Modelling, Optimization, and Simulation of Several First Aids in an Area with Plant Simulation

Jolana Sebestyénová[a] and Peter Kurdel[b]
Institute of Informatics, Slovak Academy of Sciences, Bratislava, Slovakia

Keywords: Discrete-event Systems, Modelling, Optimization, Simulation, Genetic Algorithm, Distributed Computing, Plant Simulation.

Abstract: Plant Simulation software comprises all the features needed to model the functional aspects of most real-world systems. Specification of complex optimization problem (in sense of many optimization parameters) and its solving in Plant Simulation by genetic algorithm is possible, but it leads to significantly ascending simulation time. The paper presents division of the optimization to two parts: first part of the optimization via GA using distributed computing, and the second part of optimization parameters that will be used in the second stage of the optimization. Modelling, optimization, and simulation procedure proposed for Plant Simulation is presented and tested on a simple use case. In the first stage, the placement of several first aid posts in the area where distinct happenings can go on is optimized, the second stage of the optimization is done using Experiment manager with the aim to select the best solution, i.e. optimal number of first aids in the area depending on additional optimization parameters.

1 INTRODUCTION

Dynamic systems modelling and discrete event simulation represents a very wide range of research and development effort for many years. In 1998, the authors of this paper presented their modelling and simulation tool for discrete event dynamic systems with statecharts formalism used for description of the system's behaviour in (Sebestyénová, 1998). Matlab Stateflow was used in (Kurdel and Sebestyénová, 2010, 2011) for application-based heuristic scheduling of a production process in flexible manufacturing.

Plant Simulation software based on discrete-event simulation contains all the necessary required to model the operational facets of real-world systems (Bangsow, 2015). As it abstracts to deal with just important aspects, it is able to simulate months of factory operation in just seconds. Its primary role is to provide for integrated, graphic and object-oriented modelling, simulation and animation. A lot of complicated and sophisticated systems may be modelled and displayed in great detail closely corresponding to reality using 2D/3D simulation.

Plant Simulation is well equipped for animation and visualisation of results, which are used in great extent in commercial applications to provide for communication with the user. Quite often, it is adequate to concentrate on functional aspects, as the model itself is not of the primary importance. This enables to use animation only at the debugging phase, so as to accelerate the model performance in other circumstances.

Well-structured simulation models reflect the natural hierarchy of systems to be simulated. The basic object Frame can be put into the RootFrame or in another Frame, and create thus a dynamical hierarchy of models. Moreover, one can in this way break down complex tasks into manageable parts. In a case of several similar processes, setting up of the Frame of this process and adding multiple instances of this Frame on the RootFrame enables to structure the models and make them easier to maintain, with the help of modular design and object-oriented programming.

Survey on the use of simulation for manufacturing system design and operation are given in (Smith, 2013). Blaga et al. (2018) compares modelling with Petri nets to Tecnomatix Plant Simulation in the field

[a] https://orcid.org/0000-0003-4677-9972
[b] https://orcid.org/0000-0002-8080-2411

Sebestyénová, J. and Kurdel, P.
Modelling, Optimization, and Simulation of Several First Aids in an Area with Plant Simulation.
DOI: 10.5220/0007927602850292
In *Proceedings of the 9th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2019)*, pages 285-292
ISBN: 978-989-758-381-0

