# LOGISTICS PROCESS IMPROVEMENT USING SIMULATION OPTIMISATION

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### Abstract

This paper refers to the problem of delivery process improvement. The subject of supply are parts and components for a vehicle production company. The deliveries are performed upon just-in-time strategy from the external warehouse to the factory. The authors propose a six-stage procedure which combines three research areas, i.e. process analysis, dynamic simulation and simulation optimisation. In Stage 1 of this procedure, the logistics process is analysed and modelled using process notation. The major process operations, cause and effect relationships, key human and technical resources and their assignment to the activities are identified. In Stage 2, the process' model is converted into the simulation model of deliveries to enable a dynamic simulation of its operations and to evaluate the process performance. In Stage 3, the simulation model is customised and the computational experiments are carried out. Based on the analysis of results weaknesses of the process are identified. In Stage 4, the simulation model is extended by a formulation of objective functions and constraints to run a simulation optimisation (Stage 5). Finally, the compromise solution is selected and the logistics process improvement is proposed. It is compared with the previous result of the authors' research where this problem was solved using a stochastic multiple criteria ranking approach. Then the alternative process scenarios were ranked and the one with the highest position in the hierarchy was recommended. This solution and the new one from the current research are juxtaposed in this paper, and the differences between methodological approaches are presented.

**Keywords:** Logistics process improvement, simulation optimisation, multiple criteria stochastic optimisation, ExtendSim

## 1. INTRODUCTION

### 1.1 The essence of logistics process improvement

Logistics process is connected with the concept of an integrated system of materials flow from a starting to an ending point. This integration comes from a marketing concept meeting customers' needs of planning, coordinating and controlling the whole process of the material flow instead of its operations independently. The idea of 7R in logistics, i.e., delivery of right product, in right quantity and right condition, to the right place and for right customer, at right time and price, shows the evaluation aspects of this logistics process. It is characterized by a complexity. However, due to dynamic changes of its activities, one solution of the material flow is not sufficient and to address market challenges constant improvement is required. Fulfilling all these objectives, opportunities and threats in business area, is not a trivial task and requires the use of advanced decision aiding techniques. There are three main approaches presented in the literature on logistics process improvement, including 1) qualitative methods, e.g., customer satisfaction survey and identification of evaluation criteria of transport service providers [1], application of PCDA method [2], or TQM philosophy [3]; 2) quantitative methods, e.g., optimisation techniques with a minimisation of route length using Nearest Neighbour Method and Vogel's Approximation Method [4], dynamic simulation techniques using ExtendSim software [5], Arena [6], or value stream analysis [7]; 3) a combined approach with the application of qualitative and quantitative methods, e.g., lean management tools and calculation spreadsheet [8]. The most precise information on the result is provided by the optimisation techniques. The problem is that the calculations are usually based on the static data, mostly average values, and only one evaluation criterion is taken into consideration. Therefore, the application of the simulation techniques reflecting dynamic flow of products, non-deterministic data, e.g., processing time, different evaluation criteria of the analysed process and optimisation module to solve the problem, could fulfil the existing research gap.

### 1.2 Objective of the research

Based on the previous experience of the authors of this paper [9], it is proposed to optimise the selected logistics process with the application of simulation optimisation and to compare the results with those presented in [9] dealing with the combined approach, i.e., simulation and stochastic multiple criteria decision aiding. The nature of both research studies are coherent, i.e., they are based on the simulation technique as a core tool, and the exemplary process to be improved is the same. The key question is whether the procedural changes can also be reflected in the logistics process output. To do so, the methodology presented in this paper is based on the sequence of related steps, including identification and modelling of process activities, human and technical resources, multiple criteria stochastic modelling of the evaluation criteria, process optimisation with respect to the considered criteria, and selection of the compromise solution. Finally, the procedure is tested and verified on the example of logistics process of supply of parts and components to the production line in the automotive industry.

