A WAY OF SIMULATION TRANSPORT PROCESSES AND DISTRUBANCES IN SUPPLY CHAIN

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Abstract   The paper presents a description of how to model the supply chain using simulation software. In order to make the best representation of reality, not only the route and the lorry's speed are taken into account, but also the presence of various types of disturbances, like the occurrence of severe weather conditions or the inclusion of the driver's breaks, according to the applicable regulations. The purpose of this article is to demonstrate how to model the disturbance and to present benefits of using of simulation programs to plan a route of transport.

Paper type: Research Paper

1. INTRODUCTION

Paper presents author's work about how can we model a supply chain including different disturbances occurring in transport processes. Because of range aspects including in supply chain, they concentrate on transport area. Networks in supply chain can be modeled in different way, like by using Petri net, or algorithm Dijkstra and /Floyd-Warshall algorithms or by using simulation. In this article authors want to show using of simulation to model supply chain. Based on case study they show how we can model networks in supply chain and how can we model disturbances. One of them is described in detail. In presented case study, the route for realization transport order is defined, including different variables, as: a vehicle speed and different disturbances, as: severe weather conditions and breaks in driver works. This model is created by using a modern software FlexSim, that allows build models of various degrees of complexity (https://www.flexsim.com). To model disturbances, authors integrate Discrete Event Simulation (DES) with an Agent Based Simulation approach (ABS). Disturbance is represented by own created object, which has some intelligence, which has been given by modeler.

The main aim of this article is to present a simulation model of transport route for presented using simulation software to manage of some area of supply chain. To present processes in the best reality way, authors model route with some assumptions, like vehicle's speed. Besides, they include disturbances in this route. In this case they consider two disruptions – bad weather conditions and breaks in driver working time. Authors describe in detail how one of this disturbance is created in simulation model, not only in theoretical. Thanks to using simulation to model transport task, observation and analyze of dependences and behavior is possible. Moreover, making different experiments, user can see what will change, and how it will affect to whole process.

2. THE SUPPLY CHAIN ISSUE AND ASPECT OF OCCURRENCE DISTURBANCES IN SUPPLY CHAIN

2.1. The complexity of the supply chain issue

The first thought when we hear "supply chain", is an association with transportation process of products from point A to point B. But the issue is more complexity. Of course, the main role of the supply chain is a transportation of products from one point to the other, but we have to consider many other aspects, such as: ensuring adequate quality services at the lowest cost, finding the best mode of transport, the management of different entities involved in whole process.

At present, supply chains are dispersed systems (Caddy & Helou 2007); (Wieland & Wallenburg 2011). What makes, that the next problem is how to manage links and the structure of the whole chain in order to achieve the best results (in strategical and financial dimension).

Therefore, people pay more attention to modeling the supply chains and management of them by using various computer programs. The network can be described and modeled in few ways – the most know are:

- modeled transport routes by using different type of network, for example Petri net (Skorupski, 2011);
- by using algorithm like Dijkstra and /Floyd-Warshall algorithms (Chen et al. 2009);
- in mathematical description (Wilhelm & Hollunder 2007);
- and by using simulation software (http://www.llamasoft.com/).

For the purposes of modeling the processes in the supply chain two methods are used: Discrete-Event Simulations (DES) and Agent-Based Simulation (ABS). First method is a good option when we deal with well-known processes, for which the situations of uncertainty are defined using statistical distributions. DES models are characterized by the process approach – they focuses on modeling the system in detail, not on the independent units (Cassandras & Lafortune 2008). Second method, focus on individual elements and their behaviors (Kim & Robertazzi 2006). Reffering to the supply chain – the individual chain participants (companies, manufacturers, wholesalers and retailers) can be treated as agents who have their own goals and skills, and their common goal is to produce and deliver a product to a specific customer (http://www.anylogic.com). Agent-Based Simulation is discussed in more detail in (Kim & Robertazzi 2006); (Macal & North 2013). There are also numerous articles dedicated to agent modeling and multi-agent modeling in the transport and supply chains (Balbo & Pinson 2005); (Bocewicz et al. 2013).

