sustainability

MDPI

Article

Simulation Modeling of the Sustainable Supply Chain

Patrycja Hoffa-Dabrowska [1] and Katarzyna Grzybowska [2,*]

[1] Poznan University of Technology, 60-965 Poznan, Poland; patrycja.hoffa-dabrowska@put.poznan.pl
[2] Poznan University of Technology, 60-965 Poznan, Poland; katarzyna.grzybowska@put.poznan.pl
* Correspondence: katarzyna.grzybowska@put.poznan.pl; Tel.: 48-6079-634-56

Received: 30.06.2020; Accepted: date; Published: date

Abstract: The development of the global economy affects to the environment in which we are living, often in negative way - the pollutions, exhaust emissions, depletion of natural resources, and other. Therefore, it is so important to use resources in a reasonable, sustainable manner and to be aware of impact on the environment our activities, which in the next stage translates into trying to limit a negative impacts to the environment. The aspect of Sustainable Supply Chain (SSC) become more and more popular in the last years. Entrepreneurs in their activities pay more attention to the aspect of sustainable development, especially to the exhaust emissions. The rational use of resources is also very important topic. Not only economic aspects but also environmental and social topics are taking into account in company politics, which is characteristic of sustainable development. The main purpose of this article is to show the benefits of SSC. For this purpose, the simulation models showing the supply chain and the sustainable supply chain will be built. The benefits of SSC in economic and environmental aspects will be presented with using the computer simulation tool. Using the simulation tool fits in sustainability – thanks to modeling supply chains in virtuality and analyzing them, many resources can be saved in reality (for example thanks to consolidation of freight).

Keywords: sustainability, supply chain, simulation, Industry 4.0

1. Introduction

Economic development, globalization, change of lifestyle and consumer expectations cause specific changes in the operation of the economy. Requirements for companies are grower – everything should be done as fast as can and in a good quality. Enterprises have to react very quickly to challenges and opportunities of the business world [1]. The Industry 4.0 concept has been disseminated for almost ten years [2]. In Industry 4.0, dynamic business and engineering processes enable last-minute changes to production and deliver the ability to respond flexibly to disruptions [3-7]. This attitude has specified impact of way of functioning companies. Also for transportation companies. The main key – time, made that popular form of transport is road transport. The transport volumes are growing (also the small volumes orders), which has certain effects – more trucks at road, higher fuel consumption and higher exhaust emission. That's way against the steadily growing transport orders, it is important to develop sustainability concepts. In context of supply chain, sustainability means sustainable development, which focus on three aspects – environmental protection, economic growth, and social equity [8]. Actually, companies at their activities should consider all three dimension in making decisions. These dimensions have to be connected. In other way the ecologic protection of our planet is not full. For showing advantages of consolidation orders, the simulation model are presented. By using simple simulation model authors present in three dimension benefits of cooperation at realization transport order level. Some experiments will be

made to show advantages of consolidation the transportation order. By analyzing costs of realization every order and influence for environment the two of three benefits will be considered – economic and environmental. In social aspect, the order's consolidation means less traffic, and potentially fewer accidents.

For purpose of this article the literature research about simulation of the sustainable supply chain was made. Authors want to show the usefulness of simulation model, that's way decided to show the context of used this tool in global terms. The literature review confirms own experiences of authors about advantages of using simulation model in aspects of supply chain and sustainability supply chain.

The article consists of 4 parts. At first, the literature review about using simulation tool in sustainable supply chain are described. In second part, authors present in detailed built simulation model for showing advantages of sustainable supply chain. The experiments and results from them are described at part 3. At last part the conclusion and development possibilities are presented.

2. Literature review

Supply Chain Management (SCM) has developed into a major conceptual approach inside management and business administration [9]. Supply chains are inherently complex, dynamic [10] and dispersed and open systems [11]. The supply chains are in a state of transformation. The better we understand the future needs, the better modern and future supply chain will function [12-14].

In the last two decades, aspect of Sustainable Supply Chain (SSC) become more and more popular [15], both at academia and practitioners' side. The trend recognized as Sustainable Supply Chain refers to the idea of sustainability and its implementation to supply chain structure [16]. Seuring and Muller (2008) define SSCM as the management of material, information and capital flows as well as cooperation among companies in the supply chain while taking goals from all three dimensions of sustainable development (environmental, social and economic) into account which are derived from customer and stakeholder requirements [17]. Sustainability outcomes encompass the adoption of environmentally and socially responsible practices as well as the achievement of environmental, social or economic performance [18]. Unfortunately, it can be said that most of organisations are indifferent or even opposed the SSC idea – many of unsustainable activities confirms that [19].

The literature review about popularity of aspect of simulation of the sustainable supply chain was made by using Scopus data base. Simulation is an important element in the study of sustainable supply chains [11], Sustainable World [20], supply chain simulation [21], production and distribution [22], food supply chain management [23], discrete production processes [24]. Authors decide to use different searching methods for showing the differences in number of articles. By using only sentences simulation sustainable supply chain, more number of articles are getting because of searching all worlds separately. When the searching is restricted by using quotation marks, more adequate documents are getting. The results of searching are presented at Table 1. They included all articles till 2019. It is worth to mention, that detailed literature analysis in case of searching keywords in all fields, should be expanded – by looking at every article and checking exactly the range of article. But for purpose of this article it is not necessary. The actual literature review is doing for showing importance and usefulness of using simulation in aspects of sustainable supply chain. As can be noticed using quotation marks in searching, the statistics change a lot, from about 18,5 thousand articles to 2,5 thousand in analyzed field.