### 1.3 Problem definition

The considered logistics process is an example of the supply of vehicle's parts to the factory. Two companies cooperate each other, i.e., one of them is a vehicles' producer, and the second one is responsible for supply of parts and components to the production line. The latter is a logistics service provider that operates on own warehouse facilities, forklifts, containers for the movement of components, and fleet of vehicles. Deliveries to the production line are carried out according to just-in-time strategy, i.e., based on a timetable defined by a producer.

The distance between these companies is 5.4 km and the route between them mostly coincides with one of the main access roads to the downtown. This results in a high risk of supply disruption because of the traffic. Thus, to maintain the production continuity the producer provides short-term caching of delivered components.

Both, too early and too late deliveries, are undesirable, which in any case destabilize production and inbound logistics processes. Based on the historical data the expected total time of all activities, such as loading full containers to the vehicle, delivery from supplier to producer, unloading components, loading empty containers to the vehicle, delivery from producer to supplier, and unloading of empty containers, should equal 125 minutes with the range of variations between 113 and 155 minutes. In order to meet these requirements, the sufficient amount of resources should be applied to the process. The decision problem is formulated as the determination of the best configuration of the logistics process resources involved in the analysed activities.

## 2. THE PROPOSED METHODOLOGY

An overview of methodology of the logistics process simulation optimisation proposed in this paper consists of 6 stages and it is presented in **Figure 1**. In Stage 1, the process is analysed and modelled using process notation (BPMN), i.e., key activities to be performed with associated resources are defined. Based on many research studies, including authors' of this paper experience [9-11], the main purpose of this stage is to: 1) identify all activities in the logistics process, 2) reflect the cause-effect relationships between these activities, 3) identify human and technical resources involved in the process, and 4) assign resources to each activity in the process. Thus, the final result of this stage is the comprehensive picture of the process architecture. It helps to understand the key relations and the logic of the process to be simulated and optimised in next stages.

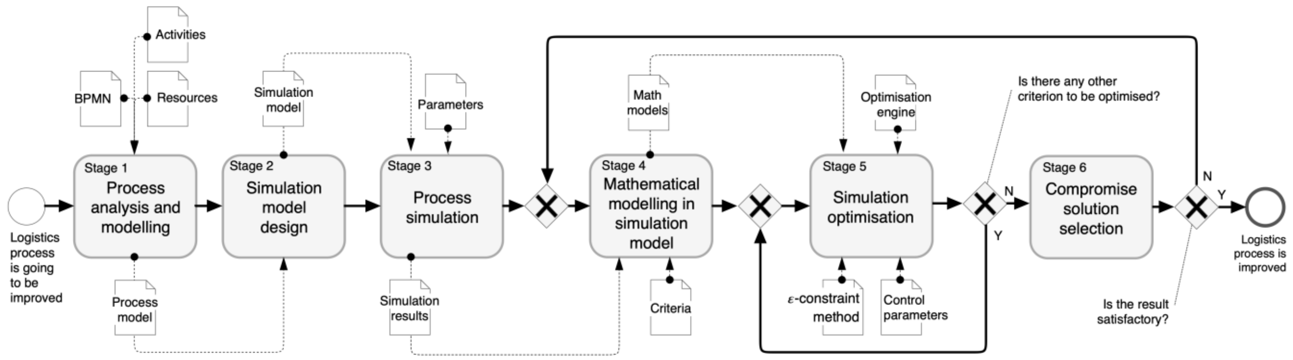


**Figure 1** A scheme of the applied methodology

In Stage 2, the BPMN model of the process is converted into the simulation model to enable a dynamic flow of products, relationships between activities and resources. Moreover, a stochastic nature of the process is reflected, as well. As a result, logistics process simulation can be performed (Stage 3).

In Stage 3, the simulation model is customised with the input parameters and simulation calculation is carried out. The output of this stage is the set of simulation results as a basis for detailed evaluation, model verification and validation. A reference point is the observation of the process in its natural environment, e.g., queues of vehicles and their locations. Based on the analysis of results, weaknesses of the process are identified. The verified and validated simulation model is a starting point to the next stage of the procedure.

