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Fast Simulation Modelling to Check New Layout for Material Flows

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Abstract:

Purpose: *The purpose of this research is to find a method that enables fast testing of new intralogistics process concepts - delivery of parts to the assembly site under the conditions of variable factory layout.*
Design/Methodology/Approach: *A new method of analyzing the intralogistics process under the conditions of layout change was proposed, using own, original idea of creating a flow model using the concept of a reference process.*
Findings: *The result of this research is the methodology for analysing and modelling intralogistics processes fast. The methodology uses a mechanism for automatic generation of routes for logisticians – suppliers of parts containers for the assembly site.*
Practical Implications: *This methodology has a practical goal – to reduce the time of simulation modeling. It is dedicated to production engineers and Lean specialists.*
Originality/Value: *This methodology is original - it presents an approach based on the so-called Reference processes - does not multiply other methods described in the literature.*

Keywords: *Material flow, simulation, intralogistics, automotive*.

Paper Type: *Research article.*

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1. Introduction

This article presents results of a research project carried out for an automotive industry company. The company has been preparing to change the layout of one of its departments as a result of an increased market demand for one of the company's products. The company is interested in an economic assessment of the new layout - and on this account it needs specific figures on distances and times of transportation operations. The new planned layout is being assessed by contrasting it against the existing layout.

The question the company wants to answer is the following: how long will it take for the investment in the new layout to return? The company wants to figure out the methodology to model material flows fast (around several hours) and analyze the considered flow scenarios quickly (almost immediately).

The authors of this article have been developing their own intralogistical simulation application. One of the tools developed in this application is the concept of the so-called reference process, the use of which allows to quickly generate a simulation model addressing the needs of the company. Such a simulation project implemented for a company provides the necessary information on distances and times of transport operations, which are later used by the company for economic calculations. Based on the experience from this project, a method has been developed enabling a rapid design of simulation models for material flows. The highlights of this article are:

- a method for analyzing the factory layout and material flows,
- a method allowing to quickly build (generate) a simulation model for material flow,
- a method dedicated to production engineers, Lean specialists and logistics specialists.

The contribution from the authors is the development of:

- the concept of reference process and cycle control based on this concept,
- the concept of generating the flow based on analyzing: BOM (Bill of Materials), assembly sites and parts containers storage (so-called supermarkets) locations.
- automated generation of flows based on the distribution of parts' usage across stations.

This article consists of 6 sections. Section 1 is the introduction, goal definition and highlights. The second section provides a brief literature overview. The research problem is defined in section 3. The conceptual solution to the problem - the methodology - is presented in section 4, whereas its implementation is covered in section 5. The article ends with results analysis and summary.

2. Literature Background

The analyzed project aims at solving an intralogistical task - an analysis of a new planned situation related with a change in the factory layout. The planned change is fueled by the need to build a new warehouse next to the existing assembly line, which entails modifications in intralogistics processes. The concept of intralogistics stems from the development of internal transport systems, accompanied by the simultaneous growth of monitoring, communication and planning systems (including digital technologies in enterprises).

Consequently, production and logistical systems were merged into a single comprehensive system. The term intralogistics is well known especially in German industry, since many scientific articles were affiliated with renowned German universities, incl. (Kartnig *et al.*, 2012; Schuhmacher *et al.,* 2019; Trott *et al.,* 2019). The term has been defined by the Intralogistics Forum Verband Deutscher Maschinen- und An-lagenbau (VDMA) (Hompel *et al.*, 2008) as: *"organization, control, implementation and optimization of the flow of materials and information inside the plant."* Although the term appeared as late as in 2008, earlier works indicate the development of intralogistics in the 1950s (Kartnig *et al.,* 2012).

