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OPTIMIZATION OF CROSS-DOCKING TERMINAL USING FLEXSIM/OPTQUEST – CASE STUDY

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ABSTRACT

The paper presents some designing and organizational problems related to cross-docking terminals. These problems were defined based on literature review. The authors identify the problem of mutual arrangement of relational areas on terminal entrance and on exit as well as possible labor savings to be achieved through the proper arrangement of these areas. Based on the literature, a typical mathematical model is presented. Moreover, the paper discusses the analytical and simulation approaches used to solve these problems. The authors describe how the problem of assignment areas can be solved using simulation software available on market and present a case study based on real data.

1 INTRODUCTION

The paper presents results of research performed over the last few years in the area of supply chain process design, modeling and simulation. Three main stages are the part of each supply chain: procurement, manufacturing and distribution. Distribution centers have an important role at the distribution stage. These centers are not only places for collecting and delivering products, but also places for complying customer demands by activities such as ordering, inventory management, transportation, information transaction etc. There are three separated strategies for the distribution out of a factory in a supply chain (Simchi-Levi, Kaminski and Simchi-Levi 2002):

- Direct transmission: shipment from vendors to retails is executed without the services of distribution center.
- Warehousing: goods are delivered based on customer orders, goods are stored in devices such as pallet rackets or shelving.
- Using cross-docking system: based on customer demands, goods are delivered to a warehouse by receiving trucks, goods are loaded into shipping trucks. Usually goods are not stored in a warehouse; if an item is held in storage, the time of storage is less than 10-15 h.

By comparing these three strategies, we can say that cross-docking system is the best of strategies. Cross-docking system is perfect for handling high volumes of items in a short time. By using this strategy it is possible to reduce cost with decreasing inventory or eliminate storage. Improving efficiency by increasing customer responsiveness and better control of distribution operation is also possible.

The major objectives of the present paper are:

- to define problems concerning cross-docking – terminals in details,
- to present the comparison between analytical approach and simulation approach to solve cross-docking problems,
- to solve the Crossdock Door Assignment Problem using the actual simulation and optimization tool available on the market,
- to present practical case study from a real cross-docking terminal in details

The main contribution of the paper is to show practical methodology to introduce optimization based on simulation experiments where decisions are made by logistics operators who use cross-docking systems. The great progress in development of simulation and optimization tools available on the market makes it possible to introduce this technology in large scale for logistics operators.

The paper structure is as follows. Section 2 describes the literature background of cross-docking problems in supply chains. Section 3 defines one of the mathematical models for cross-dock planning. Section 4 discusses an analytical versus simulation approach to solve these kinds of problems. The case study from real cross-docking terminal optimization is discussed in section 5. The final conclusions are stated in section 6.

2 CROSS-DOCKING PROBLEMS – LITERATURE BACKGROUND

Cross-docking terminals are characterized by significant circadian values of transshipments and a very short time buffering of goods before shipment. That is why, that they are practically devoid of storage and order picking systems, i.e. the two main factors of cost in the processes of storage (Boysen and Fliednerand 2010). The dynamics of the process flow of materials prevents use of developed storage areas. For this reason, picking terminals are large in form, flat objects with a relatively low height, where space is not divided physically, but only divided by horizontal marking systems. The above-mentioned characteristics of the terminals determine the scope of the project as well as organizational problems.

