SIMULATION MODEL TO OPTIMIZE PICKING OPERATIONS IN A DISTRIBUTION CENTER

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Introduction

The paper presents results of research performed over the last few years in a company which looks to cut costs and improve productivity within its warehouses and distribution centers. This company is global player in FMCG (Fast-Moving Consumer Goods) market. These goods are products that are sold quickly and at relatively low cost. The author focuses on order picking because it is the highest priority area for productivity improvements (de Koster et al., 2007) and company asked about it. Distribution centers have an important role in a supply chain – 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. Some authors state that warehousing is one of the three separated strategies for the distribution out of a factory in a supply chain (Simchi-Levi et al., 2002):

- Direct transmission: shipment from vendors to retailers 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.

Order Picking is defined as „the process of retrieving individual items (from storage locations) for the purpose of fulfilling an order for a customer" (www.abelwomack.com, 2015). Order picking is the most labour-intensive operation in a warehouse with manual (non-automated) systems.

The major objectives of the present paper are:
- to define problems concerning order picking in details,
- to solve the Order Picking problem defined as to find allocation of items for the best route to realize the defined pick list using the actual simulation and optimization tool available on the market,
- to present practical case study from a real picking process in a big Distribution Center.

One of our main research goals is also to answer the question: how to shorten the time necessary to build the simulation model of a big distribution center?

The main contribution of the paper is to show practical methodology of modeling big distribution centers and to introduce optimization based on simulation experiments. The great progress in the development of simulation and optimization tools available on the market makes it possible to introduce this technology in large scale for logistics operators and companies[1].

Warehouse operations - Literature background

As mentioned in the previous section, order picking is the most labour-intensive operation in a warehouse with manual (non-automated) systems. Warehouses are complex structures that are used for storing goods. Warehousing involves large capital expenditures. Equipment from various suppliers used in a single warehouse needs to be tested as an integrated system. Typical warehouse functions and flows are presented in Figure 1.

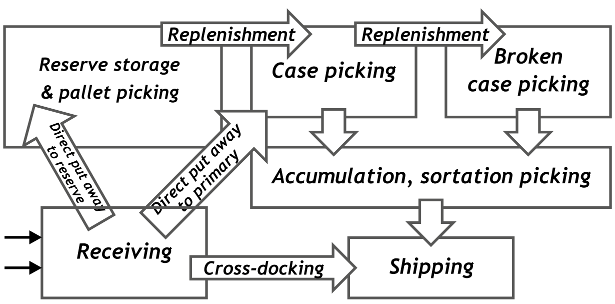


Figure 1. Typical warehouse functions and flows
Source: (Tompkins et al., 2003)

Order picking involves the process of clustering and scheduling the customer orders, assigning stock on locations to order lines, releasing orders to the floor, picking the articles from storage locations and the disposal of the picked articles. Customer orders consist of order lines, each line for a unique product or stock keeping unit (SKU), in a certain quantity. Many different order – picking system types can be found in warehouses. In this paper, the author focuses on „broken case picking". This kind of picking, also known as piece picking or pick/pack operations, describes systems where individual items are picked. Operations of this kind usually have a large SKU base in thousands or tens of thousands of items, small quantities per pick, and short cycle times. FMCG market requests broken case picking.

In distribution centers there are two types of material handling system:
- vehicle types – use a transporter to carry the load along a path that may or may not be predefined e.g.: fork trucks, pallet jacks, AS/RS, AGVs, Bridge Cranes etc.,
- non vehicle types: they usually have a fixed path and do not require a vehicle to transport the load, they may not consist of multiple sections e.g. conveyors.

The author focuses on the vehicle type material handling system, based on forklifts. Around 75% of the warehouses are manually served by forklifts (Chan, 2002). This kind of operation receives significantly less attention in research than full – or partly automated systems (de Koster et al., 2007). In (Takakuwa et al., 2000) it was pointed out, that modeling large-scale non-automated distribution warehouse with forklifts is much more difficult in comparison to AS/RS-systems due to their complexity.

According to the objective and operating cycle, the related works are categorized into three improvement fields (Clausen et al., 2013): aspects with regards to the loaded run, to the unloaded run and blocking operations.

Generally three types of data necessary for modeling must be collected about the real system (VDI Guideline, 2010):
- technical data – including the topology and structure of the system e.g. layout, equipment, capacities, process time,
- organizational data – including scheduling rules for working time, allocation of resources to tasks, restrictions of handling operations,
- system load data – including the amount of handled pallets concerning time and volume aspects.