Supply chains and factories are complex and dynamic systems. On the one hand, complexity results from the degree of complication of the manufactured products and the manufacturing technology. On the other hand, the complexity stems from the structure of the processes carried out in the factory. The paper (Cempel 2005) states: "When exploring complex systems (complexity of details and the dynamic complexity), simulation through its ability to manipulate space-time is the only tool that allows to grasp and understand cause-effect relationships that are distant in time and space and linked by multiple feedback loops (dynamic complexity)." Also, simulation is one of the key technologies for Industry 4.0 (Schwab, 2017) - *"the use of simulation and data processing tools to collect and analyze data from assembly lines, which are used for modeling and testing, is of great value for employees who want to understand industrial conditions and processes better".*

The use of simulation technology consists primarily in the design of a simulation model that represents real processes in the digital, virtual world. Simulation technology allows to perform simulation experiments (with time compression) and analyze the results for individual, future scenarios. There are many simulation packages on the market today that enable these activities to be carried out. The most popular are, Anylogic, Arena, Emulate 3D, ExtendSim, FlexSim, Plant Simulation, Simio, Simul8, Witness. Each of these providers proposes another methodology for creating simulation models that comply with the principles defined in (Law, 2007).

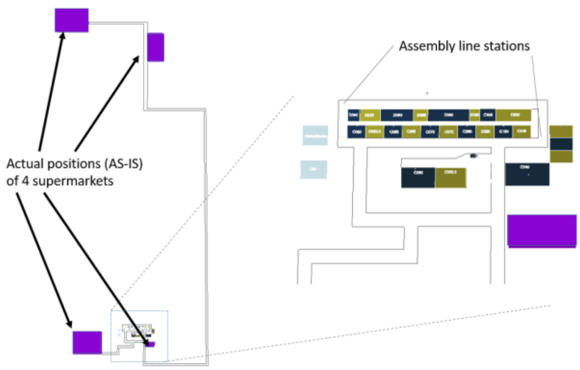
The methodologies proposed by the software vendors are based on the object-oriented approach, i.e., the user has to build the model him or herself from a set of objects (object libraries) – he or she does it on the screen in so-called working area using a computer mouse (Beaverstock *et al.*, 2017; Borschev, 2013). Usually it means building a model from scratch, although the used objects that manufacturers develop are becoming increasingly intelligent. In progress are also works addressing the automatic generation of models (Krenczyk, 2014), but the results are not commercially available, which means they cannot be used by enterprises as tools.

The achievements of Lean Manufacturing (Harris *et al.*, 2003) allow to define relationships in the factory that, when introduced to the simulation program, accelerate simulation modelling through the possibility to automatically generate the model (Pawlewski, 2018; 2019). The authors take such approach in the LogABS simulation application (www.logabs.com) dedicated to intralogistics, developed on the basis of the FlexSim GP simulation package (www.flexsim.com).

3. Motivation and Problem Statement

The research problem consists in material flows in a factory producing wheel sets. The main assembly process is not analyzed. The project focuses on a planned additional line, consisting of 12 stations, for mounting special equipment of the wheel sets. The layout of the additional line was created in an evolutionary fashion - from a few assembly stations to the formation of the current line. The line was created under the existing conditions in the company – therefore the space shortages determined the location of warehouse areas and the distribution of assembly parts. Figure 1 shows the current layout of supermarket warehouse locations in relation to assembly line stations. Supermarket is the location where a predetermined standard inventory is kept to supply downstream processes (Lean Lexikon, 2014). In this storage area parts containers are prepared for shipment.

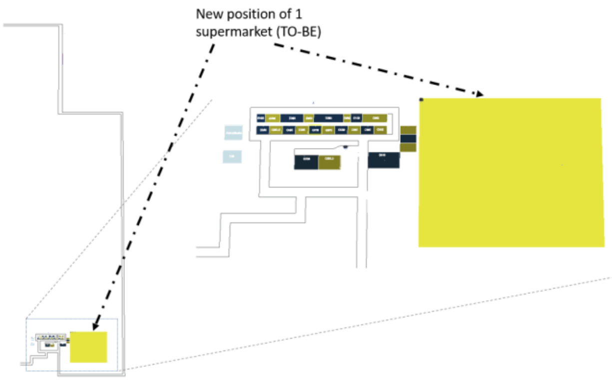
Figure 1. *Layout of the existing assembly line with 4 supermarket type warehouses - AS-IS*



Source: *Own creation.*

The company is considering to build a new supermarket warehouse closer to the assembly line - Figure 2 presents the concept of the new layout.