The literature focuses on many different project problems concerning cross-docking terminals (Belle, Valckenaers and Cattrysse 2012). One of them is an economic justification for the use of terminals and their dominance over distribution warehouses with storage and picking in the size function of cargo handling, transshipment susceptibility of materials, industry and customer requirements (Apte and Viswanathan 2000), (Li, Low, Lim and Maand 2008), (Richardson 1999). The other is the location of picking terminals and their positions in the structure of the supply chain (Gue 1999), (Gümüus and Bookbinderand 2004), (Musa, Arnaout and Jungand 2010), (Ross and Jayaramanand 2008), (Sung and Yangand 2008). Next project problem is the spatial arrangement of the building: the shape (Boysen and Fliednerand 2010), the location of the buffer areas (Vis and Roodbergenand 2008), plan of internal transport roads (Agustinaand, Lee and Piplani 2010). The network of cross-docking terminals, the work time frames, the consolidation of shipments, the combination with direct suppliers are important too (Chen, Guo, Lim and Rodrigues 2006), (Lee, Jung and Lee 2006), (Lim, Miao, Rodrigues and Xu 2005), (Musa, Arnaout and Jung 2010). Next problem is the allocation of loading docks (gates) to vehicles including the sequencing of vehicles, structures of load on a vehicle in a short and long term – considered because of the efficiency of internal transport ((Boysen and Fliedner 2010), (Bozer and Carlo 2008), (Cohen Y, Keren B. 2009). Scheduling vehicles on entry and exit, time frames – as part of the work planning of external transport can be a problem too ((Boysen, Fliedner and Scholl 2010), (Boysen and Fliedner 2010), (Yu and Egbelu 2008). The other project problems are: temporary storage and its allocation (Bartholdi III and Gue 2004), scheduling the work of equipments in internal transport (Li Lim and Rodrigues 2004), the construction of arriving and departing routes in the area of service in terms of working terminal time and operation of the entire supply chain. Some authors use simulation to solve these problems ((Aickelin and Adewunmi 2008) .

Cross-docking terminal can be described by the following characteristics (Belle, Valckenaers and Cattrysse 2012):

Physical characteristics:

- Shape: I, L, U, T, H, E – depending on the field conditions, a number of gates and the size of transshipments.
- Dimensions of the building – resulting from a number of gates, the capacity of the buffer areas
- Internal transport technology.

- Number of docks – number of gates (from a few to up to 500) depending on the size of transshipments, load structure and a vehicle structure at the entrance and exit, the working time of the object, etc.
- Scheme of the cargo movement
  - direct transshipment between vehicles at entry and exit (single-touch),
  - transshipments of putting it away in the central buffer area (two-touch),
  - unloading to buffer areas at input, transportation to fields on exit and loading at a later time (multi-touch).
- Internal transport system – use of forklift trucks or other equipment or conveyors (including sorters), principles of movement organization.

Operational characteristics:

- Allocation gates to handle input or output: constant allocation – mostly one side of a building supports input and the other output; the allocation of groups of gates to tasks, the allocation is arbitrary, the variability of allocation in daily work time.
- The ability to interrupt the operation of loading and unloading and complete them at a later time in order to properly plan the loading and make a better use of the buffer area in the terminal.
- The ability to change the format of loading units (consolidation, completion).

Material flow characteristics:

- The characteristics of the input material flow – unloading time of vehicles, which are import goods from the area of service, and shuttle vehicles from other regions.
- The characteristics of the material flow on the output – loading time of vehicles, which are responsible for the transportation of goods in the service area, and shuttle vehicles.
- Time frames of implementing arrival and shipping.
- The size of daily transshipments on input and output to a terminal.
- The filling degree of vehicles on entry and exit. Sending of incomplete vehicles.
- The interchangeability of products – the possibility of compiling a shipment with any of the products which are located in the terminal or the need to compile the dispatching of specific units, pre-determined by the sender (pre-distribution).
- The rules (and possibility) of temporary storage of materials in a terminal.

3 PROBLEM DEFINITION

A typical multiple-touch or two-stage cross-dock is presented in Figure 1. (Gue and Kang, 2001). In this case, products are received and staged on the dock; then, they are reconfigured for shipment and reloaded in outbound trucks. In a typical configuration, the incoming freight is first put in the zone corresponding to the strip doors. The goods are then sorted to the zones corresponding to the stack doors.