2.2. The aspect of occurrence the disturbances in supply chain

Analysing transportation process, it is important to see broader range of this activity, not only the moving of goods. As in any other process, we should take into account the presence of various types of interference in the realization of activities.

In literature, we can find many articles about issue of the transport of hazardous materials and the associated with this transport risks (Gheorghe et al. 2004); (Marseguerra et al. 2003); (Tixier et al. 2006). Other popular aspect are car accidents (Orlandelli & Vestrucci 2004).

Authors it their works, focus on transport area in supply chain, and aspects of realization transport task in time. That's way they decided to distinguish various disturbances in this area, and try to determine how they affect to realization of whole process and time of it (Hoffa & Pawlewski 2014b). Authors distinguished such disturbances in transport operations (Hoffa & Pawlewski 2014a): related with

means of transport (like the failure of vehicle); related with the route (like: the traffic congestion, the road accident, weather conditions, the fee payment in Toll Collection Point); resulting from the fault of the sender and receiver (like: no enough free ramps for loading/unloading); related with the driver (like: the driver working time); and other.

3. PROBLEM DEFINITION

During the analysis of the literature about various disturbances in transport, authors noticed that a little number of articles about way of modeling of these disturbances are exists. Therefore, they decided to concentrate on the modeling the disturbances with the determination of the influence of them on the transport process, on time of transport.

Authors present mathematical description of the supply system model. Next, they show simulation model of the supply chain.

3.1. The supply system model – mathematical description

Authors present general description of model of a supply system (Fig.1).
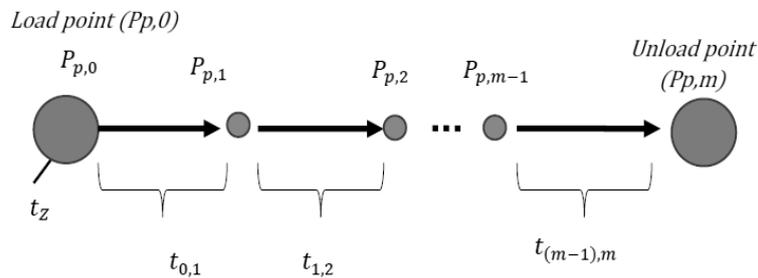
Fig. 1 The supply system model

A supply system model (Fig.1) is defined as:

$$SD = (P, D, T)$$

Where:

P - a transport route, defined as a sequence of:

$$P = \left(P_{p,0}, P_{p,1}, \ldots, P_{p,i}, \ldots, P_{p,(m-1)}, \quad P_{p,m}\right)$$

$P_{p,i}$ - $i - th$ intermediate point, where disturbances are considered,

m - the number of intermediate points,

$P_{p,0}$ - a starting point (load point),

$P_{p,m}$ - an unload point.

Intermediate points – are locations where interference may occur in the delivery.

Disturbances may affect to the delivery time.

D - a sequence of distances between intermediate points:

$$D = \left(d_{0,1}, d_{1,2}, \ldots, d_{(i-1),i}, \ldots, d_{(m-1),m}\right) \tag{3}$$

$d_{(i-1),i}$ - the distance between the point $P_{p,(i-1)}$ and point $P_{p,i}$,

T - sequence of transit times between intermediate points:

$$T = \left(t_{0,1}, t_{1,2}, \ldots, t_{(i-1),i}, \ldots, t_{(m-1),m}\right) \tag{4}$$

$t_{(i-1),i}$ - a travel time from the point $P_{p,(i-1)}$ to $P_{p,i}$ counted in contractual units of time [c.u.t.], $t_{(i-1),i} \in R$. The travel time is defined as a continuous random variable, for which it is known probability density distribution $g_{(i-1),i}(t)$. The probability of density distribution is dependent on the type of disturbance.