The order-picking time components in a typical picker-to-parts warehouse are as follow: travel (50%), search (20%), pick (15%), setup (10%) and other (5%) (de Koster et al., 2007). The travel time (equivalently travel distance) is often considered as a primary objective in the warehouse design and optimization. Another important objective would be minimizing the total cost. Other objectives which are often taken into consideration in the warehouse design and optimization are minimizing (de Koster et al., 2007): the throughput time of an order, the overall cycle time (e.g. to complete a batch of orders), the use of space, the use of equipment,the use of labor, the accessibility to all items.

Companies make decisions on the design and control of order picking systems at a tactical or operational level, with a different time horizon (Rouwenhorst et al., 2000). Common decisions at these levels are:
- layout design and dimensioning of the storage system (tactical level),

- assigning products to storage locations (storage assignment) (tactical and operational level),
- assigning orders to pick batches and grouping aisles into work zones (batching and zoning) (tactical and operational level),
- order picker routing (routing) (operational level),
- sorting picked units per order and grouping all picks of the orders (order accumulation/sorting) (operational level).

Typical decision problems in the design and control of order-picking processes can be structured by focusing on optimal (internal) layout design, storage assignment methods, routing methods, order batching and zoning. The literature review on the above-mentioned subjects can be found in (de Koster et al., 2007). Most authors focus on analytical methods. However some authors use simulation – for example:

- For both random and volume-based storage assignment methods, Petersen (2002) shows, by using simulation, the effect of the aisle length and number of aisles on the total travel time.
- Based on simulation experimental results, Petersen and Aase (Petersen, Aase, 2004) show that with regards to the travel distance in a manual order-picking system, full turnover storage outperforms class-based storage
- Ryder System, Inc. has created a flexible simulation model to be used as an engineering tool to validate automated warehouse designs, predict resource requirements, and determine operational throughput capacities for its E-channel operations (Burnett, LeBaron, 2001).

There are many simulation packages which support warehouse operations. Generally, we can classify them into two groups – packages dedicated to warehouse operations (e.g. CLASS) and general purpose packages which have dedicated objects to model a warehouse infrastructure like racks, forklifts, AGV, conveyors etc. (e.g. FlexSim, Simio, Arena, Anylogic and other). The author selected FlexSim due to the following features (Beaverstock et al., 2011):

- ease of use in a real size with drag and drop technology,
- loading an .dwg file from the layout directly to a model,
- objects ASRS vehicle, Crane, Robot, Elevator,
- extended possibilities to model conveyors,
- fitting the shape of trucks and their parameters – in real values,
- integrating built-in experimenter tool with OptQuest,
- including task sequence technology (which was crucial for this project).

Problem definition

The problem was defined by the company. One of 2nd level KPIs used by this company is „Cases picked per hour per FTE". FTE – Full-time equivalent is a unit that indicates the workload of an employed person in a way that makes workloads or class loads comparable across various contexts. An FTE of 1.0 is equivalent to a full-time worker. This KPI has value on the level of 75% of reference value, so company find the solution which improve this KPI about 15–20% in plus. To improve this KPI we proposed the two-step approach:

- 1. step – check and optimize the assignment of products to storage location,
- 2. step – we will focus on picking process in details.

This paper focuses on step 1. The company prepared for us the following data:

- layout of a warehouse in .dwg format (from AutoCad),
- data of racks – size, number of levels,
- data of operators, forklifts,
- picking lists in an excel file, (in picking list the storage assignments are defined).
- picking process – start position of forklifts and end position of output buffer.

The whole process can be divided into three steps:

- modeling the infrastructure of a warehouse – racks positions and forklifts routes,
- launching motion of forklifts based on the obtained picking list,
- finding better allocation of products to storage locations.

The project is performed in the Distribution Center which was designed a few years ago. So we have historical data – the picking lists. Typically, for the storage assignment we can use a variety of ways: random storage, closest open location storage, dedicated storage, full turnover storage and class based storage. In many warehouses the class-base storage is frequently used. In the inventory control, a classical way for dividing items into classes based on popularity is Pareto's method. The idea is to group products into classes in such a way that the fastest moving class contains only about 15% of the products stored but contributes to about 85% of the turnover. Each class is then assigned to a dedicated area of the warehouse. Storage within an area is random. Classes are determined by some measure of demand frequency of the products, such as COI or pick volume. Fast moving items are generally called A-items. The next fastest moving category of products is called B-items, and so on. Examples of class based assignments are showed in Figure 2.