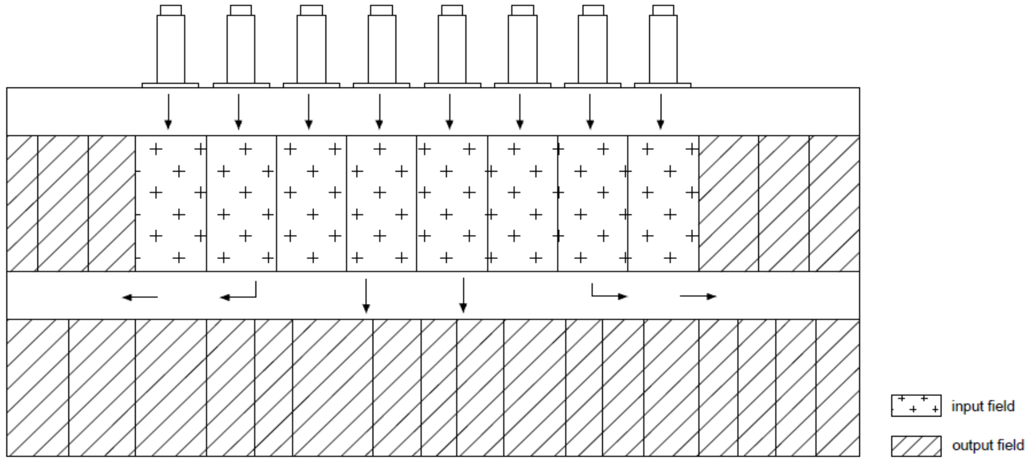


Figure 1: A multiple-touch cross-dock layout based on (Gue and Kang, 2001)

In the literature we can find many propositions about solving problems concerning cross-docking terminals. Two publications are very important:

- Cross-docking: state of the art (Belle, Valckenaers and Cattrysse 2012),
- A Review: Mathematical Models for Cross Docking Planning (Agustina, Lee and Piplani 2010).

A typical mathematical model is defined as the Crossdock Door Assignment Problem. (Aickelin and Adewunmi 2008). This Problem is related to the Dock Door Assignment Problem. It was formulated for the first time by (Tsui and Chang 1990). The objective of the Crossdock Door Assignment Problem is to find the optimal arrangement of inbound and outbound doors in a crossdock and to define the most efficient assignment of outbound doors location, so that the distance travelled by the material handling equipment is minimized. It is assumed that there are I inbound doors, J outbound doors, M origins and N destinations for the Crossdock centre, I ≥ M and J ≥ N. Let X im = 1 if origin m is assigned to inbound door i, X im = 0 otherwise. Let Ynj = 1 if destination n is assigned to outbound door j, Ynj = 0 otherwise. The distance between inbound door I and outbound door J is represented by dij. The number of trips, which are required by the material handling equipment to move an item originating from m to the Crossdock door, where freight destined for n is being consolidated, is represented by wmn. The mathematical model, formulated below, is based on work (Tsui and Chang 1990) (Bermudez and Cole 2000). It was presented in (Aickelin and Adewunmi 2008):

Parameters:

M - Number of M origins.
N - Number of N destinations.
I - Number of I inbound doors.
J - Number of J outbound doors.
w_{mn} - represents the number of trips required by the material handling equipment to move items originating from m to the Crossdock door where freight destined for n is being consolidated.
d_{ij} - represents the distance between inbound door i and outbound door j.

Decision variables:

X_{mi} - $X_{mi} = 1$ if origin m is assigned to inbound door i, $X_{im} = 0$ otherwise.
Y_{nj} - $Y_{nj} = 1$ if destination n is assigned to outbound door j, $Y_{nj} = 0$ otherwise.