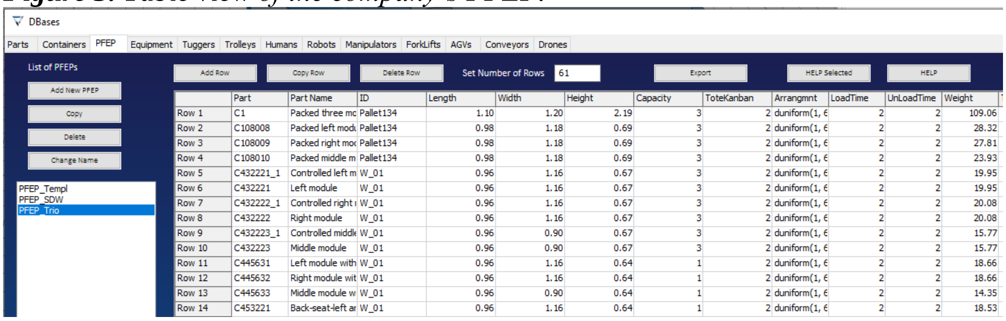
Figure 2. *Layout of the assembly line with a new input warehouse - TO-BE*



Source: *Own creation.*

The assembly process uses 870 different parts with unique indexes. The flow of these parts conforms to Lean and is based on PFEP - plan for each part. PFEP is a database in which parts indexes are assigned to container indexes in accordance with the principle that a given part is transported in dedicated containers with a predesigned (appropriate) capacity. This means that prior to designing the flows, the company had designed which parts in what quantity and in what containers shall be transported. In the analyzed process 500 different containers are used. Figure 3 shows a table view of the company's PFEP.

Figure 3. *Table view of the company's PFEP.*



	Part	Part Name	ID	Length	Width	Height	Capacity	ToteKanban	Arrangmnt	LoadTime	UnLoadTime	Weight
Row 1	C1	Packed three mc	Pallet134	1.10	1.20	2.19	3	2	duniform(1, 6	2	2	109.06
Row 2	C108008	Packed left modu	Pallet134	0.98	1.18	0.69	3	2	duniform(1, 6	2	2	28.32
Row 3	C108009	Packed right moc	Pallet134	0.98	1.18	0.69	3	2	duniform(1, 6	2	2	27.81
Row 4	C108010	Packed middle m	Pallet134	0.98	1.18	0.69	3	2	duniform(1, 6	2	2	23.93
Row 5	C432221_1	Controlled left m	W_01	0.96	1.16	0.67	3	2	duniform(1, 6	2	2	19.95
Row 6	C432221	Left module	W_01	0.96	1.16	0.67	3	2	duniform(1, 6	2	2	19.95
Row 7	C432222_1	Controlled right	W_01	0.96	1.16	0.67	3	2	duniform(1, 6	2	2	20.08
Row 8	C432222	Right module	W_01	0.96	1.16	0.67	3	2	duniform(1, 6	2	2	20.08
Row 9	C432223_1	Controlled middle	W_01	0.96	0.90	0.67	3	2	duniform(1, 6	2	2	15.77
Row 10	C432223	Middle module	W_01	0.96	0.90	0.67	3	2	duniform(1, 6	2	2	15.77
Row 11	C445631	Left module with	W_01	0.96	1.16	0.64	1	2	duniform(1, 6	2	2	18.66
Row 12	C445632	Right module wit	W_01	0.96	1.16	0.64	1	2	duniform(1, 6	2	2	18.66
Row 13	C445633	Middle module w	W_01	0.96	0.90	0.64	1	2	duniform(1, 6	2	2	14.35
Row 14	C453221	Back-seat-left ar	W_01	0.96	1.16	0.64	1	2	duniform(1, 6	2	2	18.53

Source: *Own creation.*

Based on the analysis of the demand arising within 1000 man-hours, it was calculated that a total of 1227 additions would be required - that is 1227 transport operations between a given position and the warehouse location.

In connection with the concept of changing the layout and building a new warehouse near the assembly line, the company seeks a justification to introduce the new layout. Intuition suggests that the new solution will be better because the shortening of transport routes is visible. However, for the economic analysis to be carried out, information is needed on the distances covered and the time for moving the containers with parts for the current situation (AS-IS) and for the design situation (TO-BE).