Table 1. Searching results for simulation sustainable supply chain; May 2020; own work

No case	Keyword kit	Where (place of searching)	Search results (number of documents)
1	simulation sustainable supply chain	All fields	18659

2	simulation sustainable supply chain	Article title, Abstract, Keywords	464
3	"simulation" AND "sustainable supply chain"	All fields	2500
4	"simulation" AND "sustainable supply chain"	Article title, Abstract, Keywords	62
5	"simulation" AND "sustainable supply chain" AND "case study"	All fields	1848
6	"simulation" AND "sustainable supply chain" AND "case study"	Article title, Abstract, Keywords	10

In the next step authors analyzed only articles find by restricted searching method – using quotation marks – case 3 and 4. The number of articles for case 3 and 4 in 2003-2019 are compared at Fig. 1. By searching analyzed topic in all fields the growing interesting can be noticed. In more restricted searching methods the unabated interesting can be noticed.

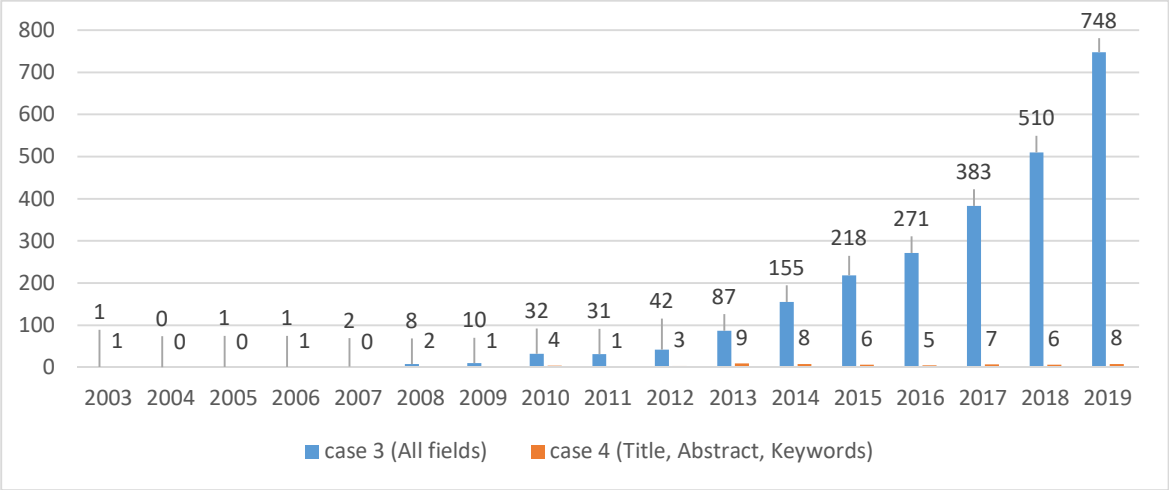


Figure 1. Comparison of number of articles for searching case 3 and 4; own study by Scopus data (access data: May 2020).

The comparison of searched papers in case 3 and 4 by country or territory is presented at Fig. 2. In ten 10 countries in both cases are: China, United States, and India.

The aspect of sustainable supply chain are simulated, what confirmed the literature review. The different area, range and type of economic branches of supply chains are simulated. Chanchaichujit et al. [25] present a literature review of mathematical modelling approaches for sustainable supply chain. Rebs et al. [26] describe a literature review and systems thinking approach for system dynamics modeling for SSC management.

Complex analysis (including economic, environmental and social indicators) for sustainable supply chain present Wang et al. [27] in their paper – they propose "a framework for evaluating the sustainability of a detergent supply chain through integration of supply chain dynamic simulation and environmental- and societal – Life Cycle Assessment (LCA)". The life cycle assessment (LCA) methodology is an ideal tool not only to quantify the related environmental impacts [28-29].

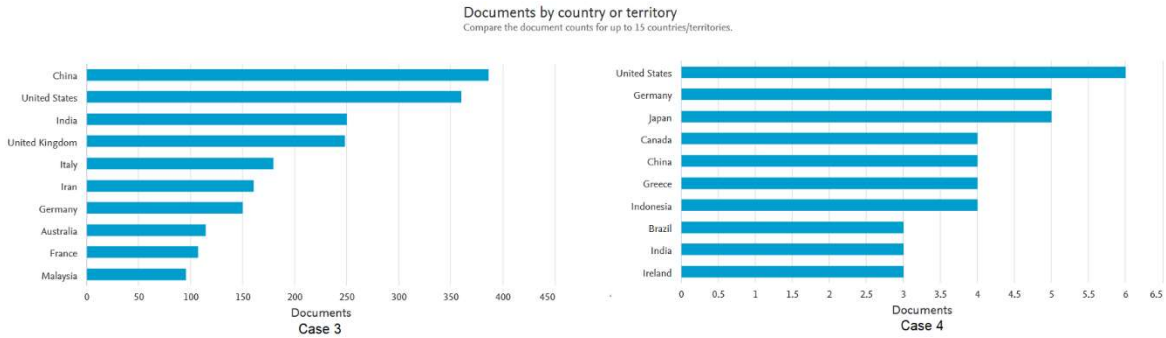


Figure 2. Comparison of searched papers in case 3 and 4 by country or territory. Source: Scopus data (access data: May 2020).

Hong et al. [30] describe using Monte Carlo simulation for sustainable supply chain. Hong and the other focus in paper not only on economic aspect but also ecologic – they pay attention for carbon emissions and PM2.5, which have a negative impact on human health. Authors in the paper "constructs a mathematical programming model that minimizes the transportation costs and the undesirable social medical costs for remedying the release of PM2.5 into the atmosphere". The ecological aspects are also described in article [31] and [32].

Examples of case studies for using simulation in aspect of sustainable supply chain are presented in table 2.