The goal function is defined as (Aickelin and Adewunmi 2008):

$$\text{Minimizing} \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} \sum_{n=1}^{N} d_{ij}\, w_{mn}\, X_{mi}\, Y_{nj} \qquad (1)$$

4 ANALYTICAL METHODS VERSUS SIMULATION METHODS

Analytical methods rely on intermediate description of an object model with use of mathematical relations – like presented in the previous section. Analytical description language includes the following groups of semantic elements: criterion, unknowns, data, math operations, restrictions. The structure of analytical models does not correspond to the structure of the modeled objects (by structural similarity we understand the explicit correspondence of elements and conjugations in the model and object). The analytical models include models built with use of mathematical programming methods, regression analysis and correlation. The analytical model is always a formal structure, which can analyze and solve mathematical methods. The model consists of (using mathematical programming) an objective function and constraints that must be satisfied by the entered variables. The objective function defines the characteristics of the system, whose value must be calculated or analyzed. Analytical models are an effective tool for solving optimization problems or calculating the characteristics of the systems. In many practical cases, the use of analytical models is difficult, mainly because of their large size – obtaining an optimal solution creates a big calculation problem. Researchers try to increase the efficiency by using the following methods:

- The division of tasks to a number of complex simpler tasks – the problem of interdependence of subtasks – not always easy to solve,
- Reduced precision of calculations – shortens time of solving a problem.

Simulation methods rely on a direct description of the modeled object. The most important feature is the similarity of object structures and models – this means that each object element, which is significant from the viewpoint of the solved problem, corresponds to an element from the object model.

The functioning terms of every object and the relationships between them are described when a simulation model is created. Working with a simulation model consists of performing the simulation experiment. The process occurring during the experiment is similar to the process occurring in the real object. Therefore, testing an object through a simulation model relays on study characteristics of a process during an experiment. The idea of formalizing the present system is to adopt the scheme with discrete events. The process of functioning of a system in time is treated as a sequence of events occurring in a system according to the principles of its operation. The notion of "event" is assigned to a specific meaning depending on the objectives of a model. There are also some downsides of simulation. Preparing a good simulation model is time-consuming and therefore the models are expensive. Each model should be treated individually, as usually it cannot be used for analyzing any other decision-making problem. They may only apparently seem easy to use and the excessive amount of details incorporated into the model can make the experiment difficult to conduct. At first, adding the detailed elements enhances the precision of simulation, yet later the accuracy decreases. It means that building very precise models may turn out to be unprofitable: the financial outlay may not translate into accuracy and precision of the simulation. However, due to the great progress in the development of simulation software available on the market, especially in terms of works facilitating simulation and interfaces for optimization tools, the above-mentioned downsides are becoming less significant.

5 CASE STUDY

This section provides an example of an optimization task solution defined by one of the logistics operators, with whom the authors cooperate. The analyzed cross-dock warehouse is a multi-touch one (presented in figure 1). This magazine has 8-ramp input, which corresponds to 8 input fields and 23 output fields. An input stream was determined on the basis of historical data for a given period of time. This stream is repeatable for a longer period of time – for, the so called, season. The structure of input data is shown in Table 1.

Table 1: Entry stream data structure.

	ArrivalTime	**ItemName**	**Direction**	**Quantity**	**Gate**	**Cargo ID**	**Area**
Arrival1	80	Item	22	9	1	Xxxxx	87
Arrival2	80	Item	20	5	1	Xxxxx	83
Arrival3	80	Item	13	3	1	Xxxxx	46
Arrival4	80	Item	23	1	1	Xxxxx	92
Arrival5	80	Item	16	4	1	Xxxxx	59
Arrival6	80	Item	9	3	1	xxxxx	38

Columns contain the following information:
Arrival Time – time of arrival of a truck at an entry ramp.
Item Name – name of pallet
Direction – in this case it is the address of an output field
Quantity – number of pallet
Gate – not used in this case
CargoID – not used in this case
Area – not used in this case

In the present case the input stream are pallets that are sorted according to the information that is written on a label of pallets – direction: it is the number of an output field on which a pallet is expected. The optimization task depends on finding such a system of output fields for the input stream (defined and unchanging), so that the road of forklift trucks (we have 5 forklifts) is as short as possible. The above description corresponds to a mathematical model defined in Section 2. The task is difficult because the number of combinations, which must be considered to find the best solution is 23!.

