WAREHOUSE PROCESS OPTIMIZATION BASED ON SIMULATION EXPERIMENTS—CASE STUDY

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Abstract
The paper presents results of research performed in a company which looks to cut costs and improve productivity within its warehouses and distribution centers. 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 distribution center. The goal function is to minimize the travel distance of picker.

Keywords:
Simulation, optimization, warehouse process.

1 INTRODUCTION
Recent years have shown the constant interest of scientists and practitioners about the knowledge about complex systems, which are created by the cooperating companies. Supply chains, because these are the purpose of our research, are systems that are characterized by high complexity. Supply chains are a system with "multiple actors" and create very complex interrelation. But the supply chain management is a decision process that not only integrates all of its participants, but also helps to coordinate the basic flows: products/services, information and funds [1].

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 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 Distribution Center.

The goal function is to minimize the travel distance of picker based on the defined one month picking list and to find the new assignment (496 addresses) better (by > 15%) than the actual assignment generated by WMS (Warehouse Management System). This goal was obtained because found solution is better by 26%.

The main contribution of the paper is to show practical methodology of warehouse process optimization based on simulation experiments and to propose the new methodology which mixes approach used by WMS producers and approach proposed in this paper with use of simulation.

The paper structure is as follows. Section 2 describes the literature background of warehouse operations. Section 3 defines the problem solved in the paper. In section 4 the preparation of optimization task is described based on real data from distribution center. The case study from real picking area in a distribution center is discussed in section 5. The final conclusions are stated in section 6.

2 LITERATURE BACKGROUND
Warehouses are complex structures that are used for storing goods. In a warehouse many different processes can be distinguished. In a warehouse with manual (non-automated) systems, order picking is the most labour-intensive operation. In a single warehouse various equipments from different suppliers are used. All of them (equipments and processes) should be treated as an integrated system. In Figure 1 are presented typical warehouse functions and flows.

Figure 1. Typical warehouse functions and flows [11].

In warehouses can be found many different types of order picking system. 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. Authors, in this paper, focus on “broken case picking” – known as piece picking or pick/pack operations. In these kind of system 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.

Two types of material handling system in distribution centers can be distinguished:
- vehicle types – in which a transporter (for example: fork trucks, pallet jacks, AS/RS, AGVs, Bridge Cranes ) are used to carry the load along a path; vehicles may or may not be predefined;
- non vehicle types – in which transport are realized in fixed path without vehicle to transport the load; path consist of multiple sections, e.g. conveyors.
In this article authors focus on the vehicle type manual material handling system. In analyzed distribution centers forklifts are used. Around 75% of the warehouses are manually served by forklifts [3]. Full or partly automated systems receives more attention than manual picking systems [4]. Modeling a large-scale non-automated distribution warehouse with forklifts is more difficult than AS/RS-systems due to their complexity [10].

Picking operations are analyzed based on three aspects: time, distance and costs. The time of order picking consist of: travel (50%), search (20%), pick (15%), setup (10%) and other (5%) [4]. During design and optimization the warehouse, the travel distance (equivalently travel time) is often taken into account. In addition, the aim is to reduce the total costs. During the design and optimize the warehouse many other aspects are considered, as: minimizing the throughput time of an order, minimizing the overall cycle time (e.g. to complete a batch of orders), maximizing the use of space, maximizing the use of equipment, maximizing the use of labor, maximizing the accessibility to all items [4].

Decisions related with picking order are taken on tactical or operational level in companies [9]. Examples of decisions in these levels are presented in table 1.

Table 1. Decisions related with picking order in tactical and operational level.

<table>
<thead>
<tr>
<th>Level</th>
<th>Decision</th>
</tr>
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<tbody>
<tr>
<td>Tactical</td>
<td>- layout design and dimensioning of the storage system,</td>
</tr>
<tr>
<td>Operational</td>
<td>- order picker routing (routing), - sorting picked units per order and</td>
</tr>
<tr>
<td></td>
<td>grouping all picks of the orders (order accumulation/sorting),</td>
</tr>
<tr>
<td>Tactical and</td>
<td>- assigning products to storage locations (storage assignment),</td>
</tr>
<tr>
<td>operational</td>
<td>- assigning orders to pick batches and grouping aisles into work zones</td>
</tr>
<tr>
<td></td>
<td>(batching and zoning),</td>
</tr>
</tbody>
</table>

The order picking operations are modeled and simulated. For modeling this area three types of data are necessary: technical, organizational and system load data. The first includes the topology and structure of systems, e.g. layout, equipment, capacities, process time. The second includes scheduling rules for working time, allocation of resources to tasks, restrictions of handling operations. The last contains information about the amount of handled pallets concerning time and volume aspects.

Order picking processes are complex issue. During the design and control of order-picking processes, the attention is usually focused on searching of 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 [4]. Most authors focus on analytical methods. However, the simulation is also used. Example of using simulation tool in picking area are:

- Petersen [7] shows the effect of the aisle length and number of aisles on the total travel time for both random and volume-based storage assignment methods;
- Petersen and Aase [8] 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 [2].

