Analysis and Simulation of Internal Transport in the High Storage Warehouse

J. Krystek and S. Alszer

Abstract The transport plays a growing role in the integrated logistics management of semifinished products and components flow. For manufacturing companies, it is important to maximize the use of production resources and optimize the process in terms of both production costs and time. The use of specific means of transport and correct organization of material flow are fundamental in order to assure continuity of production. The exemplary means of transport, their characteristics, and purpose are presented in this article. One of the elements included in the production systems and used to reduce the number of unplanned downtimes are warehouses. They may be small structures placed near workstations, storage buffers along the supply chain, or the separate buildings with a height up to several tens of meters. The choice of storage solution depends on both the profile of the industrial company and the destination of goods storage area. Due to highly complicated processes of warehouses design and management, the computer systems are currently used. These systems support the processes and allow to carry out necessary simulations. An example of using a support application, a discussion of the conducted simulations and analysis of result are presented in the final part of this paper.

Keywords Internal transport · External transport · High storage warehouse · Transport resource

J. Krystek (✉) · S. Alszer
Institute of Automatic Control, Faculty of Automatic Control,
Electronics and Computer Science, Silesian University of Technology,
Gliwice, Poland
e-mail: jolanta.krystek@polsl.pl

S. Alszer
e-mail: sara.alszer@polsl.pl

D. Mazur et al. (eds.), *Analysis and Simulation of Electrical and Computer Systems*, Lecture Notes in Electrical Engineering 452,
https://doi.org/10.1007/978-3-319-63949-9_27

1 Introduction

Growing customer demand and sublime orders force volatility of production assortment; therefore, production currently is a highly specialized production. The purpose of manufacturing plants is to produce in the shortest possible time high-quality products, assuring the company the highest income. This is the reason, why companies are constantly evolving; also they are looking for methods that allow for better capacity utilization in order to increase the productivity of the system. In this connection, it has to be considered aspects directly related to the production system, such as limited efficiency of machines and equipment, sequence restrictions associated with process route and selected manufacturing technology. There should be also taken into account requirements imposed by customers: execution of orders in time, high quality and appropriate prices of the final products. Therefore, the problem of material flow planning in the system is one of the basic tasks of company management. The reason is that shortening the path, needed to provide the semifinished products in the right place, has a direct impact on the shortening delivery times and reducing manufacturing costs. Thus, in recent years a transport area has become an important point considered while formulating a strategy for companies. The transport issues and a shipping strategy should be thoroughly analyzed before production. In addition, found solutions should meet both technical and organizational constraints.

2 Transport System in Manufacturing Plants

From the perspective of companies, it is important to provide just in time the final product to customers, to fulfill the obligations of the agreement and to meet customers' expectations. For this purpose, it is necessary to ensure an efficient system of external transport, which takes place by means of long-distance transport with unlimited range. On the other hand, in order to achieve high production efficiency and to reduce production costs and time, also the organization of internal transport should be considered.

Transport, which is directly associated with production, provides the flow of raw materials and semifinished products between workstations, sections and departments situated close to each other and within these different production shops. In turn, the second branch of internal transport concerns the following issues: storage, warehousing, and service of warehouses with raw materials, semifinished, and finished products. This branch of transport is also associated with external transport. The classification of transport is presented in the Fig. 1.

The detailed characterization of the internal and external transport with examples use of transport resources will be presented in the following sections.