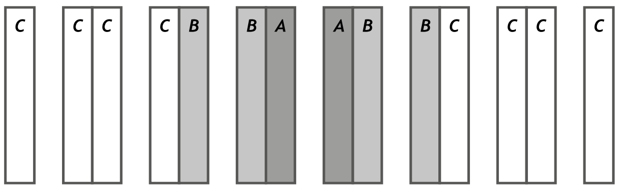


Figure 2. Example of class based storage - within aisle storage
Source: own study

In the Distribution Center the storage was assigned (on class approach) and based on this assignment the WMS (Warehouse Management System) generates picking lists – according to customer orders and taking into consideration the constraints such as: weight, order etc. Our goal is to check the assignment and to try to optimize it. Based on the generated picking lists we want to find better new assignments. The goal function is to minimize the total travel distance of pickers – it is the request of the company. The company assumes that when the total travel distance is shorter, the number of „Cases picked per hour per FTE" will increase. The Company requests the result which will be better by approx. 15% than the actual assignment. It is the main goal.

The other goal is defined by the author. Figure 3 presents the cost-benefit relation and the time which depends on the type of simulation project. We can recognize three kinds of projects (Greenwood, 2013)

- **Single-use** – Model developed to answer a specific question,
- **Mutli-use** – Single-use model that eventually gets re-used for additional analysis,
- **Decision support system** – puts sophisticated engineering tools into the hands of the decision makers to improve decision making and increase the useful life of models as well as get a greater return on the model investment.

In every case the first time period is the time when the cost goes down. The breakdown is when we have a reliable model. So the conclusion is that the second goal is to shorten the time necessary to build the simulation model.

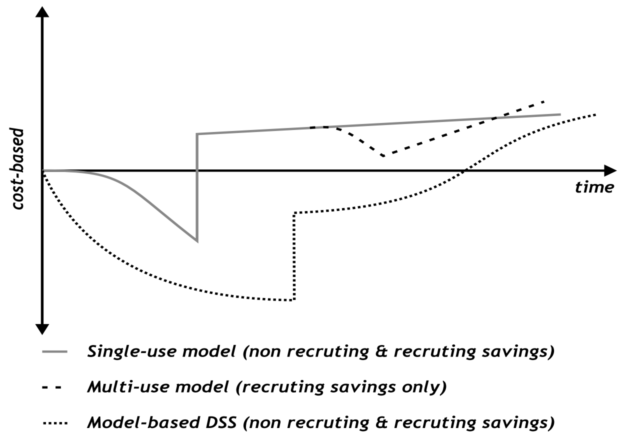


Figure 3. Relation between cost-benefit and time depends on the type of simulation project
Source: (Greenwood, 2013)

Research methodology

We define the methodology of building the simulation model of the analyzed Distribution Center in the following steps:

1. Preparation layout in .dwg format (AutoCad).
2. Identification (cataloguing) resources and modeling: fixed – racks, paths, conveyors, workstations like labeler, palletizer, wrapper etc., mobiles – operators, forklifts, trucks etc..
3. Addressing – corridor, rack, shelf and place on a shelf.
4. Creating examples of picking lists (random or historical).
5. Concept of replenishment (first approach when racks are still full) – later modeling the real replenishment.
6. Motion launch – the first simulation model based on points 1, 2, 3, 4, 5.
7. Model Validation.
8. Definition of function goals.
9. Definition of decision variables.
10. Preparing scenarios.
11. First optimization experiment.

To build the simulation model two steps are time-critical:

- Modeling fixing resources – in this case – racks and transportation network: in the analyzed Distribution Center, there are 1017 racks in the picking area. It means that 1017 different addresses are used. We need to put these racks into the layout (in 3D environment) and to build the transportation network. Every rack has to be connected to the network by an individual network node to represent the real route as well as possible.
- Motion launching – it means that we need the mechanism which controls forklifts to realize the picking list – to pick the item from the racks according to the picking list. The picking list from one month consists of about 130000 picks! The typical simulation software does not include any tools which could support this request.

To shorten the time of modeling the fixing resources we prepared a special object Rack Generator. This object creates copies of an object which is connected to the first central port based on following parameters: number of Racks in dir. X, number of Racks in dir. Y, distance between Racks in dir. X, distance between Racks in dir. Y, prefix of Racks Name, initial Number of Racks, for how many Racks – the Gap, length of Gap, creating NN (0 – yes, 1 – no), place of NN in Relation with Rack in dir. X, place of NN in Relation with Rack in dir. X. Owing to the Rack Generator, we can build the model of 1017 racks with corresponding network nodes within approximately 1 hour!