From the operator we received the following data:

- layout of a magazine in real size - a file in .dwg format from AutoCAD,
- characteristics of a forklift – all of the same type – the total number of 5,
- characteristics of an input stream in an Excel file.

The simulation experiment was performed in the following steps:

- choose a simulation program – we decided on FlexSim, due to following features (Beaverstock, Greenwood, Lavery and Nordgren, 2012):
  - ease of use in a real size with drag and drop technology,
  - loading an .dwg file from the layout directly to a model,
  - fitting the shape of trucks and their parameters – in real values,
  - integrating built-in experimenter tool with OptQuest,
- load the layout file in .dwg format,
- create and locate buffers, define logic of filing and retrieval from buffers,
- define a flow logic of a material on the basis of Direction labels,
- create points which make up a road and connect them in a network,
- define transport (forklifts of a specific type),
- experiment planning,
- define an optimization task – an idea to record combinations and their changes,

- search for the best solution using the Optimizer OptQuest from OptTek,

Figures 2 and 3 show a model realized in FlexSim program.

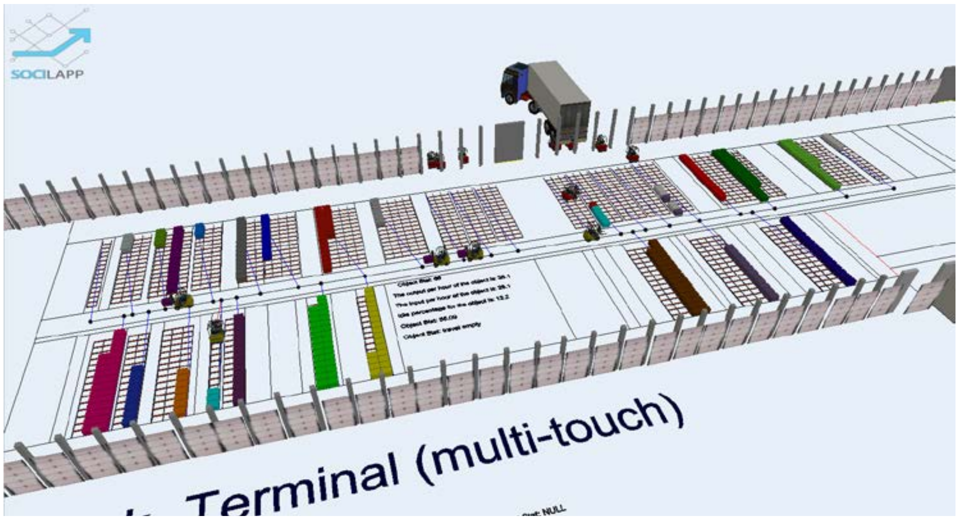


Figure 2: The simulation model of cross-docking terminal in FlexSim (source: own study)