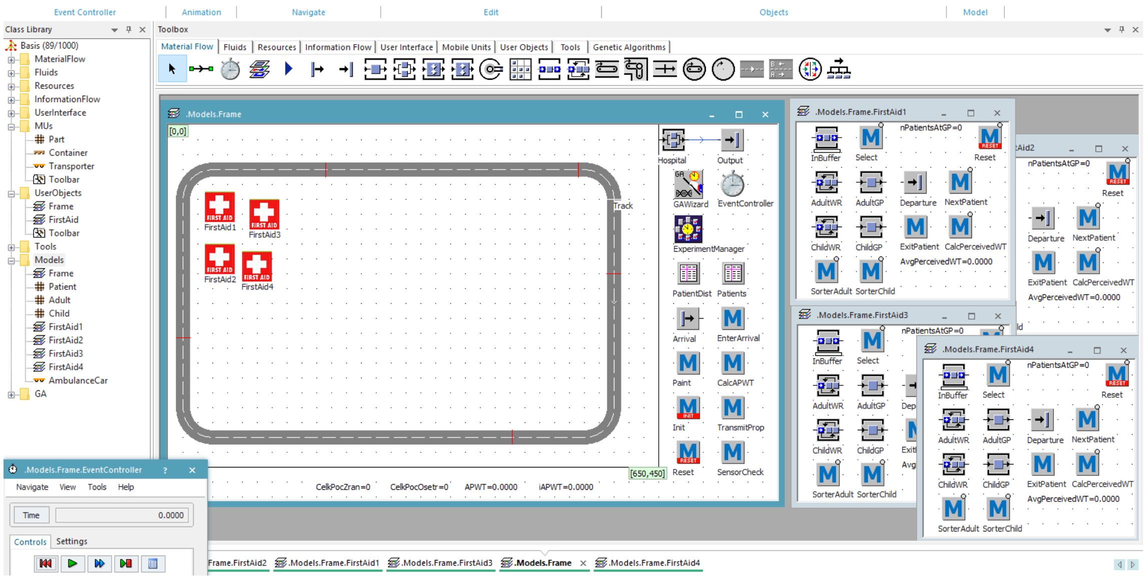

Figure 1: A frame of the model with an area, and sub-frames of four first aids (represented as icons in the area).

of manufacturing process management. In order to organize the smart manufacturing, and flexible and efficient production processes, Kokareva, Malyhin & Smelov (2015) used Plant Simulation for optimizing and validating process performance. Possibilities and examples of using Tecnomatix Plant Simulation to simulate the production and logistics processes was presented in (Siderska, 2016). Vavrík, Gregor & Grznár (2017) described Computer simulation as a tool for the optimization of logistics. This paper comes up with modelling, optimization and simulation schema proposed for Plant Simulation and testing it on the use case taken from the Plant Simulation manual (Mes, 2017, pp. 88-91); the use case was extended to comply to the purpose.

As a problem description, one can suppose there is a festivity terrain for which it is necessary to setup first aid posts. One needs to distribute first aid posts with efficiency in order to get a good coverage over the whole area. In certain cases the modelled process involves the transportation of entities (e.g., patients) and the transportation might necessitate a vehicle. The use of the Track object and the Transporter object seems to be in this case a reasonable choice.

Specification of complex optimization problem (in sense of many optimization parameters) and its solving in Plant Simulation by genetic algorithm is possible, but it leads to significantly ascending simulation time. The paper presents division of the optimization parameters to its first part used in the first stage of the optimization using GA, whereas the second part of parameters will be used in second stage of the optimization using Experiment Manager.

The programming language SimTalk extends the ways of modelling and control of the simulation. The Interpreter executes the source code entered into the Method. SimTalk 2.0 is used in presented model.

In the second section, a generic model of a first aid post is created. Instances of the model will then be used in three area frames representing placement of two, three, and four first aid posts in the areas, where many people are moving and passing their time. Some of them sometimes suffer an accident, and require a medical treatment. The third section presents the first step of two stages of optimization of the number and placement of the first aids in the area. In the section 4, some simulation results are given, and the second stage of optimization is presented.

2 FRAMES OF A MODEL

At first, a model of a first aid post is created in Class library under User objects, followed by a model of an area where some events may go on with different number of incoming people. EnterArrival method of the frame of the model, in which the area is presented, generates random appearance of some accidents in the area.

The Fig. 1 presents the frame containing the area with four derived first aids (FAs) from the user object FirstAid (see in Class Library at the left). In the frame with the area, the FAs are represented by icons, and in the right part of the picture, they are open. Some of the methods in this sub-frames are inherited, which is visualized by a little grey circle at the upper right corner of the method (to be seen in the sub-frames at the right).

The arrival rate of adults and children is given in a PatientDist tablefile of the frame with the area. A visitor having an accident selects to go to the nearest FA. Here, he/she will wait in a waiting room or move to a general practitioner (in a case that he/she is free) according to patient's urgency or time of arrival. The patients are sorted to a general practitioner (GP) for adults and GP for children. The treatment times of patients are random, some 20 minutes for adults and 30 minutes for children.