To shorten the time of motion launching, we use our own technology which we call LogABS (Log – Logistics, ABS – Agent Based System). This technology was prepared in FlexSim environment – especially for logistics applications.

To organize the control of forklifts to realize picking list we designed three special agents:

- schedule control,
- schedule generator,
- contractor.

The information flow between them is shown in Figure 4.

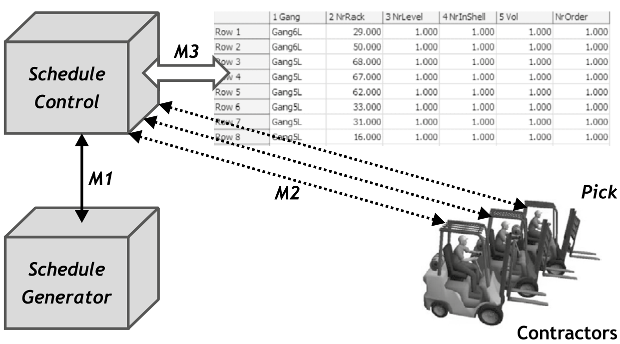
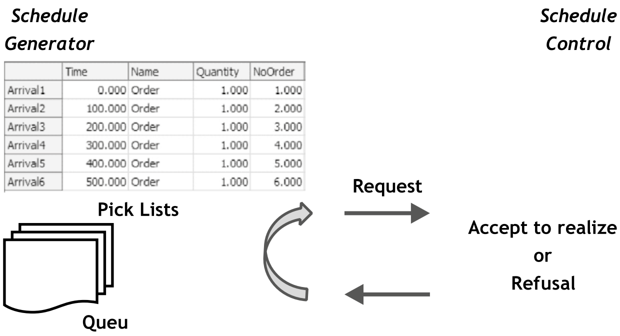


Figure 4. Flow of information between agents
Source: own study

The main agent is Schedule Control: it prepares the list of tasks (according to order number) based on the set of rows from Pick Lists table (M3 arrow from Figure 6) and sends this list to Contractor (M2 arrows from Figure 6). Schedule Control agent works as an answer to a request from Schedule Generator (M1 arrow from Figure 2) and manages the set of Contractors which are connected to Schedule Control. Schedule Generator, based on the time list, tries to send the request to Schedule Control – if it is not possible, Schedule Generator forms the queue of requests (Figure 5).

Schedule Control accepts request from Schedule Generator when one or more Contractors connected to Schedule Control are free – it means that it is ready to receive and perform the order. If all Contractors are busy, the Schedule Control waits for the first free Contractors and refuses the request from Schedule Generator. Schedule Generator agent uses a queue to save all the waiting requests.

If Schedule Control can accept the request (one or more Contactors are ready to work), it prepares the list of tasks based on Pick lists. This list is sent (loaded) to Contractor, then Contactor starts to work, i.e. to implement this list task by task independently of other agents. It means that Contractor has its own „intelligence" to realize the tasks and to react on independencies. If Contractor finishes its work, it sends the message to Schedule Control that is ready to receive the next list of tasks.



	Time	Name	Quantity	NoOrder
Arrival1	0.000	Order	1.000	1.000
Arrival2	100.000	Order	1.000	2.000
Arrival3	200.000	Order	1.000	3.000
Arrival4	300.000	Order	1.000	4.000
Arrival5	400.000	Order	1.000	5.000
Arrival6	500.000	Order	1.000	6.000

Figure 5. Request scheme between agents: Schedule Generator and Schedule Control
Source: own study

At this stage of the research, the Contractor has the following skills:

- to travel – it moves to a defined address – for example the address of a rack,
- to load – it picks and loads the item from the address,
- to unload – it unloads the item to the defined address
- to park – it moves to the parking address
- to check load – it loads the item from the address if the conditions are fulfilled – for example the weight of the picked item is less than the defined limit.

All the described agents form the LogABS library. To use this technology the modeler has to perform the following operations:

- Put on the work area the icon of agent Schedule Generator, Schedule Control and Contractors, connect Contractors to ScheduleControl by a mouse,
- Prepare the global table with pick lists for Schedule Control– see Figure 5,
- Prepare the table with time list for Schedule Generator.

