The Importance of Internal Transport in Organizing High-Bay Warehouses

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The article presents internal transport system and principles of transport organization, in order to indicate that the effectiveness of material flow management in a warehouse depends on the transport strategy used by a manufacturing plant. In the paper different means of transport enabling movement of components and semi-finished products are described. From the perspective of industrial plants, minimizing the number of transport resources and maximizing the use of devices needed to operate the storage process play an important role in effective implementation of logistics processes. At the same time, it is necessary to optimize the transport processes in terms of both time and costs. In the paper the possibility to meet these requirements on the example of a high-bay warehouse is verified, based on simulation of loading and unloading operations. Indicators intended to assess the quality of storage process are presented and used to determine the optimal number of transport resources required to operate the proposed warehouse. The results obtained during simulations are the basis for discussion on the influence of a number of transport resources on operating time of the analyzed warehouse.

Keywords: internal transport, transport resources, high-bay warehouse, storage.

1. INTRODUCTION

Growing customer demand and sublime orders force volatility of production assortment, therefore production currently is highly specialized. The purpose of manufacturing plants is to produce high quality products in the shortest possible time, assuring companies the highest income. This is the reason why companies constantly evolve. They also look for methods that allow a better capacity utilization, in order to increase the productivity of system. Therefore, aspects directly related to the production system have to be considered, such as: limited efficiency of machines and equipment, sequence restrictions associated with process route and selected manufacturing technology. There should also be taken into account requirements imposed by customers: execution of orders just in time, high quality and appropriate price of final products. Therefore, the problem of material flow planning in a system is one of the basic tasks of company management. The reason is that shortening the path, needed to provide semi-finished or finished products in the right place, has a direct impact on shortening delivery times and reducing manufacturing costs. Thus, in recent years the transport area has become an important point considered while formulating the strategy for companies.

The main purpose of the article is to present how the choice of transport strategy affects the handling time of an example high-bay warehouse. Organization of task execution in a warehouse depends on factors that are constantly changing, e.g. the number of assortments, the number of orders or the requirement for shorter delivery times. At the same time, the continuously reduction of production and storage costs and speed up production are required. Due to many aspects which should be taken into account during design of the warehouse structure, it is advisable to test storage management system before its implementation in the real factory. For such a verification information systems are used. These tools allow and support storage process simulations conducted using developed management system, based on predicted or recorded input data [1]. In the paper presented experimental studies were carried out using a high-bay warehouse simulator.

The article is organized as follows. Section 2 contains basic information about transport systems in manufacturing plants, with a focus on tasks and organization of internal transport. Section 3 presents the storage process, types and structure of warehouses and the ability to support warehouse management using simulation tools. Section 4 introduces the problem of choosing a number of transport resources needed to operate the analyzed high-bay warehouse. Section 5 includes experimental results and discussion. The final section concludes the paper.

2. TRANSPORT SYSTEM IN A MANUFACTURING PLANT

An efficient transport system, composed of external and internal transport resources, allows to maintain company's profit at a satisfactory level and ensures delivery on time of final products to customers. An external transport system is carried out by means of long distance transport with unlimited range. The amount of achieved profit depends also on appropriate organization of the production process. Thus, during production planning it is important to develop the internal transport system which ensures a proper flow of raw materials and semi-finished products between workstations and departments of a manufacturing plant – it is so called production and technology transport. In turn, the means of service and warehouse transport are intended to handle a storage of materials and final goods. The types of internal and external transport are shown in Fig. 1.