In each of the FA frames, an inherited method NextPatient moves a patient (modelled as a mobile unit Adult/Child) to the appropriate GP if free, and then moves treated patients to an exit. In a case the patient needs any further treatment in a hospital, an ambulance car appears on a track and transports the patient from one of the FA posts to the hospital. The car stops near the calling FA at the place specified by a sensor and boards the patient.

During the testing or presentation of the model, it is advantageous to animate movements of the mobile units, but as expected, eventual animation slows down optimization run.

The procedure proposed to face up to complex optimization problem (with many optimization parameters) describes all steps from starting with creation of some useful objects ... up to creation and simulation of the root frame containing the whole model. Some simulations can run simultaneously, which saves simulation time. Trying to use all optimization parameters in GA wizard (which could be done only for the version with 2 FAs, because of our educational licence with limits, specification of all optimization parameters for 3 / 4 FAs was not possible), the simulation time rose significantly.

Modelling, optimization and simulation of the use-case follows the procedure:

- Create model of an FA (mobile units MUs created here: Patient -adult, -child, General practitioner GP -for adults, -for children).
- Create the frame with an area where sub-frames of the FAs will be placed (MUs created here: an ambulance car AC on a track).
- Make separate/simultaneous optimization of placements of FAs in the area, first with 4 FAs, then with 3 FAs, and finally with 2 FAs placed in the area. (Though in simple cases one could relatively easily guess the best placements, in case of more complicated models such as e.g. workshops or logistics in a factory such an optimization can appear to be indispensable.)
- Create a root frame (main frame of the model) containing in our test 3 area frames (mobile units created here: GP that in last step after the optimizations will move to the AC of the area with optimal number and placement of the FAs, so called winner area).
- Make simulations using best placements of FAs in three different areas (modelled as sub-frames of a root frame) - this can be done simultaneously.
- The second stage of optimization runs (also simultaneously) some experiments based on additional optimization parameters, in order to get the best solutions from usage of 4, 3, or 2 FAs. This approach can bring useful results in various situations, such as in a case of planned reconstruction of a workshop, where one can acquire knowledge about how many stations of different types is optimal to use, or how many workers of different qualifications is optimal to use after the reconstruction.
- Make simulation of the whole model comprising the winner area with its FAs. In the presented case, the GP starts from the input of the root frame to move to the AC of the winner area (as it can be seen in the last figure in section 4). But in a more complicated situation, input from the root frame may be changed for interfaces connecting outputs from a number of different previous frames to this frame. Modelling, optimization and simulation schema of that kind could be helpful for a designer.

In the following, an event starting at noon with duration time 6 hours, attendance about 1000 people (40% of them being children) are supposed. Approximately 70 accidents are expected to occur during the event.

3 OPTIMIZATION USING GA

The popularity of genetic algorithms (GA) stems from the fact that they return good results while being task-independent. The GAs are therefore perfectly convenient in miscellaneous simulation-based optimization tasks. For example, routing optimization for ATM cash replenishment with many optimization parameters using GA is described in (Kurdel and Sebestyénová, 2013a, 2013b), with optimization parameters divided to pattern and route chromosomes.

The Plant Simulation wizard for GA (GAWizard) integrates GA into an existing simulation model.

At first, the definition of the optimization problem was done using fitness function specified in Optim method, which returns the fitness value. An individual representation consists of two chromosomes. The user defined optimization parameters (a number of FAs and their positions) create a placements chromosome. The fitness function used in this test:

$$f = \max (w_1 \, Treated) + \min (w_2 \, APWT) \qquad (1)$$

where *Treated* is number of the patients treated to the end of the event in the area with given number of the FAs posts (4 / 3 / 2); *APWT* is average waiting time calculated from waiting times of the patients at the FAs in the given area.

Further, the individual representation was enlarged by creating a second chromosome consisting of three more optimization parameters: fee of one FA service, and penalty cost for the number of patients not cared to the end of the event (NoWP), and penalty cost for average waiting time of the patients (APWT). The fitness function was modified to:

$$f = \min (\alpha \, cost_1 + \beta \, cost_2 + \Upsilon \, cost_3) \qquad (2)$$

where α, β, ϒ are weights,
$cost_1$ ... cost of still waiting patients at end of the event calculated: NoWP * $penalty_1$
$cost_2$ ... cost of average waiting time of the patients calculated: APWT * $penalty_2$
$cost_3$ ... cost of the FA posts calculated: number of FAs * $penalty_3$ (fee of one FA service).