Table 2. Case studies for using simulation in aspects of sustainable supply chain; Source: [33-38]

Author and data	Article title	Content
Hidayatno, A. et al., 2019 [33]	Designing a serious simulation game as a learning media of sustainable supply chain management for biofuel production	At this article the Serious Simulation Game (SSG) that focuses on the purchasing, production, sales, and finance functions, using case studies of companies that run crude palm oil mills is designed.
Mehmann J., Teuteberg F., 2016 [35]	The fourth-party logistics service provider approach to support sustainable development goals in transportation - A case study of the German agricultural bulk logistics sector	Authors used a mixed method approach (qualitative insights based on semi-structured interviews and quantitative insights based on simulations) for integrate a fourth-party logistics service provider in the German Agricultural Bulk Logistics sector for achieve sustainable in transportation, i. e.: by realizing full truck loads.
Yan et al., 2016 [38]	Green component procurement collaboration for improving supply chain management in the high technology industries: A case study from the systems perspective	In the paper two different supply chain collaboration models, from multi-layer ceramic capacitor (MLCC) and universal serial bus 3.0 (USB 3.0) cable procurements, were benchmarked and statistically validated. The System Dynamics simulation analysis were used. Moreover the statistical validations with empirical data were made. The data were collected from Taiwanese manufacturing chains.
Shamsuddoha M. et al., 2015 [37]	Sustainable poultry production process to mitigate socio-economic challenge	In this paper a sustainable model for the poultry industry in Bangladesh was developed. The model was developed with using SIMUL8 software package. The goal of this model was mitigate existing socio-economic problems in poultry industry.

Sahay N., Ierapetritou M., 2013 [36]	Supply chain management using an optimization driven simulation approach	A hybrid simulation-based optimization framework to solve the supply chain management problem is presented in this article. The optimal allocation of resources in realistic supply chain are analyzed in this case.
Li C., 2013 [34]	An integrated approach to evaluating the production system in closed-loop supply chains	In this paper authors presented the problem of comprehensively evaluating the production system in closed-loop supply chains. For better understanding they described simulation and case studies.

3. Simulation model

Authors decided to build the simulation model of supply chain/sustainable supply chain to show the advantages of cooperation in order and transportation level. A simple model for presentation the realization of transportation order was created. In first step authors, by using this model will show situation of individual realization the transport order. In the next step they will present the advantages of cooperation and combine the orders. In the context of sustainable supply chain the cooperation between transportation companies is very important. The advantages are important in economic, ecological and social site. By using built simulation model these advantages will be shown in further part of this article.

The simulation model consists of two basic parts:

- first are global table in which data are included,
- second are logical process, which look like algorithm.

The simulation model was built by using FlexSim simulation software [13]. It is a modern 3D simulation software. The logic process was built by using Process flow module, which is built in the FlexSim software. This module is very useful for programming decision, business aspects in the simulation model.

3.1. Global tables in simulation model

The built model of supply chain consists of 11 global tables. Ten of them contain entry information, in one of them the results from model are presented. All tables can be easily modified – by adding next row or column can be added more information.

First table in model is named "Order_info" (Fig. 3). In this table the information about order are consist, as: quantity of pallets to transport for every order and the number of vehicle which will be used for this transport order. Actually at this table only ten orders are added. But the can be easily extended – by adding next rows.

Order_info

	No pallets	No Vehicle
Order 1	28	1
Order 2	28	2
Order 3	28	4
Order 4	15	1
Order 5	17	1
Order 6	10	3
Order 7	18	3
Order 8	8	3
Order 9	14	3
Order 10	9	3

Figure 3. Table "Order_info"; own study with use FlexSim program

The second table is named "Vehicle_info" (Fig. 4). In this table the basic information for vehicle are added: euro type, fuel consumption [l/km], mean speed [km/h], work cost [euro/hour]. These

information are used for calculating time of realization order and cost, what is important from two of three dimensions of sustainable supply chain (economic and ecological). Depends on the number of vehicle from table 1, the proper information into simulation are loaded.

Vehicle_Info

	Euro Type	Fuel consumption [l/km]	Mean speed [km/h]	Work cost [Euro/hour]
Vehicle 1	Euro5	32.500	60	5
Vehicle 2	Euro4	35	60	4.500
Vehicle 3	Euro5	31	60	5.250
Vehicle 4	Euro6	27	60	6.500

Figure 4. Table "Vehicle_info"; own study with use FlexSim program

The third table is named "Euro_Standards" (Fig. 5). In this table the information about exhaust emission are included [39-40]. Based on this data, for used vehicle in every order the exhaust emission is calculated. It is very important from ecological point of view.

Euro_Standards

	CO [g/km]	HC [g/km]	NOx [g/km]	PM [g/km]
Euro1	3.160	0	0	0.140
Euro2	1	0.150	0.550	0.080
Euro3	0.640	0.060	0.500	0.050
Euro4	0.500	0.050	0.250	0.009
Euro5	0.500	0.050	0.180	0.005
Euro6	0.500	0.090	0.080	0.005

Figure 5. Table "Euro_Standards"; own study with use FlexSim program

Table "Info" in the model is created for added additional basic information into simulation model, which are important from different calculating aspects (Fig. 6). In this model at this table actually only information about fuel cost is saved.

Info

	Cost [Euro]
Fuel cost	1

Figure 6. Table "Info"; own study with use FlexSim program

Analyzing supply chain from three dimensions – economic, ecological and social authors decided to calculate time of realization transport order not only based on distance-speed relationship, but they also take into account time of loading and unloading pallets into the vehicle. In table "Time" basic information of time of load/unload one pallet are restored (Fig. 7). Including this variable, the time of realization, what means also cost of them, will depend on volume of pallets for transport in each order.