4. Problem Solution or Methodology

At first, Excel sheet calculations were considered. However, this approach was abandoned due to the complexity of such process, including the design of a mathematical model, collection, verification and validation of data and calculations results. Instead, a simulation technology was applied, using the .dwg (AutoCad) format layout, i.e., a digital image representing the top view of the enterprise section. This required the design of a simulation model for AS-IS and TO-BE situations. Next, the model was used for processing the material flow in both situations and finally results on the distances and transport times were collected.
The following data were available for building the simulation model:

1. Layout – a two-dimensional image of the company's layout in .dwg format;
2. Assembly diagram allowing to identify - which parts are assembled at which station - and thus where the parts containers shall be transported;
3. Layout of stations in relation to locations of containers with parts – locations reserved only for these containers;
4. Distribution of parts and containers in warehouses - this allows to identify from which locations containers with parts shall be transported;
5. PFEP (plan for every part) containing information what parts in which containers in what quantity shall be transported;
6. Stations’ work cycles data, i.e. when specific parts are used on a specific assembly station, and the related data on the container usage and replacement time.

Based on this data, one can build a simulation model based on standard methodologies proposed by manufacturers of simulation software (Beaverstock *et al.*, 2017; Borschev, 2013) by mapping the assembly process in the simulation model - in order to show the usage of parts and generate demand for container replacement. However, in view of the large number of different parts (870) and transport movements, such standard approach to building the simulation model may turn out too time consuming. Moreover, at this level of detail the time criterion defined in the previous section of this article would not be met. Therefore, a new methodology has been proposed based on the reference process and the percentage analysis of flows. The reference process is a process whose set of activities is constant, while the addresses for which the process is performed change. We assume that the activity be presented in the following format:
Address | Activity | Parameter
wherein:

Address stands for the location to which the performer activity refers,
Activity is the name/label of the performed operation,
Parameter – a number including additional characteristics of the operation.

The process of container flow may be presented as a sequence of activities performed by a transport unit, e.g. a manned forklift, AGV:

Travel - go to warehouse
Load - get container from warehouse
Travel Loaded - go loaded to station
Unload - leave container at station

In the proposed format the reference process may be shown as in Table 1:

Table 1. *Reference proces as table*

Address (Where)	Activity	Parameter
Source_N	Travel	0
Source_P	Load	1
Destination_N	TravelLoaded	0
Destinatrion_P	Unload	1

Source: *Own work.*

To multiply the process, set the number of repetitions of the process and perform them in a loop. The Source_N address indicates the point on the warehouse floor to which you need to go, Source_P indicates the containers location in the warehouse, while Destination_N and Destination_P indicate the point on the floor of the station and the location where a container should be left.

The change of addresses is defined in the table of addresses, which are the result of the statistical analysis of flows. Statistical analysis of flows based on BOM data and the distribution of indexes in warehouses for the AS-IS model is presented in Table 2 for container picking points - warehouses.

Table 2. *Percentage analysis of flows – source based.*

Source	Percentage of the full flow
Namiot H	75,79
Magazyn P	23,47
Namiot	0.57
M5	0.16

Source: *Own work.*

A flow analysis was also carried out based on the container collection points - i.e. assembly station points. Table 3 shows the percentage breakdown taking into account the container collection and drop off points.

Table 3. *Percentage breakdown of flows based on collection and transfer points*

Warehouse	Qty	St_1	St_2	St_3	St_4	St_5	St_6	St_7	St_8	St_9	St_10	St_11	St_12
Namiot H	930	10.65	0.54	1.29	5.59	1.72	6.02	27.63	3.76	5.16	21.83	9.89	5.91
Magazyn P	288	12.85	48.96	1.39	9.03	6.25	2.08	2.78	5.9	0.69	1.39	7.29	1.39

Namiot	7	0	0	0	0	85.71	14.29	0	0	0	0	0	0
M5	2	0	0	0	50	0	0	0	50	0	0	0	0
	1227												

Source: *Own work.*

Based on the Table presenting the percentage distributions of flows, one can define the rapid flow modeling methodology. The proposed methodology is outlined in the following steps:

1. Analytics - BOM analysis, flow definitions, percentage breakdown of the ,aterial stream - the result of this step is table 3.
2. Cycle analysis - definition of source points and destination points, isolation of the reference process - the result is a sequence of activities with related addresses.
3. Use of LogABS program, dedicated for intralogistics simulation modeling
    a. Load the layout,
    b. Define a group of stations - assembly line - definition of PFEP,
    c. Define in-line locations with locations - container collection points,
    d. Define locations in warehouses - container collection points,
    e. Define the reference process,
    f. Define the percentage distribution and replacement addresses.