In Stage 4, an objective function and constraints are formulated and added to the simulation model. The main purpose of this stage is to develop a comprehensive set of optimisation criteria to enable further computations. This set should encompass the criteria applied in the previous research [9], i.e., the cost of process operation, resources utilization, and compliance of process duration with the production schedule. Due to the random phenomena of many process activities, it is recommended to formulate the criteria with an application of non-deterministic mathematical modelling. Its generic form is presented in equations (1) and (2).

$$min \text{ or } max \left(f_1(\hat{x}), f_2(\hat{x}), \ldots, f_j(\hat{x})\right) \tag{1}$$

$$\text{subject to } x \in D \tag{2}$$

where: $j$ - index of criterion, $j = 1, \ldots, J$; $\hat{x}$ – non-deterministic measure of $x$; $D$ – set of feasible solutions.

In Stage 5, the simulation experiments are carried out using optimisation engine with optimisation control parameters. Due to the fact that several optimisation criteria are taken into account, to provide a representative subset of Pareto solutions, it is proposed to apply an ε-constraints method [12]. It means that for each optimisation criterion the simulation optimisation procedure is repeated until the last value of optimisation criterion is found. At this stage an evolutionary algorithm is applied. Next, for each optimised criterion the simulation is repeated to find the values of the other evaluation criteria. Finally, the vector of Pareto results is achieved.

Stage 6 is focused on the selection of the compromise solution as an output of the procedure. If the result is not satisfactory, the procedure should be repeated, starting from Stage 4. In Stage 6, the optimal results, computed separately upon each criterion, are compared to each other and a compromise solution is selected. There are many different decision aiding methods to solve a multiple criteria problem. The review of different multicriteria methods in engineering application is presented in [13]. To extend the problem of selection the most suitable method to the decision problem the reader can deal with the research of Sawicka [14], or Roy and Słowiński [15]. In the approach presented by the authors of this paper a global criterion method [16] as a typical non-preference classification method is applied to perform the analysis and to find a compromise solution, see equation (3).

$$\sum_{j=1}^{J}\left(\frac{f_j(x^*)-f_j(x)}{f_j(x^*)}\right)^2 \to \min \tag{3}$$

where: $j$ - index of criterion, $f_j(x^*)$ - ideal solution.

The result of the proposed methodology is a recommendation of logistics process improvement.

## 3. THE EXPERIMENTAL APPLICATION OF THE METHODOLOGY

The proposed methodology of logistics process improvement has been verified on the example of deliveries of parts and components in the automotive industry. In the first stage, see **Figure 1**, a detailed process analysis and modelling has been performed. With reference to [9], the considered process of delivering components to the producer is composed of the following components: 12 activities; 9 vehicles (trucks) to perform external transportation tasks between warehouse and producer; 27-persons crew of drivers, i.e., 9 drivers per shift; 4 forklifts (and operators) dedicated to loading and unloading activities, i.e., 2 forklifts per warehouse and factory.

Due the fact that simulation model, its verification and validation were performed in the previous research [9], in this part of the current research the design of simulation model has been adopted, and results of the simulations, as well.

The original set of 5 evaluation criteria proposed in [9], i.e., resource utilisation per each type of vehicle, including trucks (criterion no. 1), forklifts in the warehouse (criterion no. 2) and forklifts in the factory (criterion no. 3) total cost of the logistics process (criterion no. 4), and timeliness of deliveries (criterion no. 5), has been reconsidered in the current research. However, the timeliness of delivery has been converted to the constraint. Two types of decision variables have been adopted from the previous research studies [9], as well. The first one was the $x$ as an assignment of human $h$-resources and technical $r$-resources of each type to the process $i$-activities, i.e., drivers or operators $x_{ikh}$, and trucks or forklifts $x_{ikr}$, where $k$ is the number of iterations such as $k = 1, 2, \dots K$. The second one was the presence of each activity in the logistics process structure $y_{ik}$. It has also been assumed that the structure of the process is not the subject of the optimisation procedure, thus $y_{ik}$ is fixed ($y_{ik} = 1, \forall i, k$) and the process structure has been adopted from the variant recommended in [9].