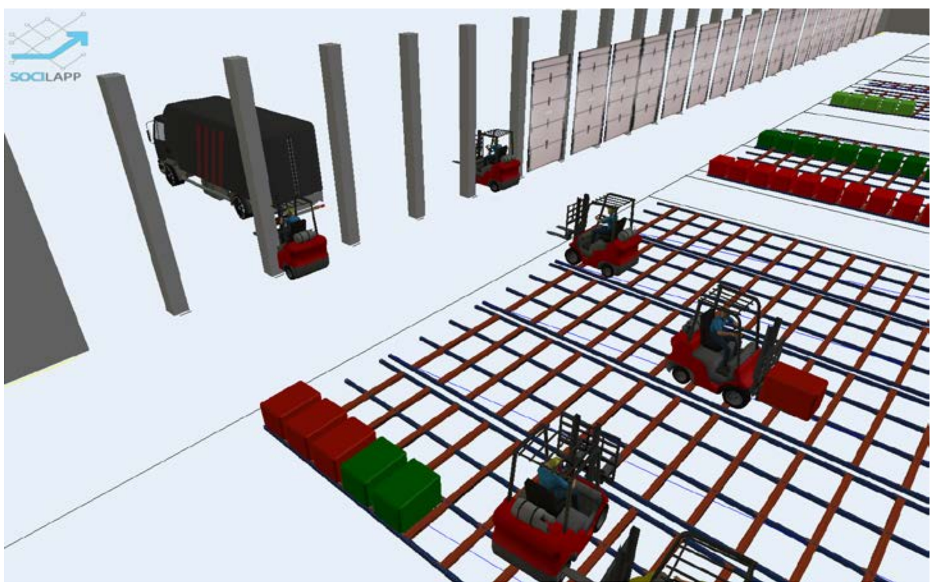


Figure 3: Details of the simulation model in FlexSim (source: own study)

The record of a definition of optimization task is interesting. As we mentioned earlier, each pallet has a label that indicates the address of an output field, in which pallets are expected – figure 4.

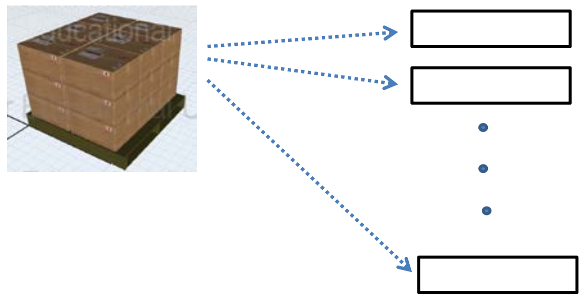


Figure 4: The scheme of base outbound addressing (source: own study)

To define an optimization problem we use a global table called COMBINATION (figure 5). In this table, addresses of output fields are defined in rows; a label on pallet indicates the address of a row in the table COMBINATION. Therefore, it is easy to change an assignment – which output field corresponds to the address indicated by a label on a pallet. An addressing mechanism was reproduced in a simulation model. This is done in such a way that each input buffer (there are 8) is connected to all output buffers by the so-called output ports. The output port address corresponds to the address of an output buffer. A palette is directed to the port number, that is specified on the label. To change the flow in an input buffer into the appropriate output buffer based on COMBINATION table, we used a mechanism which is defined in FlexSim as Using Global Lookup Table (COMBINATION). The cell of table COMBINATION is referred by label and output buffer is referred by this cell – figure 5.

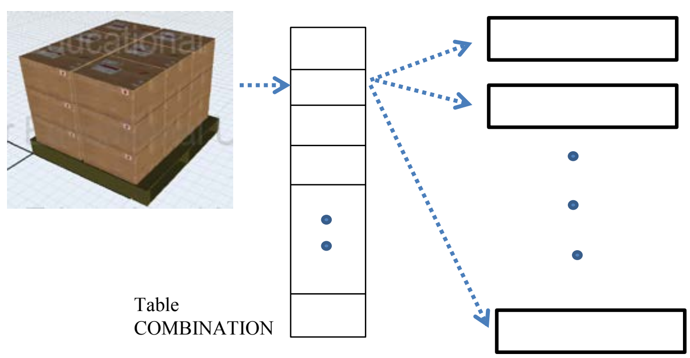
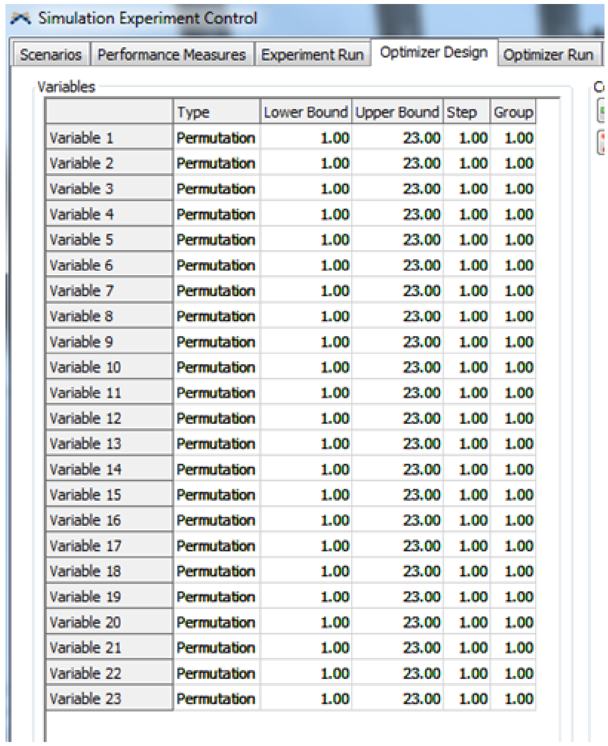