As more than 20 user defined optimization parameters were set, the specification of appropriate lower and upper bounds of the parameters has been complicated, and the work was slow. So the decision was made to use the above proposed modelling, optimization and simulation schema.

In the first stage, the placement of 4 / 3 / 2 FAs in the area of the event is optimized using as optimization parameters the total number of treated patients in 6 hours duration of the event, and minimization of the waiting time of the patients. This optimization is done using fitness function (1). (The optimization according to the second chromosome will be described later using Experiment manager.)

For the optimization problem, fitness calculation is specified by table in GA wizard, which can be seen at the bottom part of Fig. 2. Weights w_1, w_2 of this fitness calculation are set to 0.8 for number of treated patients and to 0.2 for inversion of the waiting time. GA wizard enables to maximize/minimize all parts of the fitness, but needing to maximize the first of them, and minimize the second, inversion was used. Optimization parameters are x, y positions of the FAs - their ranges are defined by lower and upper bounds and an increment as given in the top part of Fig. 2.

The number of required simulation runs for an optimization can become quite large. The number of individuals to be evaluated depends on the number of generations and size of a generation. In the first generation, Plant Simulation evaluates the specified size of generation, and in each of the following generations it has to evaluate twice as many individuals. Length of an individual is given by the length of the above mentioned chromosomes.

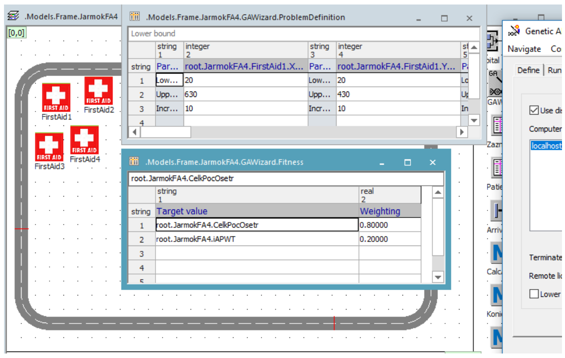

Figure 2: Problem definition in GA wizard.

In the realized test case, number of generations was set to 20, size of generation was set to 30, and a number of observations per individual was set to 10.

More people arriving to the event or happening, more accidents can occur, and more FAs will be needed. The second stage can optimize the selection of the number of the FAs placed on the area according to the number of people arriving to the given event and FA service fee, which will be described later after some simulations in section 4.

3.1 Results from GA

In the test case, running times of optimizations ranged approximately from 3 to 5 minutes. As Plant Simulation provides possibility of distributed computing, it has been used to run GA wizard.

Usage of distributed computing on PC with 4 cores reduced the optimization running times approximately to half of the values without the usage of distributed computing. In presented simple use case this speedup makes only a small difference, but the gain in complex models can be important.

Placement of 4 FAs in the area: Left part of Fig. 3 presents the best individual for 4 FAs in the area and a performance graph, where no further improvement can be observed after about the 10th generation. For illustration, a screenshot of evaluated best individuals is given at the bottom part of the picture. Best achieved fitness value is 52.1600. One can see that the best individual did not place the FAs

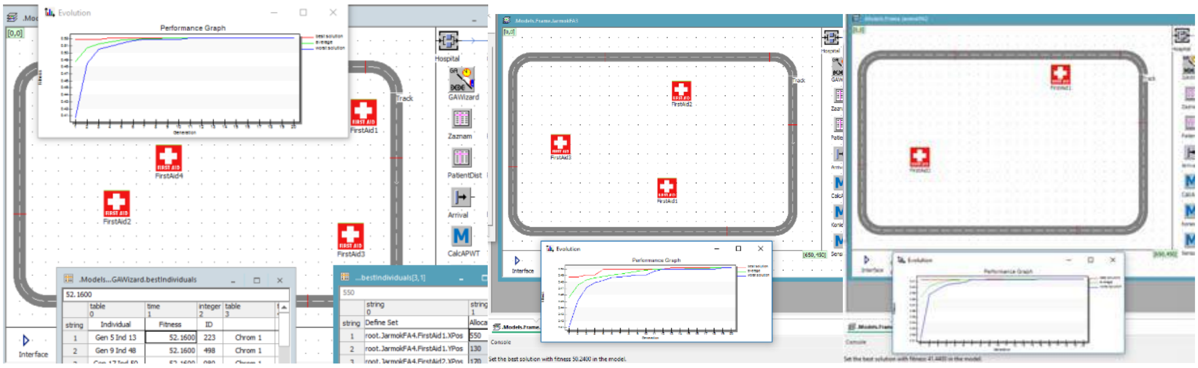

Figure 3: Best individuals for 4 / 3 / 2 FAs with performance graphs of GA.