Time

	Time [min]
Load	3.500
Unload	4.200

Figure 7. Table "Time"; own study with use FlexSim program

The simulation model is built in that way, that can be used both for simple supply chain (load point-unload point) but also for sustainable supply chain, which can include few load points and few unload points in one order. Depending on the entry information in tables "Load_Point" (Fig. 8) and "Unload_Point" (Fig. 9) the different supply chain will be simulated. Actually, it was assumed that

in one order maximum five load points and maximum five unload points can be added. But the table can be extended by adding next columns. The number 1 in these tables means place 1, 2 – place 2, etc. These tables have to had the same number of rows as table "Order_info".

Load_Point

	Load Point 1	Load Point 2	Load Point 3	Load Point 4	Load Point 5
Route 1	1	0	0	0	0
Route 2	1	0	0	0	0
Route 3	1	0	0	0	0
Route 4	4	0	0	0	0
Route 5	9	0	0	0	0
Route 6	6	0	0	0	0
Route 7	2	0	0	0	0
Route 8	3	0	0	0	0
Route 9	5	0	0	0	0
Route 10	2	0	0	0	0

Figure 8. Table "Load_Point"; own study with use FlexSim program

Unload_Point

	Unload Point 1	Unload Point 2	Unload Point 3	Unload Point 4	Unload Point 5
Route 1	3	0	0	0	0
Route 2	3	0	0	0	0
Route 3	3	0	0	0	0
Route 4	6	0	0	0	0
Route 5	2	0	0	0	0
Route 6	3	0	0	0	0
Route 7	7	0	0	0	0
Route 8	4	0	0	0	0
Route 9	1	0	0	0	0
Route 10	8	0	0	0	0

Figure 9. Table "Unload_Point"; own study with use FlexSim program

Next table "Place_Distance" (Fig. 10). is connected with tables "Load_Point" and "Unload_Point". In this table are added information about distance between each places. These distances are expressed in km units. The places intentionally do not have a city name, because for purpose of this article it is not necessary. Analyzed one example of order – order first, it can be noticed that order are loaded in point 1, and unload in point 3. From "Place_Distance" table can be read, that distance between this point is equal 120 km.

Place_Distance

	Place 1	Place 2	Place 3	Place 4	Place 5	Place 6	Place 7	Place 8	Place 9	Place 10
Place 1	15	85	120	140	360	160	270	400	380	450
Place 2	85	15	90	65	80	140	210	280	350	390
Place 3	120	90	15	410	320	420	380	80	275	180
Place 4	140	65	410	15	195	230	340	85	220	160
Place 5	360	80	320	195	15	110	280	210	360	490
Place 6	160	140	420	230	110	15	330	315	260	385
Place 7	270	210	380	340	280	330	15	100	60	255
Place 8	400	280	200	85	210	315	100	15	440	400
Place 9	380	350	80	220	360	260	60	440	15	180
Place 10	450	390	180	160	490	385	255	400	180	15

Figure 10. Table "Place_Distance"; own study with use FlexSim program

Building one simulation model, which can be used for simple transportation order (one load point – one unload point) and also collaboration transportation order (few load point – few unload point) additional information about number of pallets which are loaded in every load point, and unloaded in every unload points are needed. These information are included in tables "Order_NoPalletsLP" (Fig. 11) and "Order_NoPalletsUP" (Fig. 12). In these tables the number of rows (orders) have to be the same as in table "Order_info". Moreover, the sum of number pallets in every row have to be equal the number of pallets in table "Order_info" for the proper order. It have to be checked by person who used the simulation model. The quality of results depends of the quality of input data.

212

Order_NoPalletsLP

	No Pallets in LP1	No Pallets in LP2	No Pallets in LP3	No Pallets in LP4	No Pallets in LP5
Order 1	28	0	0	0	0
Order 2	28	0	0	0	0
Order 3	28	0	0	0	0
Order 4	15	0	0	0	0
Order 5	17	0	0	0	0
Order 6	10	0	0	0	0
Order 7	18	0	0	0	0
Order 8	8	0	0	0	0
Order 9	14	0	0	0	0
Order 10	9	0	0	0	0

213

214 **Figure 11.** Table "Order_NoPalletsLP"; own study with use FlexSim program

Order_NoPalletsUP

	No Pallets in UP1	No Pallets in UP2	No Pallets in UP3	No Pallets in UP4	No Pallets in UP5
Order 1	28	0	0	0	0
Order 2	28	0	0	0	0
Order 3	28	0	0	0	0
Order 4	15	0	0	0	0
Order 5	17	0	0	0	0
Order 6	10	0	0	0	0
Order 7	18	0	0	0	0
Order 8	8	0	0	0	0
Order 9	14	0	0	0	0
Order 10	9	0	0	0	0

215

216 **Figure 12.** Table "Order_NoPalletsUP"; own study with use FlexSim program

217

218 The last table is table "Results" (Fig. 13), in which during simulation results are renishedepl.
219 Based on created simulation model the time, cost and ecological aspects are counted for every
220 transport order.