Figure 5: Using table COMBINATION for optimization task definition (source: own study)

The COMBINATION table is a table that has one column and 23 rows. Each cell can take values from 1 to 23, which gives us the total number of as many as 23! combinations. This means that to find the best solution we should prepare 23! scenarios and review them – preferably all. Practically, it is impossible. The OptQuest optimizer (Opttek company), which is built into FlexSim, gives us the possibility to optimize simulation experiments. In optimizer we have to define the decision variables. In this case we have 23 variables (stored in following cells of the COMBINATION table). Each variable can take values from 1 to 23 in steps of 1 without repetition. In FlexSim it is achieved by selecting the type of the variable – Permutation. Defined 23 variables in optimizer are shown in figure 6.



	Type	Lower Bound	Upper Bound	Step	Group
Variable 1	Permutation	1.00	23.00	1.00	1.00
Variable 2	Permutation	1.00	23.00	1.00	1.00
Variable 3	Permutation	1.00	23.00	1.00	1.00
Variable 4	Permutation	1.00	23.00	1.00	1.00
Variable 5	Permutation	1.00	23.00	1.00	1.00
Variable 6	Permutation	1.00	23.00	1.00	1.00
Variable 7	Permutation	1.00	23.00	1.00	1.00
Variable 8	Permutation	1.00	23.00	1.00	1.00
Variable 9	Permutation	1.00	23.00	1.00	1.00
Variable 10	Permutation	1.00	23.00	1.00	1.00
Variable 11	Permutation	1.00	23.00	1.00	1.00
Variable 12	Permutation	1.00	23.00	1.00	1.00
Variable 13	Permutation	1.00	23.00	1.00	1.00
Variable 14	Permutation	1.00	23.00	1.00	1.00
Variable 15	Permutation	1.00	23.00	1.00	1.00
Variable 16	Permutation	1.00	23.00	1.00	1.00
Variable 17	Permutation	1.00	23.00	1.00	1.00
Variable 18	Permutation	1.00	23.00	1.00	1.00
Variable 19	Permutation	1.00	23.00	1.00	1.00
Variable 20	Permutation	1.00	23.00	1.00	1.00
Variable 21	Permutation	1.00	23.00	1.00	1.00
Variable 22	Permutation	1.00	23.00	1.00	1.00
Variable 23	Permutation	1.00	23.00	1.00	1.00

Figure 6: Optimizer design sheet in simulation control window in FlexSim (source: own study)

Then, the optimization is performed. Figure 7 shows the results of the optimization. An optimization experiment is limited to 1000 solutions. On a machine with a processor Intel Core i7-2677M 1,8GHz resolution time amounted 12 minutes 54,36 seconds.