symmetrically around the centre of the area, which seems to be apparently their best placement. This result can be partly due to random appearance of the accidents as well as to the fact that working with Educational license does not allow to improve GA settings via GA Optimization wizard.

Placement of 3 FAs in the area: In the middle part, Fig. 3 presents the best individual for 3 FAs in the area and a performance graph, where improvement can be observed in about 18th generation. Best achieved fitness value is 50.2400, which is less than in previous case, because more patients still wait for treatment in the FAs in this case. The bottom part of the picture contains a console with information about setting of the best solution in the model after the end of GA optimization, via configuration method TransmitProperties.

Placement of 2 FAs in the area: Right part of Fig. 3 presents the best individual for 2 FAs in the area and a performance graph. Best achieved fitness value is 41.4400, which is less than in previous two cases, because more patients still wait for treatment in the FAs in this case.

3.2 Best Fitness

For smooth comparison, a summary of the best fitness values of the three GA optimizations are given in table 1.

Table 1: Summary of best fitness of the 3 optimizations.

No of FAs in the area	Best fitness
4	52.1600
3	50.2400
2	41.4400

4 SIMULATION RESULTS

Simulations were run for all versions, i.e. for the event in the area with 4 / 3 / 2 FA posts, using their previously optimized positions. From the following simulations, one receives values of the variables: average waiting time of the patients, number of the patients still waiting for care at the closing time of the event, time when the last patient leaves the area.

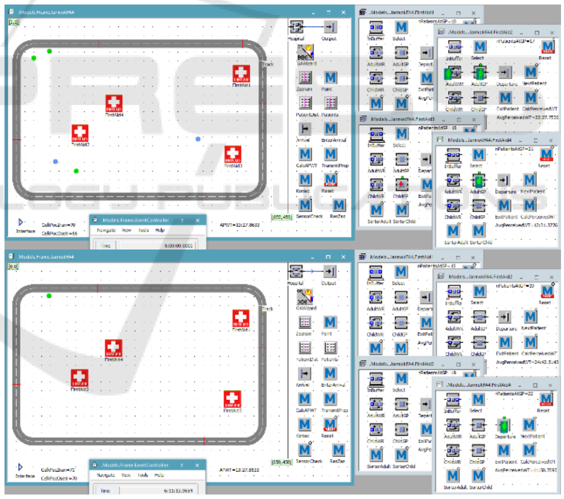

Figure 4: Top part of the picture presents situation at the closing time of the event with 4 FAs, bottom part of the picture presents situation when last patient goes away.

Fig. 4 presents simulation results in the case of 4 FAs in the area. Top part of the picture presents situation at the closing time of the event (6:00:00 [h:m:s]). The blue and green circles in the area represent locations where these last patients suffered accidents. These circles representing the accident placements are removed after any patient leaves any FA. At the end of the event, 4 patients remain to be cared for. In the opened frames of the FAs, the patients are animated at the closing time of the event. The last patient goes away at 6:11:13, and one can see this last patient animated on the departure in the open frame of the FA. Average waiting time of all the patients is 13:27 in this case.

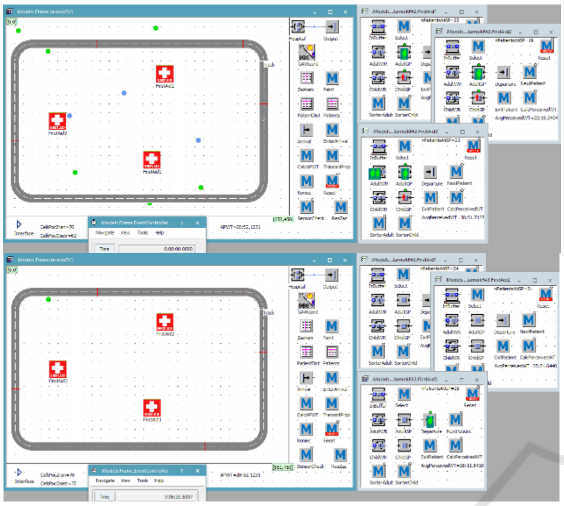

Figure 5: Top part presents situation at the closing time of the event with 3 FAs, bottom part presents time when last patient goes away.