221

Results

	Time load and unload [min]	Time route [min]	Total time [min]	Distance [km]	Fuel consumption [l]	Fuel cost [euro]	Worker cost [euro]	Total cost [euro]	CO [g/km]	HC [g/km]	NOx [g/km]	PM [g/km]
Order 1	0	0	0	0	0	0	0	0	0	0	0	0
Order 2	0	0	0	0	0	0	0	0	0	0	0	0
Order 3	0	0	0	0	0	0	0	0	0	0	0	0
Order 4	0	0	0	0	0	0	0	0	0	0	0	0
Order 5	0	0	0	0	0	0	0	0	0	0	0	0
Order 6	0	0	0	0	0	0	0	0	0	0	0	0
Order 7	0	0	0	0	0	0	0	0	0	0	0	0
Order 8	0	0	0	0	0	0	0	0	0	0	0	0
Order 9	0	0	0	0	0	0	0	0	0	0	0	0
Order 10	0	0	0	0	0	0	0	0	0	0	0	0

222

223 **Figure 13.** Table "Results"; own study with use FlexSim program

224 *3.2. Logical process in simulation model*

225 Second part in described simulation model is the logical process, which look like algorithm
226 (Fig. 14). This logical process can be divided into three parts:

227 • part 1 – in which the basic information from global tables are downloaded, as: order info, vehicle
228 and worker info, process time and route info,
229 • part 2 – in which information about load points and unload points for every order are
230 complemented,
231 • part 3 – in which results are calculated and saved in table "Results" for future presentation.

232

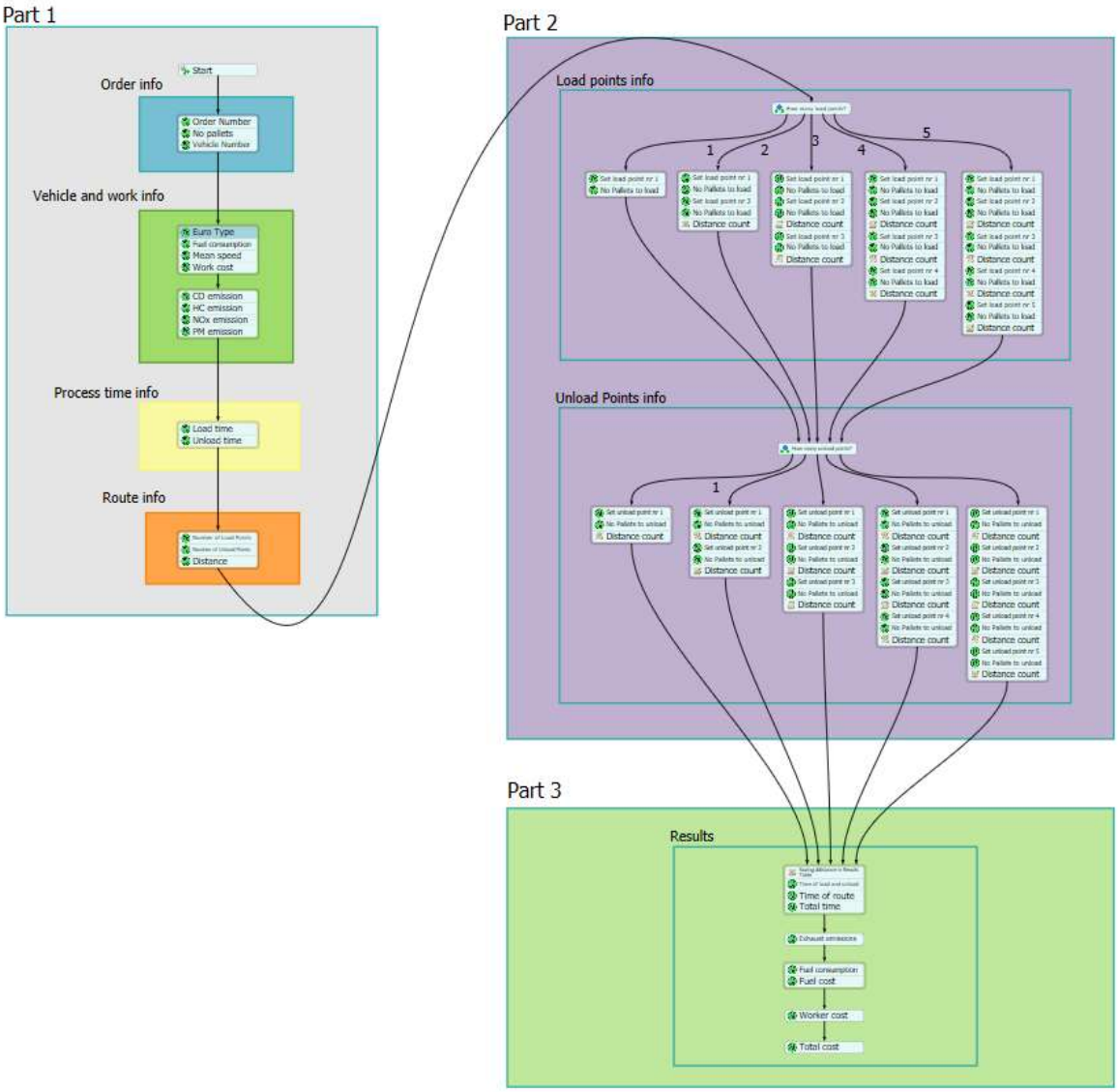


Figure 14. Logical process for transportation simulation model; own study with use FlexSim program

The logical process look actually simple. But in every point (cube) some programming code is added. For purpose of this article – to present the advantages of sustainable supply chain (in which the cooperation and connection of transport orders are taking into account) in compare to simple supply chain this model is adequate. In next chapter, based on results it will be proven. Currently, at part 2 is permanently determined that maximum 5 load or unload point can be defined in order. Authors intentionally defined this step like that – to show better the idea of describe the number of load point and quantity on it.

4. Experiments

16 experiments were made. The experiments were divided into two cases:

- in first case authors made experiments of single supply chain (10 order),
- in second case some order from step 1 were combine to show advantages of cooperation. In case 2 the following orders are combined: order 4 and 5, order 6 and 7, and order 8, 9 and 10.

Defined next experiments authors intentionally made first three very similar – the same route, the same order quantity, but changed used vehicle (with different euro norm). Thank to this, the economic and ecologic benefits of using truck with higher norm standard can be showed in simple way. The experiments 1 and 2 and 3 are cases of it – in first truck with norm 5 was used, in second with norm 4, and in third with norm 6.