The first three criteria are the expected values of the resources utilisation – $Q_{rh}$ of each $r$-type with associated $h$-resources, i.e., trucks, forklifts in the warehouse and forklifts in the factory. These criteria are to be maximised and they are dimensionless. By these criteria it is expressed the way all the resources are utilised to achieve the desired process output, see equation (4). The fourth criterion is the expected value of the total cost of the logistics process – $C$. It is a minimised criterion, expressed in Polish currency (PLN). It is related to the key cost of all activities in the logistics process, especially cost associated with human and technical resources, fixed and variable factors, see equation (5). The timeliness of delivery constraint is expressed in minutes. By this formulation it is assumed that the deliveries from the warehouse to the factory are to meet tight deadlines. It is expressed as the variation between duration of each $k$-instance of the logistics process, the upper time limit $t^{upp}$ and lower time limit $t^{low}$. To measure this value it is necessary to identify the process duration $t_{ik}$ for each $k$-instance with respect to $i$-activity. Thus, the simulation model is prepared to reflect all time factors of waiting for available resources $t_{ik}^{w}$, and performing the task $t_{ik}^{a}$. This is expressed as a maximum deviation from time limits, see equations (6) and (7).

$$\text{Max } \mathrm{E}Q_{rh} = \left(\sum_{i=1}^{I}\sum_{k=1}^{K}\mathrm{E}(t_{ik}^{a} z_{ikr} x_{ikr}) + \sum_{i=1}^{I}\sum_{k=1}^{K}\mathrm{E}(t_{ik}^{a} z_{ikh} x_{ikh})\right) / \sum_{i=1}^{I}\sum_{k=1}^{K}\mathrm{E}\big(y_{ik}(t_{ik}^{w}+t_{ik}^{a})\big)\,;\ \forall r, h \tag{4}$$

$$\begin{aligned}\text{Min } \mathrm{E}C = {} & \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{r=1}^{R}\left(c_{ir}^{v}\mathrm{E}\big((t_{ik}^{w}+t_{ik}^{a})z_{ikr}x_{ikr}\big) + c_{ir}^{f}\mathrm{E}(y_{ik})\right) + \\ & + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{h=1}^{H}\left(c_{ih}^{v}\mathrm{E}\big((t_{ik}^{w}+t_{ik}^{a})z_{ikh}x_{ikh}\big) + c_{ih}^{f}\mathrm{E}(y_{ik})\right)\end{aligned} \tag{5}$$

$$\text{subject to: } \max_{k} T_k \le 0\text{, where:} \tag{6}$$

$$\max_k T_k = \begin{cases} t^{low} - \sum_{i=1}^{I} y_{ik}(t_{ik}^a + t_{ik}^w) & \text{if} \quad \sum_{i=1}^{I}(t_{ik}^a + t_{ik}^w) < t^{low} \\ 0 & \text{if} \quad t^{low} \leq \sum_{i=1}^{I}(t_{ik}^a + t_{ik}^w) \leq t^{upp} \\ \sum_{i=1}^{I} y_{ik}(t_{ik}^a + t_{ik}^w) - t^{upp} & \text{if} \quad \sum_{i=1}^{I} y_{ik}(t_{ik}^a + t_{ik}^w) > t^{upp} \end{cases} \tag{7}$$

where: $i$ – activity index, $k$ – process instance index, $r$ – technical resource index, $h$ – human resource index, $E()$ – expected value, $c_{ir}^v, c_{ir}^f$ – variable $v$ and fixed $f$ cost of $i$-activity performed by $r$-resource, $c_{ih}^v, c_{ih}^f$ – variable $v$ and fixed $f$ cost of $i$-activity performed by $h$-resource, $t_{ik}^a, t_{ik}^w$ – action $a$ time and waiting $w$ time of resource for $i$-activity and $k$-instance, $t^{low}, t^{upp}$ – lower $low$ and upper $upp$ limit of process duration, $x_{ikr}, x_{ikh}$ – decision variables, i.e., an assignment of $r$- resource and $h$-resource to $i$-activity within $k$-instance, $y_{ik}$ – appearance of $i$-activity within $k$-instance, $z_{ikr}$, $z_{ikh}$ – a degree of involvement of $r$-resource and $h$-resource in $i$-activity within $k$-instance.