Fig. 5 presents simulation results in the case of 3 FAs in the area. At the end of the event 8 patients remain to be cared for. The last patient goes away at 7:06:39. Average waiting time of all the patients is 20:52.

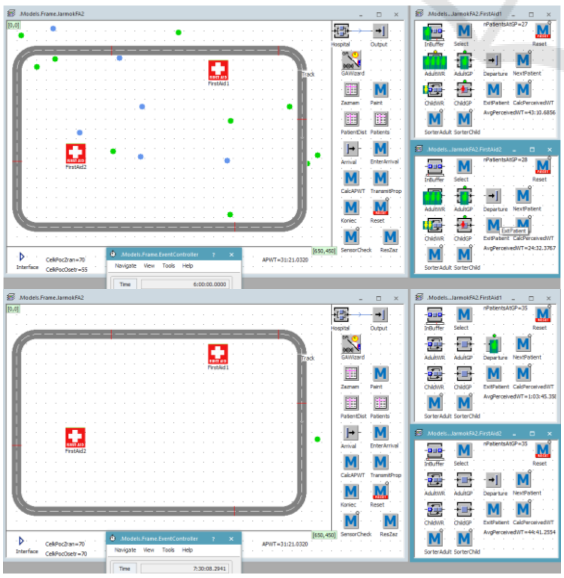

Figure 6: Top part presents situation at the closing time of the event with 2 FAs, bottom part presents time when last patient goes away.

Fig. 6 presents simulation results in the case of 2 FAs in the area. At the end of the event 15 patients remain to be cared for. The last patient goes away at 7:30:08. Average waiting time of all patients is 31:21.

To make some comparison, part of the simulation results are summarized in table 2.

Table 2: Simulation results.

Area with:	4 FAs	3 FAs	2 FAs
Average waiting time	13:27	20:52	31:21
No of waiting patients at closing time	4	8	15
Time of last departure	6:11:13	7:06:39	7:30:08

4.1 Resource Statistics

Resource statistics charts in Fig. 7 present GPs working (green) and waiting (grey) times for all three cases (top for 4 FAs, middle for 3 FAs, bottom for 2 FAs).

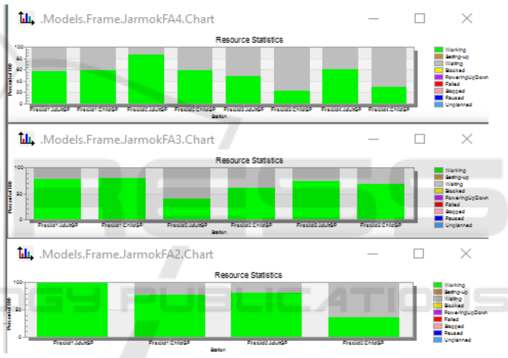

Figure 7: Statistics of the working time of the adult/child GPs.

4.2 Second Stage of Optimization

In case of too expensive service fee of the FA post, it may sometimes be better to provide fewer FAs. One will select the best solution (number of FAs in the area) depending on the following parameters: service fee of one FA, average waiting time of the patients, number of patients still waiting for treatment at the closing time of the event. The second stage of the optimization is done using Experiment manager of Plant Simulation. Optimization using Experiment manager is a good option in cases similar to tested one, as one can add on a step by step basis new experiment specifications based on formerly found best solutions. Results from Experiment manager are given in Fig. 8 in a form of a screenshot, but it is also possible to export results from the Plant Simulation model to Excel file and continue analysis of achieved big data using another approaches.