For the supply system modeled by the SD (1), in addition total time of delivery is defined T_{proc}.

$$T_{proc} = \sum_{i=1}^{L_{pal}} T_{Z_i} + \sum_{i=1}^{m} t_{i,(i+1)} \tag{5}$$

where:

T_{Z_i} - a time of loading of i-th pallets [c.u.t.],

L_{pal} - a number of pallets.

Total time of realization the delivery T_{proc} determine date of unloading Ra_o:

$$Ra_o = Z_0 + T_{proc} \tag{6}$$

where:

Z_0 - date of loading [c.u.t], $Z_0 \in R$,

Ra_o - expected date of unloading, $Ra_o \in R$.

For presented system, is searched answer for question: Is there a time of starting the loading Z_0, which ensures, with the specified probability Pd, ending the delivery at defined interval $Ra_o \in (Ra'; Ra)$?

$$(Z = ?) \Rightarrow \left[P\left(Ra_o \in (Ra'; Ra)\right) \geq Pd\right] \text{ for } SD, (Ra'; Ra)$$

3.2. The simulation model of supply chain - general information

In order to show how can we use simulation to model different processes in the supply chain, example of transport route was created. This simulation model was

built using FlexSim software. Using FlexSim is very simple by build-in tool and objects (https://www.flexsim.com).

This route includes travel from Komorniki city to Żary city, both of them are located in Poland.The distance is equal 167 km. The planned route includes journey using national road No. 32 and 27.

During build the simulation model, in order to present reality in the best way, some assumptions were made. One of them is vehicle's speed at national routes, which is equal 70 km/h (+ - Acceleration/Deceleration). This speed is intentionally not a random value, because authors want to clearly show the influence of various disturbances on the modelled route - at the time of realization the transport order.

The purpose of presented simulation model is show the possibility of modeling the transport route, which will includes some disturbances. By made few experiments on this model, it will be possible to defined the time, which is needed to travel this route, what will be shown at next part in this article.

4. CASE STUDY

This section provides an example of modelling the transport route, with including some disturbances. Authors taken into account only two disruptions, because they want to show, how they impact of whole process. Moreover, they want to present in detail how we can model disturbances. Analysing transportation order, we have to focus on transportation time from the start to the final point.

Building a simulation model with regard to certain assumptions (for example speed) and including disturbances, will simplify the observation and analysis of the individual activity in the whole process. By addition of the randomness of emergence of disturbances, and then carried out a series of experiments, it is possible to get an answer about the travel time from point A to B (including defined assumptions). Supplying the model with real data, we get a good tool, which can improve transportation planning in the company.

In this model, authors included two disturbances:

1. Weather conditions – authors treated severe weather conditions like downpour, blizzards, high winds, as disturbances. The occurrence of these phenomena is associated with reduction of travel speed. And, of course, it has an impact of time of realization the transport. A detailed description of the method of modeling of this disturbance is included in further parts of article.

2. Driver's working time – in conjunction with the applicable provisions (http://isap.sejm.gov.pl/) authors decided to consider time of driver's working. This disruption is a certain – we exactly know when the driver should have a break and how long. Of course it makes that travel time will be longer. Authors consider one option of driver working time - 4.5 hours of driving/work, then 45 min of break, then 4.5 hours of driving/work and then a 11 hours of break. They do not take into account other cases of breaks in work, because

on the market exist many software to manage of time of driver working. In created model, this disturbance has function as a reminder that the driver must have breaks! In the present model, the time of driver's working starts at time, when vehicle received the message about new transport order. So, loading and unloading operations are included in time working.