In Stage 5 (**Figure 1**), all required parameters are introduced into the simulation model of the logistics process and experiments are run using ExtendSim simulation tool. The input data, i.e., list of process activities, processing times defined by triangular distribution, have been adopted from the previous research studies [9]. There is only one exception, i.e., the upper limit of the process duration has been updated to the current situation, and it has increased from 144,5 to 155 min. After a series of simulation optimisation sessions, the set of Pareto results have been generated, see rows 1-4 in **Table 1**. In the last two rows, the reference results are presented, i.e., current status (ref.0), and the result recommended in [9] (ref.5).

**Table 1** The set of expected results and assumed number of resources after simulation optimisation

(1) results for $\boldsymbol{r}$-resources: trucks (1), forklifts in the warehouse (2), and forklifts in the factory (3), *optimal result (ideal point); $\boldsymbol{CPU}$ – computation time; $\boldsymbol{Conv.}$ – convergence

| Solution | Results(1) | | | | | Resources | | | | Procedure | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C$ (PLN) | $Q_{r=1}$ (%) | $Q_{r=2}$ (%) | $Q_{r=3}$ (%) | | $x_{ikr;}\, r=1$ (item) | $x_{ikr;}\, r=2$ (item) | $x_{ikr;}\, r=3$ (item) | | $CPU$ (min.) | $Conv.$ (%) |
| 1 | 42,262* | 95.74 | 59.27 | 35.77 | | 5 | 2 | 2 | | 13.51 | 95.45 |
| 2 | 69,862 | 96.14* | 9.95 | 5.29 | | 5 | 12 | 13 | | 10.33 | 99.59 |
| 3 | 62,348 | 43.76 | 59.94* | 13.92 | | 11 | 2 | 5 | | 10.05 | 99.44 |
| 4 | 76,734 | 44.68 | 7.02 | 70.08* | | 11 | 17 | 1 | | 10.19 | 98.55 |
| ref.0 | 51,500 | 59.00 | 54.00 | 63.00 | | 9 | 2 | 1 | | - | - |
| ref.5 | 55,000 | 48.00 | 55.00 | 58.50 | | 10 | 2 | 1 | | - | - |

The optimal results are generated with the application of evolutionary algorithm. It is assumed that the minimum convergence is 95% and the maximum number of iterations is 1000. The computation time is between 10.1 and 41.1 min.

With the application of global criterion method the comparison among generated results has been carried out. Using equation (3), the minimum value is for solution 1 and it equals 0.2454. Therefore, this solution is recommended as a direction of the logistics process improvement with the following number of technical resources: 5 trucks, 2 forklifts in the warehouse and 2 forklifts in the factory, as well as 5 drivers, 2 forklifts' operators in the warehouse and 2 forklifts' operators in the factory.

## 4. CONCLUSION

In this paper the methodology of logistics process improvement with the application of simulation optimisation has been presented. Based on it, it is possible to analyse, model and simulate the current status of the process, and to find an optimal solution of activities evaluated by different criteria. The proposed procedure has been applied on the case study previously analysed by the authors of this paper [9] and updated in the current research.

From the practical point of view, the recommended solution to be applied is no. 1, which is almost 13,000 PLN cheaper than the solution recommended in [9]. The degree of utilization of trucks and forklifts in the warehouse increased from 59% and 54% to 96% and 59%, respectively. It is also a positive change. Finally, it is proposed to apply 5-2-2 items of each type of resources, being a better result than 9-2-1 in the current status and 10-2-1 in the solution recommended in [9].

The proposed methodology gives the possibility to get a better result than previously received by the authors. It means that the procedural change has an influence on the logistics process output. The main advantage of the simulation optimisation is that it generates a solution that is very close to the ideal one. Moreover, the constructed simulation model with the optimisation module can be reused in the longer term, after the validation. The future directions of this research are as follows: 1) the set of evaluation criteria should be extended, 2) the range of activities to be modelled should be developed, 3) the proposed methodology should be verified on the other examples of logistics processes to be improved, 4) the sensitivity analysis should be carried out.