.Models.Frame.ExperimentManager.Results

		root.cenaFA	root.cenaCakania	root.cenaCakPoSkonc	root.noPatients	root.cf4	root.cf3	root.cf2
1	Exp 1	10	1	1	70	65.1460816238252	69.2715687445877	80.4406107513618
2	Exp 2	5	1	1	70	45.1460816238252	54.2715687445877	70.4406107513618
3	Exp 3	15	1	1	70	85.1460816238252	84.2715687445877	90.4406107513618
4	Exp 4	20	1	1	70	105.146081623825	99.2715687445877	100.440610751362
5	Exp 5	30	1	1	70	145.146081623825	129.271568744588	120.440610751362
6	Exp 6	30	2	2	70	170.29216324765	168.543137489175	180.881221502724
7	Exp 7	30	3	3	70	195.438244871476	207.814706233763	241.321832254085

Figure 8: Results from Experiment manager.

In the first three columns, the fee of one FA service, the fee of the waiting time of the patients, and the fee of number of the patients still waiting for treatment after the end of the event are set. (In the 4th column, a total number of the patients was in all experiments equal.) Last three columns give the best fitness in cases of 4 / 3 / 2 FAs. Thus, the experiment 6 e.g. reveals that the best solution is to place 3 FAs in the area, because in this second stage of optimization a minimum total cost is the best one.

Finally, the presentation of the complete model follows, where the GP working in the AC moves to

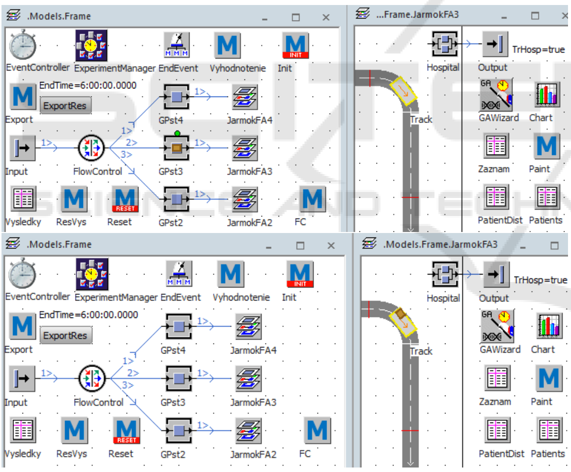

Figure 9: Start of the complete model simulation.

the AC created in the frame with the best result, which is for example (according to above mentioned experiment 6) the area frame with 3 FAs. Top part of Fig. 9 presents movement of the GP serving in the AC from Input in direction to the frame with 3 FAs (represented by a small brown square icon). The bottom part presents him/her sitting in the AC on the Track (the small brown square icon moved from the root frame to AC parking close to the hospital on the Track in the winner area frame), in the next step of the simulation.

Program code of FC method applied as exit strategy in Flow control object (move of the GP to the AC is based on it):

```
-> integer
-- @ is the movable unit
var r:integer
if bestNoOfFA = 4
  if  .Models.Frame.JarmokFA4.TrHosp  =
true
    r := 1
  end
elseif bestNoOfFA = 3
  if  .Models.Frame.JarmokFA3.TrHosp  =
true
    r := 2
  end
elseif bestNoOfFA = 2
  if  .Models.Frame.JarmokFA2.TrHosp  =
true
    r := 3
  end
end
return r
```

In presented test case, the necessity of the transport is represented by a boolean variable TrHosp. Its value is set by the FA that provided the treatment of the patient needing the further care in the hospital. For simple test purpose, the patients with highest urgency are all supposed to need the transport.

5 CONCLUSIONS

Dynamic systems modelling and discrete event simulation represents a very wide range of the research and development effort for many years. Plant Simulation software comprises all the features needed to model the functional aspects of most real-world systems. The procedure proposed to face up to complex optimization problem (with many optimization parameters) describes all steps from starting with creation of some useful objects ... up to creation and simulation of the root frame containing the whole model. Some simulations can run simultaneously, which saves simulation time. The proposed modelling, optimization and simulation schema for Plant Simulation was tested on a simple use case taken from the Plant Simulation manual.

Two optimization steps are used according to proposed schema. In the first stage, three optimizations of several FAs placement in the area are separately done using GA with distributed computing. Subsequent simulations of the three distinct happening areas with their movable objects can be done simultaneously. Acquired results, such as e.g. average waiting time of the patients, are used in the second stage of the optimization besides some additional optimization parameters, e.g. fee of FA service. This second stage of optimization is done by Experiment manager.

