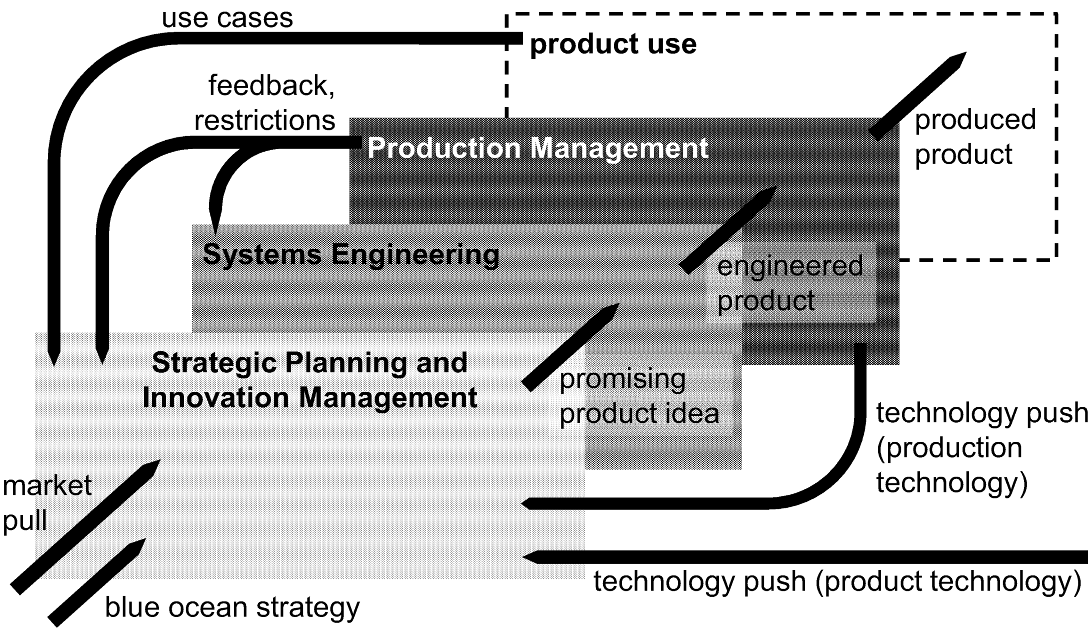

Figure 1: Action Field of Product Creation

In case of mechatronic and Cyber-physical systems, assigned product ideas are engineered in a multidisciplinary way searching for an overall optimum across the disciplines. Following systems engineering approach, technical aspects are geared with organizational aspects. For example, project team structure is derived from functional product architecture. Considering existing definitions from relevant professional societies (Weilkiens 2004, INCOSE 2014) and taking implementation relevant aspects into account, the term Systems Engineering is defined as follows:
"Systems Engineering constitutes a structured multi-disciplinary approach for the development of complex technical systems. The goal is to achieve an optimum across disciplines in a specified time frame and budget. For this purpose, the discipline specific views are structured and linked up using models." (Graessler 2015)

In parallel to product engineering, suitable production concepts including logistics concepts, production line design and shop floor layout are planned within Production Management. Resulting restrictions are fed back towards product engineering. The element "Production Management" of the action field Product Creation builds the interface to current Holistic Production Systems.

Virtual Engineering serves as the enabling element to all other elements of the action field. Virtual Engineering comprises Virtual Reality and Augmented Reality. Virtual Reality describes the CAx specific representation of the respective result level in Strategic Planning and Innovation Management, Systems Engineering and Production Planning. An integrated product and process model serves as the basis of representation. Augmented Reality supports by providing additional information to the graphical representation of products and processes. Thus, pictures or videos are supplemented with computer-generated virtual objects or additional information by means of insertion or superposition. For example manufacturing or assembly instructions can be provided to line operators using Augmented Reality.