    The result of this step is a simulation model for the AS-IS vs TO-BE situation.
4. Definition and performance of AS-IS vs TO-BE simulation experiments.
5. Analysis of the results.

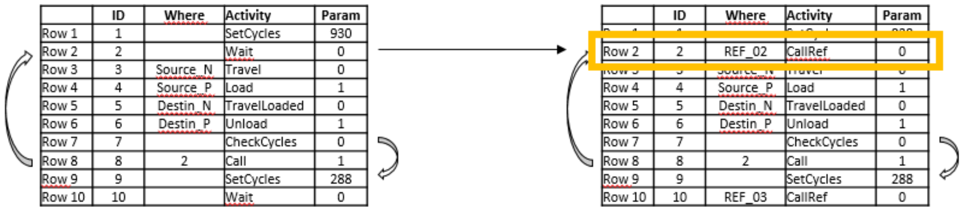
5. Implementation

Based on the presented methodology, a simulation model was designed in LogABS allowing to analyze distances and implementation times for the AS-IS vs TO-BE situations, as defined in section 3. Figures 1 and 2 have used images of the designed simulation model. The presented layout has been prepared in AutoCad, which enables processing the 3D model in actual units, and positioning each object in the simulation model in agreement with their actual locations.

It was critical for the methodology implementation to prepare tables with the reference process parameters and to propose an instruction that would draw (according to the constant schedule) a cycle – i.e. addresses for performing the cycle. Figure 4 (left table) shows the logic behind the standard preparation of a route for an operator who performs the cycles as shown in Figure 4.

A cycle consists of the instructions in lines 2, 3, 4, 5, 6. The SetCycles instruction in line 1 sets the number of cycles. The 7th line instruction CheckCycles verifies if the fnal cycles was completed. If not, the following instruction is performed (return to cycle). If yes, the following instruction is skipped and the next one is performed. Entering the CallRef instruction with the REF_02 address (Figure 4, table on the right) means that a number from the range 0-100 is drawn, according to the constant distribution. The drawn number indicates which addresses are picked from the previously defined table REF_02 for replacement. Figure 5 shows the situation.

Figure 4. *Route logic preparation improvement.*

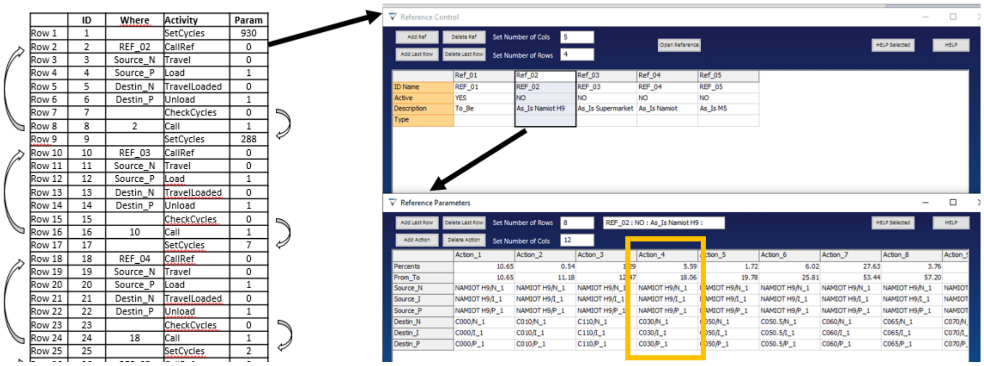


	ID	Where	Activity	Param
Row 1	1		SetCycles	930
Row 2	2		Wait	0
Row 3	3	Source_N	Travel	0
Row 4	4	Source_P	Load	1
Row 5	5	Destin_N	TravelLoaded	0
Row 6	6	Destin_P	Unload	1
Row 7	7		CheckCycles	0
Row 8	8	2	Call	1
Row 9	9		SetCycles	288
Row 10	10		Wait	0