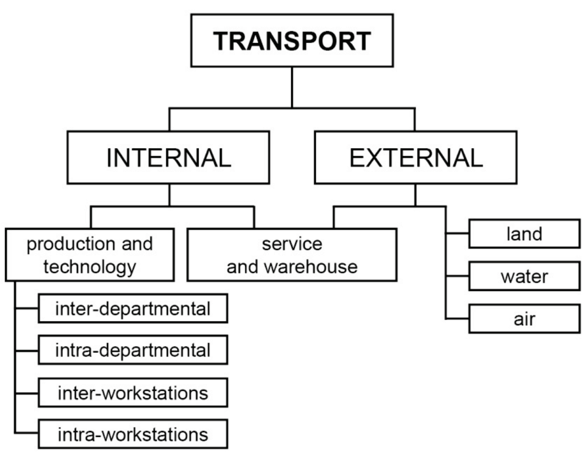

Fig. 1. The classification of transport system.

In the article internal transport and its organization are discussed as an important element in management of material flow and ensuring the optimal handling time of an example high-bay warehouse.

2.1. INTERNAL TRANSPORT SYSTEM

Internal transport means includes any activities related to the movement of goods within area of the manufacturing plant. The issues of internal transport are particularly important from the point of view of production and distribution organization, because each material represents value only when it is available at the right time and at the place where it is currently needed. Therefore, currently the tendency to reduce or eliminate the manual handling of transport resources, by partially or completely automating activities of machines and devices, is observed.

The internal transport infrastructure is generally created by means of technological transport and auxiliary transport resources. These resources allow movement of goods during the production and storage, which are executed as a part of logistic processes [2]. The means of technological transport are used during the movement and distribution of materials, semi-finished and finished products. These include: hoists operating, cranes, forklifts, conveyors, chargers, manipulators, industrial robots, palletizers and de-palletizers. The most popular and the most commonly used means of technological transport are industrial forklifts. This is due to their high flexibility, low occupation of the surface and the relatively low investment costs [3]. In turn, the auxiliary devices allow for efficient movement of cargo, using technological transport resources. These devices, generally used repeatedly, enable mechanization and automation of ongoing operations and provide adequate security of products, as well as preservation of safe working conditions [4]. Among the auxiliary means of transport following resources can be distinguished: cargo containers, cargo pallets, pallet collars, transport and storage containers, dock and platform levellers, feeder of empty pallets, devices for securing cargo units.

The rapid increase in production, high volatility of production orders and the number of provided services, require of the company to improve systematically the internal transport management and to modernize existing transport infrastructure. This is due to the fact that the organization of internal transport resources utilization affects the ability of production optimization. Efficient management of material flow is understood as moving the right number of the produced elements on the shortest possible paths, while making maximum use of transport resources [5]. There are many principles allowing to achieve the high efficiency of transport processes.

2.2. INTERNAL TRANSPORT SYSTEM

Planning of the organization of internal transport in production plant should be carried out simultaneously with a design of the whole factory, taking into account the size of plant, its nature and the type of conducted technological processes. The aim of proper management of internal transport is to ensure continuous material flow between all workstations as well as control stations and warehouses. There are several important aspects related to the organization of transport infrastructure, such as:

- shortening of transport paths,
- adjusting the load units to the possibility of transport resources,
- avoiding crossing of transport paths at one level of warehouse,
- using of gravity for transport from higher to lower levels.

Applying these principles affects the later performance both of the production and storage processes.

3. STORAGE IN MANUFACTURING PLANT

According to Polish standard PN-84/N-01800 Warehouse management – Basic terminology, storage process is a set of activities that are related to the tasks such as: receiving, storing, completing, moving, maintaining, reporting, controlling and issuing of material goods. The diversity of these activities has an impact on the organization of a warehouse, what is discussed in detail in the paper. In turn, a warehouse is a functional and organizational entity that is designed to store material goods in a separate space of storage building and can be used both as delivery and receiving area, as well as a kind of buffer that ensures the continuity of the production process. Warehouses are a critical link in the production logistics, what necessitates the implementation of modern management concepts. One of them is Lean Management – this approach assumes the elimination of waste, i.e. all activities that raise cost production without making a useful contribution to production. Certainly, improper warehouse management, surplus of inventory and products unreasonably increase storage costs without increasing the value of final goods. These additional costs are associated with incomplete use of storage space or long search times for location of stored components. Therefore, structure and management of warehouses, like organization of internal transport, should be considered and tested already during production planning [6]. The planning process is often supported by IT tools that enable:

- defining the company's storage and logistics capacities;
- current registration of deliveries;
- monitoring the status of orders execution;
- defining the sequence of order executions;
- better use of existing warehouse infrastructure without its extension;
- faster response to changes in the environment;
- providing information on inventory, taking into account different criteria;
- efficient location of each consignment;
- quantitative and assortment control of material directed to the warehouse, e.g. in terms of the consistency of the deliver with the previous order.

After implementation of management system, IT systems are used for decision making and monitoring the work of stationary or mobile devices and other storage equipment. Especially important is also support the correct allocation of goods in the warehouse and control of warehousing turnover. Using IT tools it is possible to define and precisely calculate the parameters of individual warehouse zones, so that the warehouse does not become a bottleneck in the supply chain. All calculations of storage costs are conducted based on square meter – this is a unit of storage efficiency. In order to achieve the maximum storage efficiency, all three dimensions of storage area should be used – the most important is height, because high warehouses give ability to store goods at different levels and to maximizing fill of storage space. In terms of height warehouses are divided
into [8]:

- low – height up to 4.2 m,
- medium – height from 4.2 m to 7.2 m,
- high (called high-bay warehouse) – height from 7.2 m to 40 m.

Regardless of the warehouse height, the storage areas are divided into the following zones [7]:

- receiving – implementation of such tasks: acceptance of delivery to the warehouse, unloading goods from the transport resources, quantitative control, preparation of loading units for storage;
- storage – the largest area of the warehouse, intended for storing goods on shelves and equipped with handling paths for the movement of transport resources;
- picking and packing – preparation of orders strictly according to customer requirements;
- shipping – unloading products from the warehouse and loading on different means of transport.

The characteristic of individual storage areas indicate that practically in each part of warehouse there is displacement of stored products, what requires the use of various transport resources. Therefore, there is a question how to organize the movement of goods in order to ensure maximum storage efficiency. This problem has been considered during conducted simulation research.

4. SIMULATION RESEARCH

In order to draw attention to the importance of ensuring proper transport infrastructure in a manufacturing plant, simulation of storage process on the example of a high-bay warehouse was carried out. This process is understood as the execution of the following operations: loading and unloading products .

The example of a high-bay warehouse is a warehouse where the shelves create supporting structure for housing components (walls and roof). Products are stored in special transport units – containers, on shelves or specialized racks [8]. The analyzed warehouse consisted of 144 slots, arranged in 6 shelves, each of which was composed of 6 rows and 4 levels
(Fig. 2). The storage structure had horizontal arrangement of particular zones with separate receiving, storage and shipping zones. The receiving and shipping zones were adjacent to each other, but had other functions. Thus, they could not be regarded as one receiving-shipping zone. The designation of warehouse zones was based on the ABC method with two criteria – number of orders and frequency of orders. The ABC storage philosophy was used in order to maximize space utilization, maximize picking efficiency and minimize putaway labour [9].

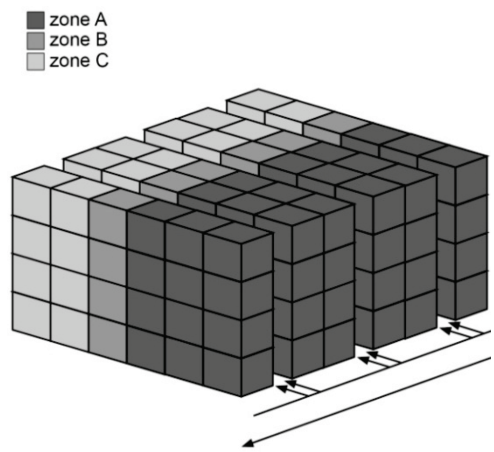

Fig. 2. Analyzed high-bay warehouse with ABC zones.