3 STRUCTURE AND CONTENTS OF GPCS

A Lean Production System forms a company-specific, methodological set of rules for comprehensive design of company processes and structures (Dombrowski et al. 2006). Thus, it contributes significantly to secure and increase the competitiveness of a company (VDI 2870). Transferred to multidisciplinary product engineering, such a set of rules enables a sustainable increase in effectiveness and efficiency.
Further, a Lean Production System supports the cultural change among employees at all levels towards a continuous improvement mentality (VDI 2870). The early experiences with the introduction of Lean Production Systems show that it is not the type and number of applied methods and tools which are critical to success, but rather to understand the cause-effect relationships ("understand" instead of "copy"), see also (VDI 2870).

Corresponding to the industrially prevalent concepts of Lean Production Systems (Dombrowski et al. 2006), a Generic Product Creation System (GPCS) has been developed. In the following, structure and contents of the Generic Product Creation System are presented. The basic structure of the Generic Product Creation system is based on an approach of Ankele et al. and structured into the levels objectives (value system), guiding principles (classification system) and building blocks: methods and tools (working system), figure 2, compare (Ankele et al. 2008).

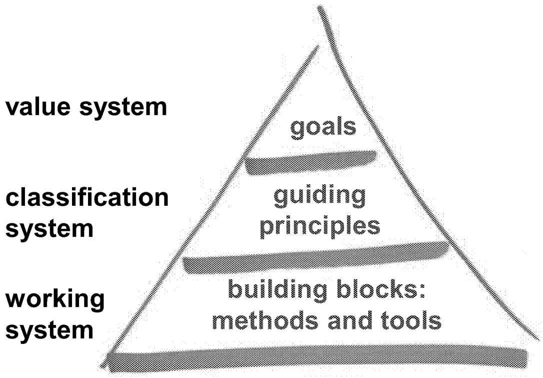

Figure 2: Basic structure of the GPCS, inspired by (Ankele et al. 2008)

Due to documented guiding principles, employees as well as managers are put into the position to measure their actions and decisions by the defined guiding principles (classification system) and their contribution to the underlying business objectives (value system). Guiding principles are operationalized by standardized building blocks, i.e. methods and tools. These building blocks enable the realization of the guiding principles and form the working system. Their standardization is an important prerequisite for managing and continuously improving Product Creation.

The proposed structure serves as a generic framework and as a basis of a company-specific Product Creation System. Objectives, guiding principles and building blocks of the Generic Product Creation system must be configured and prioritized according to specific restrictions of the company, branch of industry, product segment and application where required. Company specific configuration is valid for a specific time horizon. After this time period, they have to be questioned and updated. Overall entrepreneurial goals which are defined in the value system affect the whole company and should be orientated for a long term, e.g. 5-10 years. Guiding principles are deduced from the goals according to the particular function, such as strategic product planning, sales & marketing, product engineering or manufacturing. They should be set up for a mid-term, such as 2-5 years. Standardized methods and tools are applied in projects and tasks, which results in rather short time spans of about 1-2 years, until the working system has to be updated.

4 VALUE SYSTEM OF GPCS

The detail structure of the Generic Product Creation System has been drafted according to the specific conditions of product creation. In the following, a generic instantiation is proposed in order to illustrate the application.

The value system answers the question:
"What do we strive for in Product Creation?"
Starting from general entrepreneurial goals, such as market share, profit, liquidity, flexibility and adaptability, specific goals for product creation are deduced. The value system thus is divided into the following goals being relevant for product creation:

- Excellence in Product Creation
- Convincing Product Functionality
- Zero-Defect Quality in Products and Processes
- Target Costing (setting & realizing target costs)
- Short Lead Times from Strategic Planning to Market Entry

The two goals "Excellence in Product Creation" and "Short Lead Times from Strategic Planning to Market Entry" address all elements of the action field Product Creation. "Convincing Product Functionality" is realized in Strategic Planning/Innovation Management and Product Engineering. "Zero-Defect-Quality in Products and Processes" is worked upon in Product Engineering and Production. "Setting Target Costs" is addressed within the Strategic Planning/ Innovation Management while "Realizing Target Costs" leads towards Product Engineering and Production. This analysis shows all relevant elements of the action field Product Creation which is represented by the above listed initial generic instantiation of the value system.