Pick lists are built based on an excel file obtained from logistics operator. The structure of this file is as follow:

- a row in a table – one pick from the location indicated by columns,
- columns contain the name of a sector of racks (the sector represents a line of racks), the number of a rack in a sector, the number of a level (the shield of a rack), the number of item position on the level.

An additional column contains the order's number.

Case study

As mentioned in the previous section we performed a project defined by a company. We obtained from the company all the necessary data according to our methodology including short picking list. The company requested first results based on this short list. We built the model in a very short time – less than 4 hours using RackGenerator objects and LogABS library – Figure 6.

To prepare the optimization task we use a tool built into FlexSim – the experimenter. FlexSim uses OptQuest (www.opttek.com) solver for optimization. The function goal was defined by the company – minimizing the total travel distance of pickers based on the defined short picking list (see section 3). The Company requests the result which will be better by approx. 15% than the current assignment. We have 1017 addresses so the domain of feasible solutions is 1017!. To prepare the optimization task we extended the picking list by the column Item_ID (Table SchedTableAdr – Figure 7) and we prepared the new Global Table called Placement with 1017 rows and 4 columns: Item_ID, name of the sector, number of the rack in the sector and number of the level in the rack. All cells in the column: Number in level in rack – are set on 1, because, for the sake of the experiment, the company assumes that products are on the floor – it means on the level 1. We use cells of column Item_ID from table Placement as decision variables, so we have 1017 decision variables. Every cell can be set on the value from1 to 1017. The company assumes that an individual product can use only one address so we have 1017! combinations (without repetition).

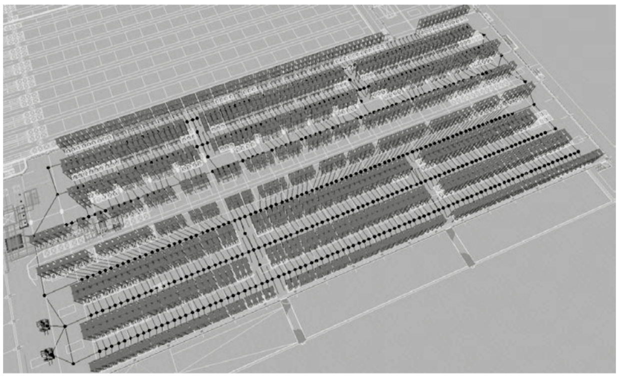
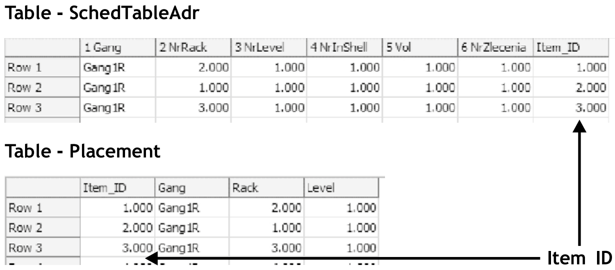


Figure 6. The model of picking area of Distribution Center in FlexSim
Source: own study



	1 Gang	2 NrRack	3 NrLevel	4 NrInShell	5 Vol	6 NrZlecenia	Item_ID
Row 1	Gang1R	2.000	1.000	1.000	1.000	1.000	1.000
Row 2	Gang1R	1.000	1.000	1.000	1.000	1.000	2.000
Row 3	Gang1R	3.000	1.000	1.000	1.000	1.000	3.000

	Item_ID	Gang	Rack	Level
Row 1	1.000	Gang1R	2.000	1.000
Row 2	2.000	Gang1R	1.000	1.000
Row 3	3.000	Gang1R	3.000	1.000

Figure 7. Relation between tables to prepare the set of decision variables
Source: own study