The assumed number of product types was 6. Each of goods had an assigned zone (A, B, C) and a priority in the range of 1 to 7. The priorities were defined based on the assumption that the order of goods unloading from the warehouse must take place before loading products, in order to assure the best customer service. It was assumed that the lower priority number, the more important the order. Table I presents summary of priorities assigned to particular type of goods, separate for loading and unloading operations.

Table 1. Summary of order priorities.

Code of product	Priority of operation	
	loading	unloading
1	6	2
2	5	1
3	5	1
4	7	3
5	5	1
6	7	4

Simulation parameters related to the access time of forklifts to warehouse locations are presented below. Times are given in contractual units of time [u.t.]:

- access time to a shelf, specifying time it takes to transport product between two consecutive shelves: 10 x No. shelf;
- access time to a row, specifying time it takes to go the way between adjacent rows: 2 x No. row;

- access time to a level, specifying time needed to overcome a distance of lifting the loading units between levels: 1.5 x No. level;
- time of loading/unloading, so manipulation time of postponed and downloaded goods from the slot: 3;
- time needed to transport goods between loading and unloading zones is 30.

For the research purpose, 333 operations of loading and unloading products were defined. The proposed simulation was conducted for three days – the first order falls on Monday, at 7.00 am and the last on Wednesday, at 6.45 am. It was assumed that the work is carried out 24-hours a day and in three shift arrangements. In order to define the sequence of loading and unloading operations and products location in a high-bay warehouse, the following criteria were selected (in a hierarchy consistent with the presented order):

- minimum execution time of operation (MinETO),
- minimum priority operation (MinPRO),
- minimum waiting time of operation (MinWTO),
- maximum waiting time of forklift (MaxWTF).

The obtained solutions were evaluated based on three proposed quality indicators:

- average execution time of operation (AET),
- average waiting time of operation (AWT),
- maximum waiting time of operation (MaxWT).

For the proposed assumptions, simulation was carried out for the different (1-15) number of the most common means of transport – forklifts, used to operate the proposed warehouse.

5. EXPERIMENTAL RESULTS

This section presents experimental results obtained during simulations of storage process. Table 2 contains values of quality indicators for each number of forklifts used to perform loading and unloading operations. Fig. 3-6 are intended to observe the trend of indicator changes, depending on the number of forklifts.

Table 2. The summary of quality indicator values for different number of forklifts.

Number of forklifts	**Quality indicator**		
	average execution time [u.t.]	average waiting time [u.t.]	maximum waiting time [u.t.]
1	41.97	487.88	1432.00
2	47.30	328.75	1413.00
3	46.27	250.50	1334.00
4	48.73	189.28	1320.00
5	50.23	146.44	1291.00
6	54.15	115.18	1284.00
7	55.61	81.83	1063.00
8	58.71	61.63	1024.00
9	60.62	45.09	641.00
10	61.81	32.08	398.00
11	61.08	22.41	368.00
12	61.99	16.41	210.00
13	61.66	11.97	197.00
14	61.10	9.46	197.00
15	60.13	7.36	197.00

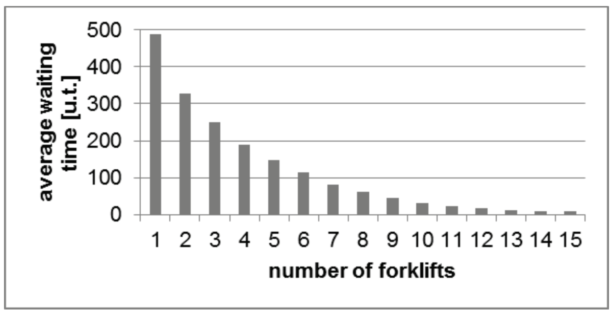

Fig. 3. Dependence of the average waiting time on the number of forklifts.