All entry data for case 1 are presented at point 2.1 in this article. In case 2 these tables were changed:

- "Order_info" (Fig. 15) – for consolidated orders the quantity of number pallets was summed up,
- "Order_NoPalletsLP" (Fig. 16) – for consolidated orders the number of pallets to load are assigned in the right places,
- "Order_NoPalletsUP" (Fig. 17) – for consolidated orders the number of pallets to unload are assigned in the right places,
- "Load_point" (Fig. 18) – for consolidated orders the number of load point are assigned in the right places,
- "Unload_Point" (Fig. 19) – for consolidated orders the number of unload point are assigned in the right places.

Order_info

	No pallets	No Vehicle
Order 1	28	1
Order 2	28	2
Order 3	28	4
Order 4 and 5	32	1
Order 6 and 7	28	3
Order 8 and 9 and 10	31	3

Figure 15. Table "Order_info" in experiment case 2; own study with use FlexSim program

Order_NoPalletsLP

	No Pallets in LP1	No Pallets in LP2	No Pallets in LP3	No Pallets in LP4	No Pallets in LP5
Order 1	28	0	0	0	0
Order 2	28	0	0	0	0
Order 3	28	0	0	0	0
Order 4 and 5	15	17	0	0	0
Order 6 and 7	10	18	0	0	0
Order 8 and 9 and 10	8	14	9	0	0

Figure 16. Table "Order_NoPalletsLP" in experiment case 2; own study with use FlexSim program

Order_NoPalletsUP

	No Pallets in UP1	No Pallets in UP2	No Pallets in UP3	No Pallets in UP4	No Pallets in UP5
Order 1	28	0	0	0	0
Order 2	28	0	0	0	0
Order 3	28	0	0	0	0
Order 4 and 5	15	17	0	0	0
Order 6 and 7	10	18	0	0	0
Order 8 and 9 and 10	8	14	9	0	0

Figure 17. Table "Order_NoPalletsUP" in experiment case 2; own study with use FlexSim program

Load_Point

	Load Point 1	Load Point 2	Load Point 3	Load Point 4	Load Point 5
Route 1	1	0	0	0	0
Route 2	1	0	0	0	0
Route 3	1	0	0	0	0
Route 4 and 5	4	9	0	0	0
Route 6 and 7	6	2	0	0	0
Route 8 and 9 and 10	3	5	2	0	0

Figure 18. Table "Load_Point" in experiment case 2; own study with use FlexSim program

Unload_Point

	Unload Point 1	Unload Point 2	Unload Point 3	Unload Point 4	Unload Point 5
Route 1	3	0	0	0	0
Route 2	3	0	0	0	0
Route 3	3	0	0	0	0
Route 4 and 5	3	2	0	0	0
Route 6 and 7	3	7	0	0	0
Route 8 and 9 and 10	4	1	8	0	0

Figure 19. Table "Unload_Point" in experiment case 2; own study with use FlexSim program

For every simulated experiments the time, distance, cost, and exhaust emissions were calculated. The calculation in these models are simple, but for showing advantages of consolidation orders they are enough. By building simple model and showing few experiments specific benefits can be presented. The differences of every measurement between situation of consolidation the orders (experiments case 2) and realization single orders (experiments case 1) are presented at Table 3. For consolidated orders (line 4, 5 and 6 at fig 20) the result was calculated according to the following formula:

$$Rs_{CF} = CRs - (Rs_1 + \cdots + Rs_n),$$

where:

Rs_{CF} – results for calculated factor,

CRs – results for calculated factor for consolidated orders,

Rs_n – results for calculated factor for single order,

n – number of order.

Table 3. Differences in results for experiments in case 2 and case 1; own study

	Time load and unload [min]	Time route [min]	Total time [min]	Distance [km]	Fuel consumption [l]	Fuel cost [euro]	Worker cost [euro]	Total cost [euro]	CO [g/km]	HC [g/km]	NOx [g/km]	PM [g/km]
Order 1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Order 2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Order 3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Order 4 and 5	0,00	-3,17	-3,17	-190,00	-61,75	-61,75	-0,26	-62,01	-95,00	-9,50	-34,20	-0,95
Order 6 and 7	0,00	-0,33	-0,33	-20,00	-6,20	-6,20	-0,03	-6,23	-10,00	-1,00	-3,60	-0,10
Order 8 and 9 and 10	0,00	-0,75	-0,75	-45,00	-13,95	-13,95	-0,07	-14,02	-22,50	-2,25	-8,10	-0,22

In presented situation of order's cooperation the distance for consolidated orders decreased. Thanks to this fuel consumption and fuel cost are lower also. Lower distance means lower route time (the simple assumption that route time depends on distance and mean speed of vehicle). It is also equivalent to lower worker cost and total cost. Moreover, thanks to the consolidation of routes, which contributed to decreased of number of kilometers in analyzed cases, the emission exhaust decreased. From environmental point of view it is very important.

In made experiments the first three of them intentionally are the same, but the type of used vehicle is another. In order 1 was used vehicle with Euro 5, in order 2 – Euro 4, in order 3 – Euro 6. The differences for every measurement between order with using vehicle with the best Euro norm (Euro 6, order 3) and between other orders (1 and 2) are presented at Table 4.