5 GUIDING PRINCIPLES OF GPCS

In order to achieve the company's objectives, twelve guiding principles have been defined which build the necessary framework of action and decision-making (figure 3).

For detection and selection of guiding principles, proper preparations for the concept and industrial implementation of Product Development Systems found their input (Graessler 2003 and Graessler 2012). These were transferred to the considered Field of Action Product Creation and supplemented by the missing aspects. First implementation examples of Product Development Systems can be found at large companies in the automotive and capital goods industries, see also (Graessler 2003 and Graessler 2012).

6 BUILDING BLOCKS

Guiding principles are realized by standardized building blocks. Building blocks comprise established methods and tools which are recommended in dependence of application criteria. Possible building blocks within Strategic Planning and Innovation Management are:
- Business model definition
- Conjoint analysis
- Scenario technique
- Anticipating future requirements
- Exploring use cases
- Balanced Score Card and strategy implementation
- Portfolio analysis

Examples of building blocks within product engineering are:
- Design for X
- Systems engineering

- Lean engineering
- Iterative and incremental planning
- Models and simulation
- Verification and validation

Production building blocks are for example:
- Zero-defect quality
- One-piece flow
- Supermarkets on shop floor level
- Total Productive Maintenance
- Job rotation and enrichment

guiding principles	definition	all functions	strategic planning	M & product engineering	production planning
1. result orientated	Focus on economic performance variables such as rate of return, time and cost compliance			X	X
2. transparent	performance, quality, milestone status, implementation difficulties are always known		(X)	X	X
3. robust	Repeatability and Insensitivity to disturbances			X	X
4. open to change	managing uncertainty and flexibility towards environment or customer induced change requests		X	X	
5. fast	short lead times from strategic business area planning to market launch	X			
6. test driven	model based verification and validation of the respective result levels based on simulations and experiments			X	
7. multidisciplinary	information driven cross linking of involved disciplines with the aim to generate a higher-level optimum			X	
8. promoting innovations	systematic generation and realization of promising product ideas		X		
9. application orientated	consequent orientation of product creation on use cases and experience worlds		X	X	(X)
10. standardized	using scale and learn effects by reuse of products and processes			X	X
11. employee-centered	considering employee perception and needs with the goal of high identification	X			X
12. continuously improving	continuous improvement of employee participation, technology, IT-tools, organization, processes and methods	X			

Figure 3: Guiding principles and their classification

7 SUMMARY AND FUTURE PERSPECTIVES

In this paper a Generic Product Creation System (GPCS) was developed starting from defining and delimiting the action field of Product Creation.

As basis structure of GPCS, the widespread industrial Lean Production Systems are used as a model. The GPCS comprises a value system, a classification system and a working system. High implementation and results orientation is thus ensured. The success factor lies in the understanding of cause and effect relationships. The classification system of the developed product creation system is specified by twelve guiding principles. This characterizes the framework of action and decision making. Building blocks enable the realization of guiding principles and form the working system. Their standardization is an important prerequisite for Continuous Improvement Process.

For implementing the Product Creation System in industrial practice, a role model is necessary, in which roles and responsibilities of building block experts, process owners and promoters are defined.

Objective of future research is the development of a generic multidisciplinary reference model for product creation.

BIOGRAPHY

Prof. Dr.-Ing. **IRIS GRAESSLER** studied mechanical engineering and graduated in 1999 as a PhD (Dr.-Ing.) at Aachen University of Technology (RWTH Aachen), Germany. In 2003 she qualified as a university lecturer (Habilitation) at RWTH Aachen. For 14 years she has been working at Robert Bosch GmbH in several management functions in the field of Innovation Management, Product Engineering, Lean Manufacturing and Continuous Improvement Process. Since 2013 she is in charge of the Chair for Product Creation at the Heinz Nixdorf Institute at University of Paderborn.

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