4.1. Breaks in the weather - description and method of modeling

Severe weather conditions (downpour, blizzards, high winds) make, that travel by car is harder, sometimes impossible. Because of this disturbance, we have to reduce the running speed, what have an impact of the extension of the travel time. Of course, collection data about weather condition is difficult problem, but not impossible. Based on historical data and information obtained from the weather maps, it is possible to determine the likelihood of severe weather conditions in the analyzed area. Besides, based on data on current weather conditions at certain points available on the Internet (for example http://www.traxelektro-nik.pl/), we can introduce new data to the model, in order to take into account them in the experiments. Moreover, based on these data, it is possible to create a base of weather conditions – for example we can define places where rain is rare phenomenon or place where is often windy.

This disturbance can be modelled in two ways. Both of them, in theoretical are described in (Hoffa & Pawlewski 2014a). In presented case study, this disturbance is modelled according to method 1 described in the above mentioned article. Difficult weather is represented by an agent with two specified ranges of action, what is described in detailed in (Hoffa & Pawlewski 2014a).
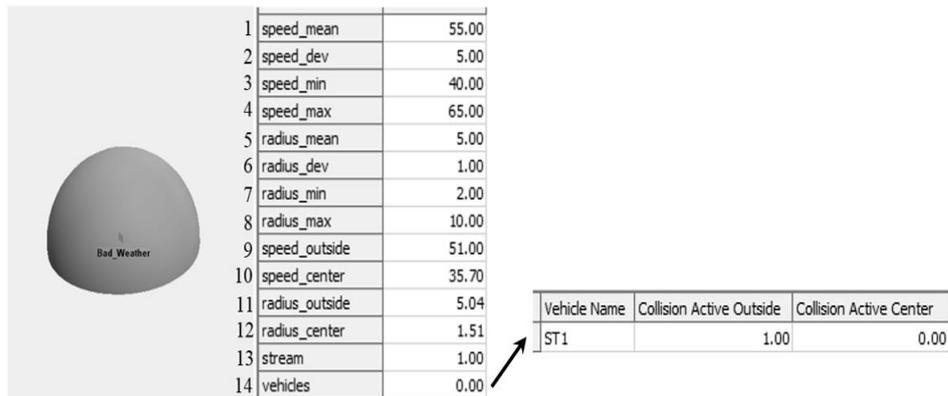
To model break in weather authors created own object with special labels and some assigned intelligence to model a particular interference (Fig.3). Each bad weather condition has been mapped on a single object named Bad_Weather. Authors created this object with using TaskExecuters Object in FlexSim. They used this type because it has additional function – definition of collision and possibility to check if other objects are in this area. Extent of this disturbance is expressed by two circle. Radius of bigger circle are defined by modeler, by using normal statistical distribution (with mean, deviation, and with minimum and maximum value of this aspect). The radius of smaller circle (center of weather change) has been set as 0,3 radius value of a bigger circle. The same situation is about a truck's speed – speed in the area surrounding the center are exactly defined by modeler (in labels), while speed in center is converted – 0,7 speed value.

Information about random values are description in labels in object. Created Bad_Weather object has 14 labels.
- Labels 1-4 - contain information about mean, deviation, minimum and maximum value of speed in bigger area of disturbance (in the ring, which

forms the area surrounding the center). These information have to be defined by modeler.

- Labels 5-8 - include information about radius of bigger area. These information have to be defined by modeler.
- Label 9 - contains information about speed outside (in ring), which is defined based on labels 1-4.
- Label 10 - includes information about speed in center of disruptions, is equal as 0,7*speed_outside.
- Label 11 - contains information about radius outside (the whole radius of disruptions), which is defined based on labels 5-8.
- Label 12 - includes information about center radius, is equal as 0,3*radius_outside.
- Label 13 – presents a number of stream, it is changeable in this model too.
- Label 14 – it includes table of information about type of active collision (center or in surrounding area) and the name of truck, which is in this area. Based on this information, it is possible to manage of objects which are in range of interference, and change them speed.