Table 4. Differences in realization of orders depends of type of Euro of vehicle; own study

	Time load and unload [min]	Time route [min]	Total time [min]	Distance [km]	Fuel consumption [l]	Fuel cost [euro]	Worker cost [euro]	Total cost [euro]	CO [g/km]	HC [g/km]	NOx [g/km]	PM [g/km]
Order 3 - Order 1	0,00	0,00	0,00	0,00	-6,60	-6,60	5,44	-1,16	0,00	4,80	-12,00	0,00
Order 3 - Order 2	0,00	0,00	0,00	0,00	-9,60	-9,60	7,25	-2,35	0,00	4,80	-20,40	-0,48

The result is calculated according to the following formula:

$$RS = Rs_{O3} - Rs_{Om},$$

where:

RS – results for calculated factor,

Rs_{O3}– results for calculated factor for order number 3,
Rs_{Om}– results for calculated factor for order number m,
m– number of order, $m = 1 \vee 2$.

Analyzing data from Table 4 can be notice that fuel consumption and cost decreased. The worker cost is higher, because it was assumed that hour of work of driver is growing with growing of Euro standard of vehicle. Important is also, that level of NOx and PM is decreased.

5. Conclusion and future work

The simulation is a tool with huge possibilities. At this article authors show the measurable benefits from a simple simulation model of the supply chain and consolidation of transport order to strive for the sustainable supply chain.

Analyzing obtained results from the simulation model can be noticed that consolidation of transportation orders have many advantages. For presented examples of orders the cost and emission exhaust decreased. The quantities are not very big – but including scale of realized orders in terms of months, or for big company which have about 250 or more vehicles – the volume of savings will be huge. From results can be noticed also, that depends on type of vehicle, exactly Euro norm, the exhaust emission are different – higher Euro norm means lower NOx and PM emissions. But it should be remembered, that buying a new car is expensive. Analyzing cost, ecologic and social aspects it should be consider not only the cost of realization orders and amount of exhaust emission in that cases, but also during considering the option of using newer vehicle (with higher Euro norm) the cost of buying it, and the influence for environment (also from production point of view). Instead of buying new car, the hire of a vehicle can be considered or outsource the order to other company.

Basic benefits of consolidation's transport orders are presented by built model. It is worth to distinguished, that thanks to consolidate the orders, the amount of trucks at road will decrease, what have also positive impact of social aspects, as: less traffic, potentially fewer accidents.

The simulation model can be improved in further work. Firstly, part 2 presented at Figure 14 should be rebuilt, to be universal for every number of load points and unload points. Secondly, the way of combine orders should be extended – in this paper authors present simple way – they combine them only by looking at quantity of pallets to move. In reality, the orders should be also analyzed in terms of dependence of location load and unload point. Also the type of used vehicle should be chosen. Thirdly, the calculation of fuel consumption can be extended – different consumption depends on speed of truck. What means also including changed speed for vehicle in model in different section of road. Besides, getting real data from transport company – they orders, and base of vehicle with all information will be an invaluable contribution.

Funding: This research was funded by POZNAN UNIVERSITY OF TECHNOLOGY, grant number 0812-SBAD-4170

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Saniuk, A.; Saniuk, S.; Caganova, D. et al., Control of strategy realization in metallurgical production, 23rd International Conference on Metallurgy and Materials, **2014**, 1876-1881.
2. Pawłyszyn, I.; Fertsch M.; Stachowiak, A.; Pawłowski, G.; Oleśków-Szłapka, J. The Model of Diffusion of Knowledge on Industry 4.0in Marshallian Clusters. *Sustainability* 12, **2020**, 3815.
3. Jasiulewicz-Kaczmarek, M.; Gola, A. Maintenance 4.0 Technologies for Sustainable Manufacturing – an Overview. *IFAC PapersOnLine* 52(10), **2019**, 91-96.
4. Burduk A., The role of artificial neural network models in ensuring the stability of systems, 10th International Conference on Soft Computing Models in Industrial and Environmental Applications, Advances in Intelligent Systems and Computing, Springer, **2015**, 427-437.
5. Saniuk, S.; Grabowska, S.; Gajdzik, B. Social Expectations and Market Changes in the Context of Developing the Industry 4.0 Concept. *Sustainability* 12, **2020**, 1362.