Warehouse operations can be supported with different simulation programs. Simulation programs on the market can be classified into two groups:

- dedicated to model warehouse operations (e.g. CLASS);
- dedicated to model warehouse infrastructure, for example: racks, forklifts, AGV, conveyors (e.g. FlexSim, Simio, Arena, Anylogic and other).

Authors used FlexSim to simulate warehouse infrastructure and operations in warehouse due to the following features [1]:

- using drag and drop technology,
- the ability to load layout in an .dwg file directly to a model,
- possibility of modeling objects in a real size based on loaded layout,
- using following objects: ASRS vehicle, Crane, Robot, Elevator,
- extended possibilities to model conveyors,
- possibility of 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).

3 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.

The company uses the WMS system to improve operations. WMS for the storage assignment uses class based storage. It is one of many ways to do it. Other are: random storage, closest open location storage, dedicated storage, full turnover storage. In WMS systems the class-based storage is frequently used. 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.
Based on this assignment the WMS generates picking lists – according to customer orders and taking into consideration the constraints such as: weight, order etc. The goal was to check the assignment and to try to optimize it. 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.

To build the simulation model of the analyzed Distribution Center was used following methodology [5]:

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) Import the picking lists from WMS.
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) Optimization experiment.

As mentioned in Section 2 to build the simulation model the FlexSim software package was used. To shorten the time of modeling the fixing resources were modeled using special tool Rack Generator [5] and to shorten the time of motion launching the technology LogABS [6] was used.

4 PREPARATION OF OPTIMIZATION TASK

FlexSim software package uses OptQuest [12] solver for optimization. FlexSim has special tool to define the optimization task – the experimenter. The goal of this section is to describe how the data obtained from company (from WMS) – the picking list - were transformed to the form requested by the FlexSim’s experimenter.

The function goal was defined as – minimizing the total travel distance of pickers based on the obtained one month picking list. In analyzed picking area are 891 addresses, but for optimization it was analyzed 495 addresses, because of places which were omitted – places to storage: pallets, bins, spot and fresh goods. So the domain of feasible solutions is 495!

To prepare optimization task data obtained from company need to be translated to data entered into simulation program. Based on excel file with picking list and data about goods and places of storage of these goods was preparing entered information to simulation model. In first step every transfer order number was translated into next number in FlexSim (started from 1). In second step Storage Bin was translated into Row and Nr rack in row. Figure 3 presents example of transferred data from WMS to FlexSim. Based on these information picking list for simulation model was prepared. In column 1 and 2 and 6 we have information according to translated data from WMS. In column 3 (Level) – we have value 1, because products are stored on the floor – it means on the level 1. In column 4 we also have number 1 – we assume that on one level we have can have one goods (or one container with goods). And in column 5 we also assumed value 1, which means the quantity of goods in this place (Figure 4).

In simulation model were created few global tables (Figure 5). First table is “Group” table, which stores information about the amount of racks in each group (row). The values adopted incrementally. Based on this table we know that, racks in group A01 starts from 1 to 39 – so we have 39 racks, the group A03 start from 40 to 88 – so we have 49 racks etc. Table “Groups” is linked with next table “Addresses”. In table “Addresses” are stored physical addresses of every rack in model, based on table “Groups”. It means that rows 1 presented first rack in group A01. Rows 40 presented first rack in group A03 etc. Next table is table “Sequence”. This table is related with table “Addresses”. In both of these tables we have 495 rows. Number in every row in table “sequence” shows number in table “Addresses”. At the beginning, in the table “Sequence” assumed a value from 1 to 495 – it’s basic scenario (real). If we change number in table “sequence” it will means that we change localization of goods in warehouse. So in optimization we will play with value of each rows in table “Sequence”.

The function goal is minimizing the total travel distance of pickers. In optimization is changed storage place for products. Products in group A (A01 and A03) have to be in these groups. Others goods can be storage in other part of warehouse – other group. In one cell can be only one product at the same time. So we should write some
constrains or make double optimization – first for goods from group A01 and A03, next for goods from groups C02-D04. The part of definition of optimization task is presented in Figure 6.

5 CASE STUDY – RESULTS
Simulation experiments were performed based on real data from company – 21524 picks to prepare 1847 pallets. Based on methodology defined in section 3 the simulation model in FlexSim was built – Figure 7.

6 CONCLUSIONS AND FURTHER WORK
The paper presents results of optimization the distance of operator in picking area using simulation experiments. For optimization the OptQuest optimizer was used. The main OptQuest behaviours are:

- Scatter Search – population based metaheuristic – we need evaluate a wide range of solutions to achieve good results,
- Tabu Search – single solution improved based, have a list of solutions that couldn’t be evaluated again – we need to evaluate many solutions, at least more than list size.

The obtained new allocation results the low level of improvement – 1.2 % (based on 6800 iterations). So we need more iterations to improve. We have two other opportunities:

- make the model faster – using FlexScript programming and deleting all superficial objects,
- use a optimization outside FlexSim, then implement the solution: Metaheuristic approach and MIP approach (optimum guarantee, but slower).

These opportunities define our further works. The main conclusion is the that besides opportunities, the products seem well allocated. We need a better analysis to show it the trade-off, impact vs effort, worth the searching for the optimum.

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