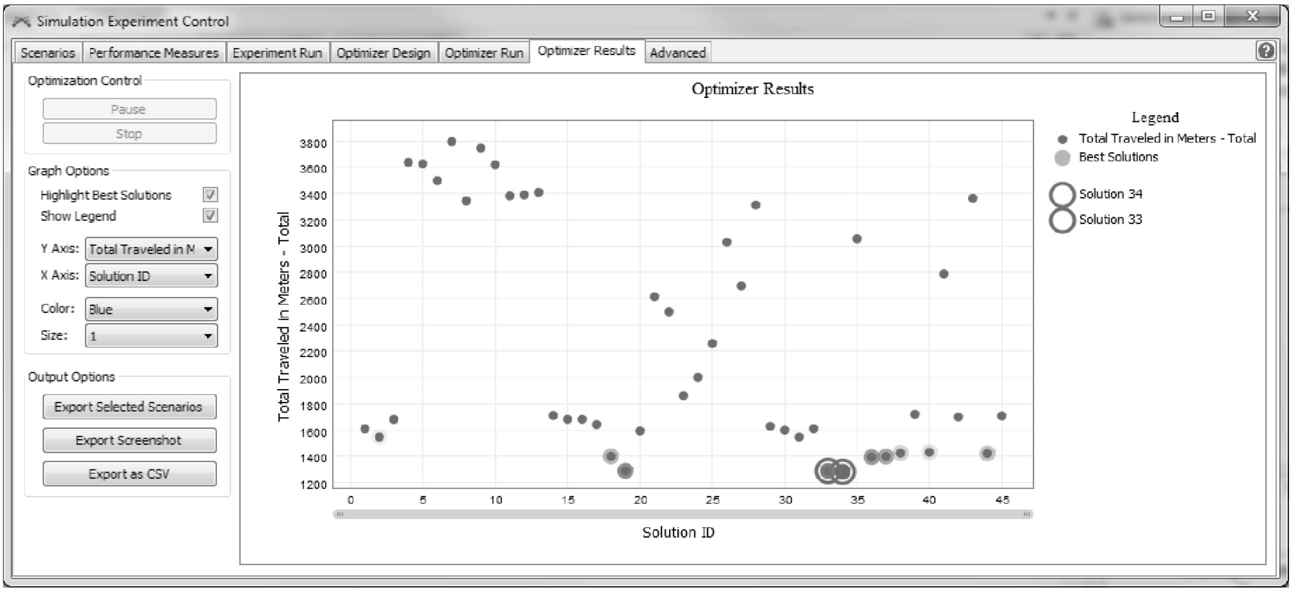


Figure 8. Optimizer results window in FlexSim
Source: own study

At the beginning of calculations, when the Optimizer prepares a new set of values (as new scenario) for decision variables, we reload the picking list with the new assigned addresses (based on table Placement). The obtained results are really valuable – Figure 8.

The total mileage of pickers in the current actual assignment was 1550 meters. The assignments found as a result of the experiments (scenario 33 and 34) need fewer than 1290 meters. These solutions for the question of short picking list is better than the initial settings: the total travel distance is about 20% shorter. The model and results were validated and verified by the company on this stage of the research. The company accepted the results and methodology for the next stage – preparing optimization experiment based on one month picking list – 130,000 picks.

Conclusions

The paper presents results of the work on Order Picking problem. The problem, although difficult to solve by analytical methods, is relatively easy to solve with simulation methods with use of commercially available simulation and optimization software packets. The proposed methodology with designed tools (special object Rack Generator and technology LogABS) make it possible to find in short time a better product assignment than the currently applied one. The proposed solution needs validation with a picking list from one month – it is the goal of the next stage of this project. The simulation imitates the performance of the Distribution Center in a controlled environment so the validation and verification is more valuable – the acceptance of the company was crucial in our case. For the experiments we used FlexSim GP v7.5.2 software with a built-in optimizer OptQuest. Our investigations were carried out in a real-life situation.

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Endnote

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Model symulacyjny do optymalizacji procesu kompletowania w centrum dystrybucyjnym

Streszczenie

W artykule skupiono się na przykładzie przedsiębiorstwa operującego globalnie na rynku FMCG – dóbr konsumenckich szybkorotujących. Opisano problemy związane z operacjami realizowanymi w centrach dystrybucyjnych, skupiając się szczególnie na obszarze kompletacji. Głównym celem artykułu jest rozwiązanie problemu kompletacji, który polega na znalezieniu takiej alokacji towarów, aby dla zdefiniowanej listy kompletacyjnej znaleźć najkrótszą drogę operatora realizującego tę listę, w celu dokonania redukcji kosztów. Do rozwiązania tego problemu wykorzystano technologię symulacyjną (opartą na DES – systemach zdarzeń dyskretnych) dostępną na rynku, która została rozszerzona o metodykę opartą na autorskiej technologii LogABS – symulacji opartej na agentach dla logistyki. Technologia ta pozwala zbudować model symulacyjny dużego centrum dystrybucyjnego w krótkim czasie. Przeprowadzone eksperymenty symulacyjne i optymalizacja bazowały na danych rzeczywistych uzyskanych od operatora logistycznego.

Słowa kluczowe

symulacja, centra dystrybucyjne, kompletacja, optymalizacja