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## REFERENCES

[1] MOLENDA, M. Quality study and improvement of logistics processes on the example of a chosen enterprise. *Management Systems in Production Engineering*. 2019, vol. 27(1), pp. 18-22, doi: 10.1515/mspe-2019-0003.

[2] AMARAL, V.P., FERREIRA, A.C., RAMOS, B. Internal logistics process improvement using PDCA: A case study in the automotive sector. *Business Systems Research Journal*. 2022, vol.13(3), pp.100-115, doi: 10.2478/bsrj-2022-0027.

[3] ZIMON, D. The impact of TQM philosophy for the improvement of logistics processes in the supply chain. *International Journal for Quality Research*. 2017, vol. 11(1), pp. 3-16, doi: 10.18421/ijqr11.01-01.

[4] PEČENY, L., MEŠKO, P., KAMPF, R., GAŠPARIK, J. Optimisation in transport and logistic processes. *Transportation Research Procedia*. 2020, vol. 44, pp. 15-22, doi: 10.1016/j.trpro.2020.02.003.

[5] STRAKA, M., KHOURI, S., LENORT, R., BESTA, P. Improvement of logistics in manufacturing system by the use of simulation modelling: A real industrial case study. *Advances in Production Engineering & Management*. 2020, vol. 15(1), pp. 18-30.

[6] DE OLIVEIRA, A.V., PIMENTEL, C.M.O., GODINA, R., MATIAS, J.C.D.O., GARRIDO, S.M.P. Improvement of the logistics flows in the receiving process of a warehouse. *Logistics*. 2022, vol. 6, 22, doi: 10.3390/logistics6010022.

[7] ACERO, R., TORRALBA M., PÉREZ-MOYA, R., POZO, J.A. Value stream analysis in military logistics: The improvement in order processing procedure. *Applied Sciences*. 2020, vol. 10(1), 106, doi: 10.3390/app10010106.

[8] AMARAL, H.P., FERREIRA, A.C., RAMOS, B. Internal logistics process improvement using PDCA: A case study in the automotive sector. *Business System Research*. 2022, vol. 13(3), pp. 100-115, doi: 10.2478/bsrj-2022-0027.

[9] SAWICKI, P., SAWICKA, H. Logistics process improvement using simulation and stochastic multiple criteria decision aiding. *Procedia - Social and Behavioural Sciences.* 2014, vo. 111(5), pp. 1142-1154, doi: 10.1016/j.sbspro.2014.01.054.

[10] STELLING, M., ROY, R., TIWARI, A. A novel modelling and optimisation technique for business processes: An evolutionary computing based approach. *Applications of Soft Computing.* 2009, vol. 52, pp. 75-85.

[11] WESKE, M. *Business process management*. Berlin: Springer-Verlag, 2012.

[12] MAVROTAS, G. Effective implementation of the ε-constraint method in multi-objective mathematical programming problems. *Applied Mathematics and Computation*. 2009, vol. 213(2), pp. 455-465, doi: 10.1016/j.amc.2009.03.037.

[13] CHIANDUSSI, G., CODEGONE, M., FERRERO, S., VARESIO, F.E. Comparison of multi-objective optimization methodologies for engineering applications. *Computers & Mathematics with Applications*. 2012, vol. 63(5), pp. 912-942, doi: 10.1016/j.camwa.2011.11.057.

[14] SAWICKA, H. The methodology of solving stochastic multiple criteria ranking problems applied in transportation. *Transportation Research Procedia*. 2020, vol. 47, pp. 219-226, doi: 10.1016/j.trpro.2020.03.092.

[15] ROY, B., SŁOWIŃSKI, R. Questions guiding the choice of a multicriteria decision aiding method. *EURO Journal on Decision Processes*. 2013, vol. 1(1-2), pp. 69-97, doi: 10.1007/s40070-013-0004-7.

[16] HWANG, C.L, MASUD, A.S.M. *Multiple objective decision making - Methods and applications: A State-of-the-art survey*. New York: Springer-Verlag, 1979.