1	speed_mean	55.00
2	speed_dev	5.00
3	speed_min	40.00
4	speed_max	65.00
5	radius_mean	5.00
6	radius_dev	1.00
7	radius_min	2.00
8	radius_max	10.00
9	speed_outside	51.00
10	speed_center	35.70
11	radius_outside	5.04
12	radius_center	1.51
13	stream	1.00
14	vehicles	0.00

Vehicle Name	Collision Active Outside	Collision Active Center
ST1	1.00	0.00

Fig. 3 Created Bed_Weather Object.

When bad weather condition occurs, area of effect is defined by normal distribution with parameters stored in object labels. The level of speed decrease is defined in the same way. Described object checks, with certain time interval, if there is another object in range. When an object (mean of transport) is detected, its travel speed is decreased to specific value, first to speed adequate to surrounding area (case 2 at Fig. 4), then to speed for center area (case 3 at Fig. 4) and then again at speed for surrounding area (case 4 at Fig. 4). When this objects leaves area, its speed is set back to original value (case 5 at Fig. 4). Checking time interval is relative small (currently 0.01 time unit). It provides, that moment when the vehicle has left the disturbance is quickly noticed. Figure 4 shows described situations.
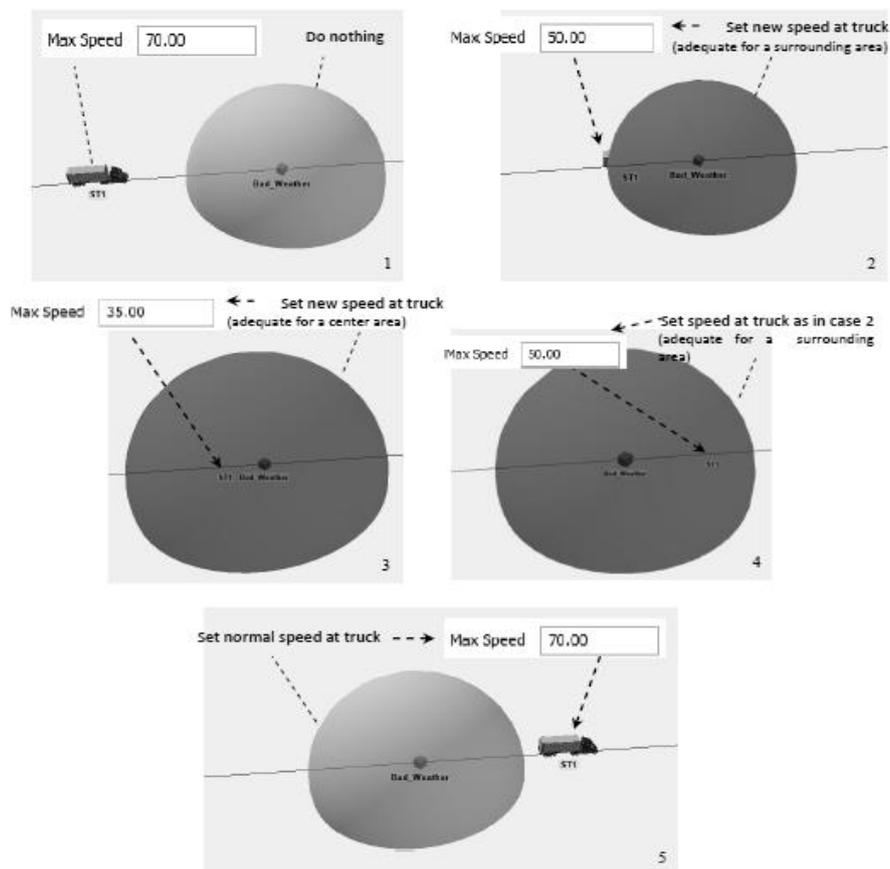
Fig. 4: Bed_Weather Object – mode of action.

4.2. Description of simulation experiments

For presented simulation model with transport route four experiments (4 scenarios) were made. Each experiment was made 10 times (10 replications) to show influence of random value setting in disturbance. Experiments were made by using built-in experimenter tool in FlexSim.