In final simulation, the Flow control directs the GP serving in the ambulance car to the winner area frame, and only this area frame with its FAs frames works in this simulation besides the root frame.

Presented results can be seen as the first part of the project research. In further work, the authors plan to examine in more detail some logistics problems, a.o. the movement of the ambulance car transporting the patients to the hospital if they need further treatment. The proposed modelling, optimization and simulation procedure (tested on a simple use case) can prove its usefulness when dealing with more complex processes.

ACKNOWLEDGEMENTS

The authors are grateful to Scientific Grant Agency of Slovak Republic and Slovak Academy of Sciences for partial support of this work by projects VEGA 2/0167/16 and VEGA 2/0155/19.

REFERENCES

Bangsow, S, 2015, *Manufacturing Simulation with Plant Simulation and SimTalk- Usage and Programming with Examples and Solutions*, Springer-Verlag, Berlin Heidelberg, viewed 10/12/2018 https://link.springer.com/content/pdf/10.1007%2F978-3-319-19503-2.pdf

Blaga, F, Stanasel, I, Pop, A, Hule, V & Karczis, A, 2018, ´The use of modeling and simulation methods to improve the performance of manufacture lines´ in *ModTech2018 IOP Conf. Series: Materials Science and Engineering 400 (2018)* 042006, viewed 20/2/2019 https://www.researchgate.net/publication/327731392_The_use_of_modeling_and_simulation_methods_to_improve_the_performance_of_manufacture_lines

Kokareva, V, Malyhin, A & Smelov, V, 2015, ´Production Processes Management by Simulation in Tecnomatix Plant Simulation´ in *Applied Mechanics and Materials*, Vol 756 (2015), pp. 604-609, Trans Tech Publications, Switzerland, viewed 20/2/2019 https://www.researchgate.net/publication/277662116_Production_Processes_Management_by_Simulation_in_Tecnomatix_Plant_Simulation

Kurdel, P, Sebestyénová, J, 2010, ´Statecharts model for application based scheduling of a manufacturing process´ in *Process Control 2010*, pp. C059a-1-C059a-8. ISBN 978-80-7399-951-3.

Kurdel, P, Sebestyénová, J, 2011, ´Statecharts model and heuristic scheduling of a production process´ in *IEEE INES 2011* - Budapest, pp. 309-314. ISBN 978-1-4244-8955-8.

Kurdel, P, Sebestyénová, J, 2013a, ´Routing optimization for ATM cash replenishment´ in *International Journal of Computers*, 2013, vol. 7, pp. 135-144. ISSN 1998-4308.

Kurdel, P, Sebestyénová, J, 2013b, ´Parallel genetic algorithm for periodic vehicle routing and scheduling problem´ in *IEEE ICSSE 2013* - Budapest, pp. 111-116. ISBN 978-1-4799-0007-7.

Mes, M, RK, 2017, *Simulation Modelling using Practical Examples. A Plant Simulation Tutorial*. University of Twente, viewed 15/10/2018 https://www.utwente.nl/en/bms/iebis/staff/mes/plantsimulation/tutorialplantsimulation13v20170726.pdf

Sebestyénová, J, 1998, ´Stacha: a computerized modelling tool for DEDS´ in *Advances in Systems, Signals, Control and Computers*. Edited by V. J. Bajic. IAAMSAD. Vol III, 1998 Durban, pp. 389-393. ISBN 0-620-23136-X.

Siderska, J, 2016, ´Application of Tecnomatix Plant Simulation for Modeling Production and Logistics Processes´ in *Business, Management and Education*, ISSN 2029-7491/eISSN 2029-61692016, 14(1), pp. 64-73, viewed 20/2/2019 https://www.researchgate.net/publication/305269846_Application_of_Tecnomatix_Plant_Simulation_for_Modeling_Production_and_Logistics_Processes, DOI: 10.3846/bme.2016.31

Smith, JS, 2013, ´Survey on the use of simulation for manufacturing system design and operation´ in *Journal of Manufacturing Systems* 22(2), pp. 157-171, viewed 20/2/2019 http://dx.doi.org/10.1016/S0278-6125(03)90013-6

Vavrík, V, Gregor, M & Grznár, P, 2017, ´Computer simulation as a tool for the optimization of logistics using automated guided vehicles´ in *Procedia Engineering* 192, pp. 923-928.