	ID	Where	Activity	Param
Row 2	2	REF_02	CallRef	0
Row 4	4	Source_P	Load	1
Row 5	5	Destin_N	TravelLoaded	0
Row 6	6	Destin_P	Unload	1
Row 7	7		CheckCycles	0
Row 8	8	2	Call	1
Row 9	9		SetCycles	288
Row 10	10	REF_03	CallRef	0

Source: *Own creation.*

Figure 5*. Drawn numbers indicating addresses for replacement.*

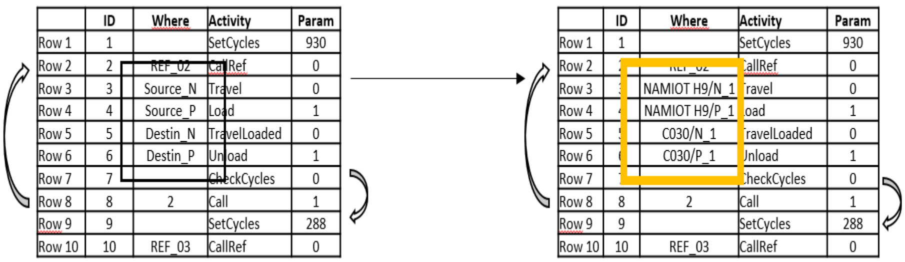


	ID	Where	Activity	Param
Row 1	1		SetCycles	930
Row 2	2	REF_02	CallRef	0
Row 3	3	Source_N	Travel	0
Row 4	4	Source_P	Load	1
Row 5	5	Destin_N	TravelLoaded	0
Row 6	6	Destin_P	Unload	1
Row 7	7		CheckCycles	0
Row 8	8	2	Call	1
Row 9	9		SetCycles	288
Row 10	10	REF_03	CallRef	0
Row 11	11	Source_N	Travel	0
Row 12	12	Source_P	Load	1
Row 13	13	Destin_N	TravelLoaded	0
Row 14	14	Destin_P	Unload	1
Row 15	15		CheckCycles	0
Row 16	16	10	Call	1
Row 17	17		SetCycles	7
Row 18	18	REF_04	CallRef	0
Row 19	19	Source_N	Travel	0
Row 20	20	Source_P	Load	1
Row 21	21	Destin_N	TravelLoaded	0
Row 22	22	Destin_P	Unload	1
Row 23	23		CheckCycles	0
Row 24	24	18	Call	1
Row 25	25		SetCycles	2

Source: *Own creation.*

REF_02 address refers to the list of tables containing the percentage ranges of flows and the real addresses assigned to these ranges. The CallRef instruction replaces variable addresses with actual addresses as assigned. The actual route, performed by the operator, is shown in Figure 6 - see the table on the right with the marked addresses that correspond to the marked addresses in the bottom table of Figure 5.

Figure 6*. Actual route performed by operator.*



	ID	Where	Activity	Param
Row 1	1		SetCycles	930
Row 2	2	REF_02	CallRef	0
Row 3	3	Source_N	Travel	0
Row 4	4	Source_P	Load	1
Row 5	5	Destin_N	TravelLoaded	0
Row 6	6	Destin_P	Unload	1
Row 7	7		CheckCycles	0
Row 8	8	2	Call	1
Row 9	9		SetCycles	288
Row 10	10	REF_03	CallRef	0