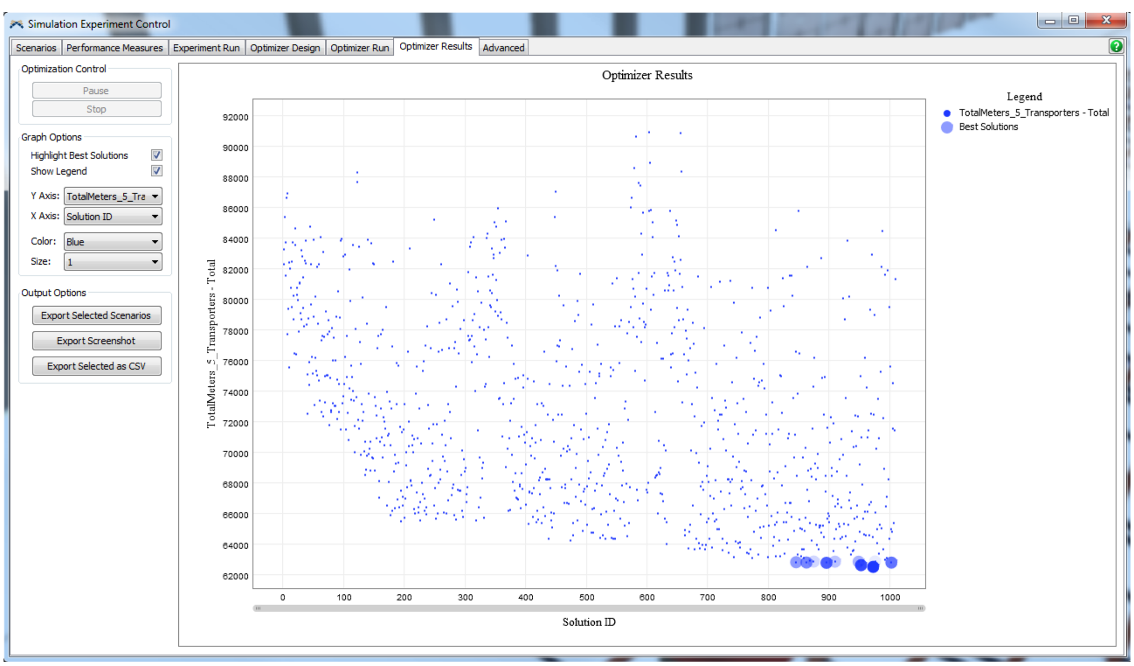


Figure 7: Optimizer results window in FlexSim (source: own study)

Total mileage of forklift trucks in current actual assignment was 83000 meters. The assignment found as a result of experiment needs less than 63000 meters - this solution for the question input stream is better than initial settings – total mileage of forklift trucks is shorter about 20%. Optimization was performed based on real data obtained from logistics operator. The excel input file prepared by operator contains 260 arrivals. It covers one typical working day. The input data structure (pallets destinations) depends on season, it means that operator change the plan a couple of times a year. The model and results were validated and verified by logistics operator where the researches were performed. Company accepted the results and methodology.

6 CONCLUSIONS

The article presents results of the work on cross-docking problem. The problem, although difficult to solve by analytical methods, is relatively easy to solve with simulation methods with use of commercially available simulation tools and optimization. As mentioned in chapter 4 analytical methods need preparing data which are difficult to obtain and to describe – many of them are averaged so the validation and verification of them are questionable. Simulation is defined as experimentation with a simplified reproduction of a real life model (on a computer) as it progresses through time, for the purpose of better understanding and/or improving that system. The simulation imitates the performance of the Crossdock centre in a controlled environment so the validation and verification is more valuable – acceptance of logistics operator was crucial in our case. For experiments we used FlexSim GP v7.1.4 software with a built-in optimizer OptQuest. Our investigations were carried out in a real-life situation – the research works were implemented for a logistics provider which operates on the market. Main goal of our optimization was finding the shortest road of forklift trucks. Mileage depends on location of output fields for the input stream. The proposed solution turned out to be 20 per cent better than the solution used by the operator. In new solution road of forklifts is shorter about 20000 meters then in initial scenario. The logistics operator was acquainted with results of the research and the methodology of solving the problem and now they are considering the possibility of using simulation technology and optimization to make decisions in their operations.

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