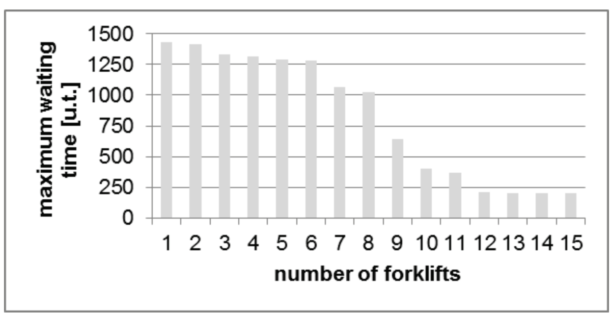

Fig. 4. Dependence of the maximum waiting time on the number of forklifts.

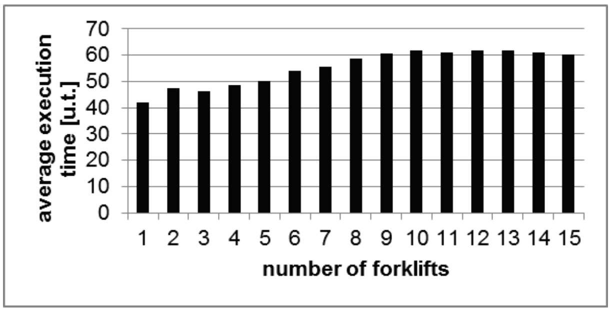

Fig. 5. Dependence of the average execution time on the number of forklifts.

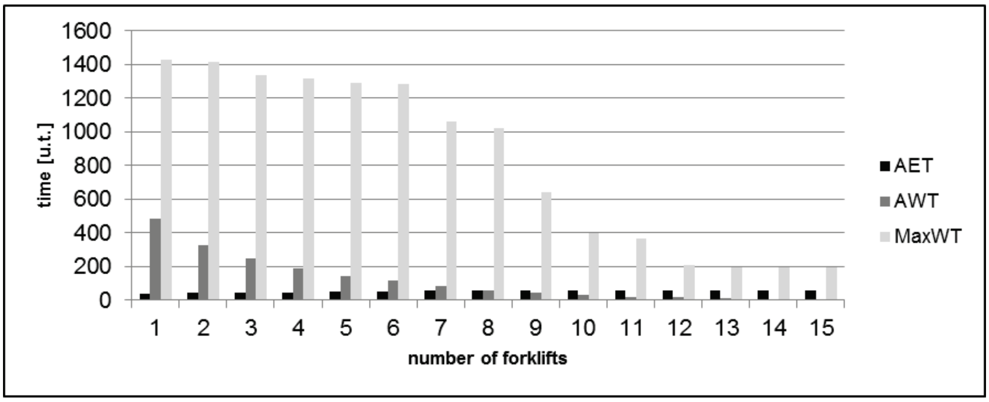

Fig. 6. Summary of the results obtained for different number of forklifts.

It can been observed that increase in the number of transport resources significantly reduced the average waiting time of operation (Fig. 3). Using the maximum number of forklifts (15), the AWT indicator was 65 times smaller than in the case when only one resource was used. The maximum waiting time was also decreasing with the increase in number of forklifts (Fig. 4), but the decrease was not as gradual as in the case of the average waiting time. The biggest difference (243 time units) in MaxWT indicator can be observed for the cases when 9 and then 10 forklifts were used. On the other hand, for 12 or more transport resources the changes of MaxWT indicator were small or absent. Fig. 5 shows the tendency to increase the average execution time with the increase in the number of transport resources.