In every experiments main variables in weather disturbance were changed, to show how this disruption affects to the time of realization the transport process. In present case authors do not take into account the possibility of a detour – the alternate route. The issue of seeking a new route, because of disturbances, is not the aim of this study. The main goal is show changeable time of realized transport, which depends on random value in disturbances (like radius of this dis-ruption or truck speed in area of this disruption). To show relations between pro-

cess time versus disturbances, authors made some simplifications. First: only two disruptions are considered in model. Second: acceleration and deceleration aspects are not taken into account in the model.

Table 1 Definition of simulation experiment

Experiment No	Take into account the driver's working time	Definition of speed				Definition of range			
		Mean value of speed	Dev of speed	Min value of speed	Max value of speed	Mean value of radius	Dev of radius	Min value of radius	Max value of radius
1	yes	55	5	40	65	5	1	2	10
2	yes	60	10	40	65	10	2	2	15
3	yes	55	10	40	67	10	3	2	15
4	yes	40	15	30	55	10	5	2	15

Information about the experiments are summarized in Table 1. Important information is the fact, that the travel time from point A to point B without any disturbance is equal 2.38 hour.

4.3 Results of experiments

The main purpose of these experiments was present the transportation time, which depends on random value in disturbances, as speed and radius. Table 2 presents results of this experiments. As we can see, the transportation time is the smallest at experiment 1, because the values in weather disturbance are the least slow down the process. The smallest speed, and the largest radius of this disruptions was defined at scenarios 4, which is reflected in the obtained results.

By using built-in experimenter tool in FlexSim, we can have information about interval of values of the analyzed time for the confidence interval as 90, 95 or 99%. Figure 6 presents results for 90% confidence interval. Referring to the description of model of supply system and given there question about existence of time of starting the loading Z_0, which ensures ending the delivery at defined interval $Ra_o \in (Ra'; Ra)$, we can say- that it exists and it can be defined it by using Experimenter tool in FlexSim software.

process_time

	Mean (90% Confidence)	Sample Std Dev	Min	Max
Scenario 1	2.453 < 2.465 < 2.476	0.020	2.445	2.506
Scenario 2	2.499 < 2.537 < 2.575	0.065	2.456	2.647
Scenario 3	2.489 < 2.518 < 2.546	0.050	2.462	2.613
Scenario 4	2.583 < 2.679 < 2.775	0.165	2.452	2.909

Fig. 6 Confidence interval for analyzed time. Source: results obtained from FlexSim model

Table 2 Results of simulation experiments. Source: results obtained from FlexSim model

	Transportation Time [h]									
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
Sc. 1	2,48	2,46	2,46	2,44	2,45	2,51	2,46	2,44	2,44	2,48
Sc. 2	2,61	2,52	2,65	2,50	2,57	2,60	2,47	2,48	2,52	2,46
Sc. 3	2,59	2,46	2,47	2,51	2,51	2,53	2,47	2,53	2,49	2,61
Sc. 4	2,72	2,56	2,75	2,72	2,91	2,91	2,55	2,47	2,45	2,75

5. CONCLUSION AND FURTHER INVESTIGATIONS

The presented approach to modeling a supply chain enables precision analysis of processes and impact of them to whole transport process. Thanks to using the simulation, observation and analysis of process is possible. In addition, including aspect of disturbances, a good tool to determine the time required for transport is created. Authors in detailed description present a way of modeling processes in supply chain and disturbances. In order to show the use of the described aspects, the simulation model for the sample transport routes have been created. By performing a number of experiments is shown a relationship between "the strength" of the interference and times of transport realization.

Obviously, there is an opportunity for further development of the proposed work: modelling next disturbances in described way (with combining ABS and DES approach). And check relation between them and time of realization the transport task. Creating library with disturbances, fast building of simulation model will be possible. Next step is "play" with simulation model and definition of time of analyzed process, with using build-in experimenter tool.

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