6. Grzybowska, K.; Łupicka, A. Future competencies in the automotive industry – practitioners' opinions. *Vision 2020: Sustainable Economic development, Innovation Management, and Global Growth*; Khalid S. Soliman (ed.) XLVI, **2017**, 5199-5208.
7. Grabowska S. Improvement of the heat treatment process in the industry 4.0 context. *27th International Conference on Metallurgy and Materials*, May 23rd - 25th, 2018, Brno, Czech Republic, **2018**, 1985-1990.
8. Souza, J.P.E.; Alves, J.M. Lean-integrated management system: A model for sustainability improvement. *Journal of Cleaner Production*, 172, **2018**, 2667–2682.
9. Seuring, S. Assessing the rigor of case study research in supply chain management. *Supply Chain Management*, 13(2), **2008**, 128-137.
10. Surana, A.; Kumara, S.; Greaves, M.; Raghavan, U.N. Supply chain Networks: a Complex Adaptive Systems Perspective. International Journal of Production Research, 43(20), **2005**, 4235–4265.
11. Grzybowska, K.; Hoffa, P. Approving with application of an electronic bulletin board, as a mechanism of coordination of actions in complex systems, Omatu, S. et al. (eds.), Distributed Computing and Artificial Intelligence, 12th International Conference Advances in Intelligent Systems and Computing, 373, **2015**, 357–365.
12. Grzybowska, K. Stachowiak, A. Classification of trends and supply chains development directions. Springer, Smart and Sustainable supply chain and logistics – trends, challenges, methods and best practices, P. Golińska (ed.), **2020**, in press.
13. Kiciński, M.; Witort, P.; Merkisz-Guranowska, A. Multiple Criteria Optimization for Supply Chains – Analysis of Case Study. Sierpiński G. (eds) Integration as Solution for Advanced Smart Urban Transport Systems. TSTP 2018. Advances in Intelligent Systems and Computing, 844, **2019**, 150-160.
14. Wieczerniak, S.; Cyplik, P.; Milczarek, J. Root cause analysis methods as a tool of effective change. International Scientific Conference on Business Logistics in Modern Management, **2017**, 611-627.
15. Oelze, N.; Gruchmann, T.; Brandenburg, M. Motivating Factors for Implementing Apparel Certification Schemes – A Sustainable Supply Chain Management Perspective. *Sustainability*, 12, **2020**, 4823.
16. Mardani, A.; Kannan, D.; Hooker, R.E. Evaluation of green and sustainable supply chain management using structural equation modelling: A systematic review of the state of the art literature and recommendations for future research. *Journal of Cleaner Production* 249, **2020**, in Press.
17. Seuring, S.; Muller, M. From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production* 16, **2008**, 1699–1710.
18. Koberg, E.; Longoni, A. A systematic review of sustainable supply chain management in global supply chains. *Journal of Cleaner Production 207*, **2019**, 1084–1098.
19. Etzion, D. Management for sustainability. *Nature Sustainability*, 1(12), **2018**, 744–749. https://doi.org/10.1038/s41893-018-0184-z
20. Wróbel, G.; Oleśków-Szłapka, J. Simulation Method for the Benefits of a Small Business in Sustainable World. Pawlewski P., Greenwood A. (eds) Process Simulation and Optimization in Sustainable Logistics and Manufacturing. EcoProduction (Environmental Issues in Logistics and Manufacturing). Springer, Cham, **2014**, 3-21.
21. Kleijnen, J. Supply chain simulation tools and techniques: a survey. *International Journal of Simulation and Process Modelling* 1(1/2), **2005**, 82–89.
22. Sitek, P.; Wikarek, J. A multi-level approach to ubiquitous modeling and solving constraints in combinatorial optimization problems in production and distribution. *Applied Intelligence* 48, **2018**, 1344–1367.
23. Sitek, P.; Wikarek, J.; Nielsen, P. A constraint-driven approach to food supply chain management. *Industrial Management & Data Systems*, 117(9), **2017**, 2115-2138.
24. Juszczyński, M.; Kowalski, A. Achieving Desired Cycle Times by Modelling Production Systems. Saeed K., Chaki R., Cortesi A., Wierzchoń S. (eds) Computer Information Systems and Industrial Management. CISIM 2013. Lecture Notes in Computer Science, 8104**, 2013**, 476-486.
25. Chanchaichujit, J.; Pham, Q.C.; Tan, A. Sustainable supply chain management: A literature review of recent mathematical modelling approaches. *International Journal of Logistics Systems and Management*, 33(4), **2019**, 467-496.

26. Rebs, T.; Brandenburg, M.; Seuring, S. System dynamics modeling for sustainable supply chain management: A literature review and systems thinking approach. *Journal of Cleaner Production*, 208, **2019**, 1265-1280.
27. Wang, P.C.; Halim, I.; Adhitya, A.; Srinivasan, R. Integrating Economic, Environmental and Social Indicators for Sustainable Supply Chains. *Computer Aided Chemical Engineering*, 29, **2011**, 1220-1224.
28. Pomponi, F.; Moncaster, A. Circular economy for the built environment: A research framework. Journal of Cleaner Production, **2017**, 143, 710–718.
29. Kakkos, E.; Heisel, F.; Hebel, D.E.; Hischier, R. Towards Urban Mining—Estimating the Potential Environmental Benefits by Applying an Alternative Construction Practice. A Case Study from Switzerland. Sustainability, 12, **2020**, 5041.
30. Hong, J.; Alzaman, C.; Diabat, A. et al. Sustainability dimensions and PM2.5 in supply chain logistics. *Annals of Operations Research*, **2019**, 275, 339–366. https://doi.org/10.1007/s10479-018-3077-7.
31. Alzaman, C. Impact of optimisation on idle time's fuel consumption and CO2 emissions in urban transportation. *International Journal of Business Performance and Supply Chain Modelling* 8(2), **2016**, 157-179.
32. Georgiadis, P.; Iakovou, E.; Vlachos, D.; Besiou, M. A system dynamics modeling approach of ecological motivation in sustainable supply chains. *WSEAS Transactions on Systems*, 5(1), **2006**, 48-55.
33. Hidayatno, A.; Zulkarnain, Hasibuan, R.G.; Nimpuno, W.; G.C.; Destyanto, A.R. Designing a serious simulation game as a learning media of sustainable supply chain management for biofuel production. *Energy Procedia*, **2019**, 156, 43-47.
34. Li, C. An integrated approach to evaluating the production system in closed-loop supply chains. *International Journal of Production Research*, 51(13), **2013**, 4045-4069.
35. Mehmann, J.; Teuteberg, F. The fourth-party logistics service provider approach to support sustainable development goals in transportation – A case study of the German agricultural bulk logistics sector. *Journal of Cleaner Production*, 126, **2016**, 382-393.
36. Sahay, N.; Ierapetritou M. Supply chain management using an optimization driven simulation approach. *AIChE Journal*, 59(12), **2013**, 4612-4626.
37. Shamsuddoha, M.; Quaddus, M.; Klass, D. Sustainable poultry production process to mitigate socio-economic challenge. *Humanomics*, 31(3), **2015**, 242-259.
38. Yan M.-R.; Chein, K.-M.; Yang, T.-N. Green component procurement collaboration for improving supply chain management in the high technology industries: A case study from the systems perspective. *Sustainability*, 8,(2), **2016**.
39. https://www.flexsim.com/, access data: May 2020.
40. http://www.ngk.de/pl, access data: October 2015.



© 2020 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).