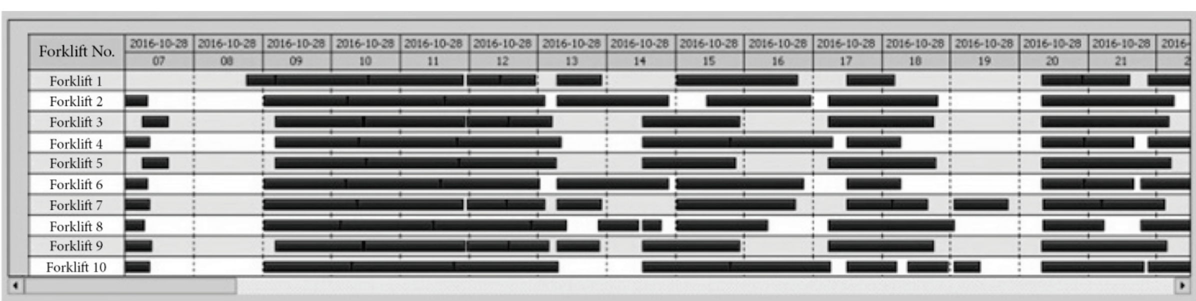

Fig. 7. Occupancy of used forklifts.

The summary of the obtained results, presented in Fig. 6, shows that the optimal number of forklifts intended for handling the proposed high-bay warehouse is 10. The differences in average waiting time and average execution time for more transport resources were not significant, and in turn, the maximum waiting time was clearly less than for 9 forklifts and slightly higher than for 11 resources. The selection of the optimal number of forklifts was based not only on the proposed quality indicators. Into consideration was taken into account also the fact that the number of used transport resources should be as minimal as possible, due to the additional costs of purchasing and handling these forklifts.

The part of Gannts chart which presents the occupancy of ten forklifts used in simulation, and the chart of warehouse occupancy were presented in Fig.7 and Fig. 8.

6. CONCLUSIONS

The planning of the material flow in the manufacturing system is one of the most important stages of production management. Both transport paths within the plant as well as infrastructure of external transport ensuring that the finished goods are distributed and delivered to the customer just in time, should be analyzed and taken into account

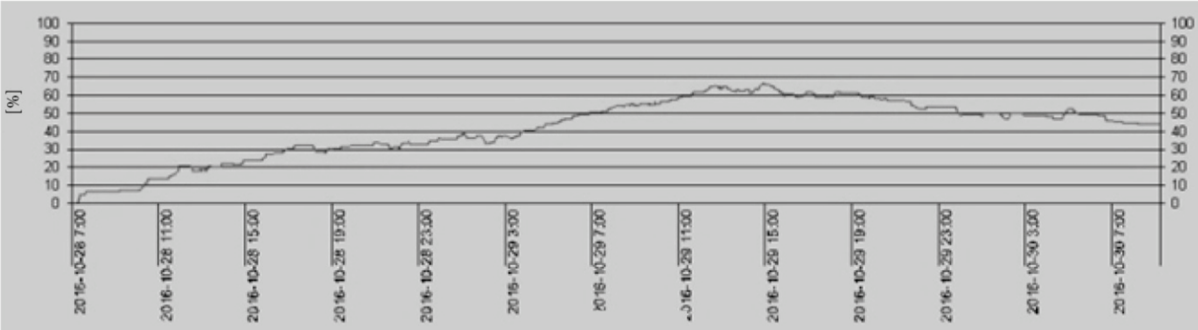

Fig. 8. Warehouse occupancy.

during this planning process. The use of applications to support the design of the product flow and organization and management of warehouse space is a significant facilitation for specialist and, in addition, reduces the probability of mistakes and errors at the stage of development the prototypes of storage structure. Using a system designed to simulate the processes of exemplary high-bay warehouse handling, several experimental studies were carried out. The obtained results required additional analysis in order to select the optimal number of transport resources. It has been taken into account that increase in the number of forklifts is related to the increase in the cost of their purchasing and servicing. The fact that bigger number of resources require better organization of transport infrastructure in order to avoid crossing paths and to ensure collision-free movement was also considered. Thus, the use of simulation applications only supports decision-making. It should be supported by additional analysis of results obtained from information systems.

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