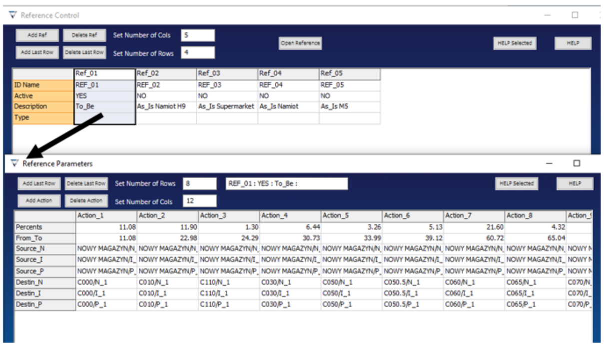
	ID	Where	Activity	Param
Row 1	1		SetCycles	930
Row 2			CallRef	0
Row 3		NAMIOT H9/N_1	Travel	0
Row 4		NAMIOT H9/P_1	Load	1
Row 5		C030/N_1	TravelLoaded	0
Row 6		C030/P_1	Unload	1
Row 7			CheckCycles	0
Row 8	8	2	Call	1
Row 9	9		SetCycles	288
Row 10	10	REF_03	CallRef	0

Source: *Own creation.*

Figure 5 presents the current AS-IS route. Figure 7 shows the TO-BE situation - the operator's route with the REF_01 table containing the new percentage distribution.

Figure 7. *TO-BE route (upper tables) with percentage distribution (bottom table).*

	ID	Where	Activity	Param
Row 1	1		SetCycles	1227
Row 2	2	REF_01	CallRef	0
Row 3	3	Source_N	Travel	0
Row 4	4	Source_P	Load	1
Row 5	5	Destin_N	TravelLoaded	0
Row 6	6	Destin_P	Unload	1
Row 7	7		CheckCycles	0
Row 8	8	2	Call	1
Row 9	9		ReadyForTask	0



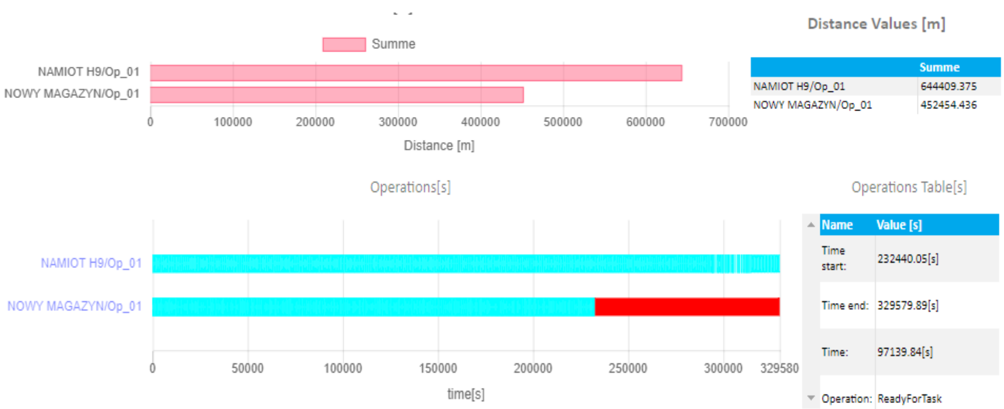
	Action_1	Action_2	Action_3	Action_4	Action_5	Action_6	Action_7	Action_8	Action_9	Action_10	Action_11	Action_12
NowyMag.	11,08%	11,90%	1,30%	6,44%	3,26%	5,13%	21,60%	4,32%	4,07%	16,87%	9,21%	4,81%

Source: *Own creation.*

6. Conclusions and Further Research

The methodology proposed in section 4 has been implemented in LogABS simulation application and presented to the company. With the built-in reference process mechanism, a single simulation model was built for which AS-IS vs TO-BE layout experiments were performed. All analytical and modeling works were performed within 1 working day (8h), of which most of the time, around 70%, was devoted to analytical work. The simulation experiment itself lasted 27.67 seconds on the machine - Intel Core i7-7700HQ CPU @ 2.80 GHz, RAM 32GB. Figure 8 shows the results of the experiments. The notion NAMIOT H9/Op_01 refers to AS-IS situation, while NOWY MAGAZYN/Op_01 refers to TO_BE situation.

Figure 8. *AS-IS vs TO-BE experiment results.*



Source: *Own creation.*

The designed methodology allows to significantly shorten the simulation modeling time. The company has accepted the proposed methodology. The significantly shorter modeling time enables testing / checking more alternative scenarios.

Further work will focus on improving the level of detail in the methodology and on covering not only percentage, but also quantitative and time-related changes.

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