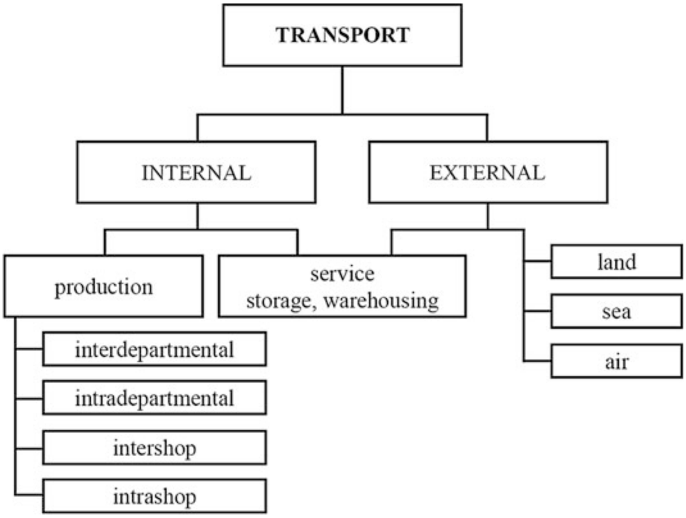

Fig. 1 The classification of transport

2.1 The External Transport

Products delivery on the domestic or global market forces company to develop an external transport system. This type of transport can be carried out both by its own means of transport and by transport providers or forwarding services. Regardless of the type of transport resources, it is important to optimize the use of vehicles working time, mileage, and payload and to protect products during transport. Below are presented the possibilities and limitations of each branch of external transport [1]:

- rail transport—advantages: possibility of mass transport, vast rail network, high spatial accessibility, regular and rhythmic connection, profitable transport time, disadvantages: products, which are sensitive to high levels of vibration and shock, are not suitable for carriage by rail, because there are not guaranteed safe conditions for transport, there is also a high risk of transported products theft;
- road transport—advantages: the highest density and coherence of car network, profitable transportation time, the ability to deliver goods directly to customers, disadvantages: high transport costs;
- maritime transport—advantages: ability to mass transport, worldwide coverage of sea routes, disadvantages: low operating speed of ships, problem with frequency and punctuality of connections, products sensitive to moisture are not properly secured, long travel time;
- inland waterways—advantages: possibility of mass transport, disadvantages: problems with the regularity of transport, delivery times, availability of space and safety assurance of products;

- air transport—advantages: ability to transport small production batches, requiring specific conditions during transport, the relatively short transport time, high security of transported products, disadvantages: need to ensure the delivery means of transport, high transport costs.

The aspects mentioned above, characteristic to the external transport resources, illustrate some of the possible advantages and disadvantages of use of these means of transport. The choice of a particular branch of transport, used in the company, is largely determined by a thorough analysis of transport costs and profits calculation. As mentioned earlier, the external transport system ensures the distribution of manufactured goods, but reaching the final stage of production requires prior planning of the internal transport system.

2.2 The Internal Transport

The term internal transport stands for all activities related to the movement of products within the area of the manufacturing plant or company [2]. Each of the materials is valuable only if it is available at the right time and in the place, where it is currently needed [3]. This is the reason, why the issues of internal transport are mainly important for distribution and production rationalization.

The internal transport infrastructure determines the general means of technological transport and auxiliary transport resources. These resources allow the movement of products during the manufacturing processes and storage, which are executed as a part of logistic processes [4]. The means of technological transport are used during the movement and distribution of materials, semifinished, and finished products. These include: hoist operating, cranes, trolley trucks, conveyors, chargers, manipulators, industrial robots, palletizes, and depalletizes.

The most popular and the most commonly used means of internal transport are industrial trolley trucks. This is due to their high flexibility, low occupation of the surface, and the relatively low investment costs [5].

In turn, the auxiliary devices allow efficient movement of cargo, using the resources of technological transport. These devices can be generally used repeatedly and enable mechanization and automation of ongoing operations. They also provide adequate security of products, as well as the preservation of safe working conditions [6]. Among the auxiliary devices can be distinguished: freight containers, pallets, pallet collars, transport and storage boxes/containers, bridges and loading platforms, warehouses-feeders empty pallets, devices for securing cargo units.

Optimization of the production is not possible without proper organization of internal transport, which should be adapted to the type of the executed processes. By efficient managing of materials and semifinished products flow, it can be understood, among other things, moving the right amount of these elements on the shortest possible routes, while making maximum use of means of transport. At the same time, the least possible consumption should be ensured. The next section will present some principles regarding the organization of internal transport.

2.3 The Principles of Internal Transport Organization

The development and organization of internal transport in a company should be carried out simultaneously with the design of the entire manufacturing plant. It should take into account also the size of this plant and the type of process. Proper organization of internal transport aims to provide continuous, unidirectional flow of materials and other components by all workstations, as well as storage and control stations [4].

It lists several important aspects related to the preparation of transport infrastructure and affects subsequent the capacity of the system:

- avoid crossing of transport routes on one level;
- use gravity to transport from a higher to a lower level;
- striving to the shorten transport routes;
- adaptation of loading units to the possibility of transport resources.

The rapid growth of production, high volatility of orders, and the scope and number of provided services require the company systematically improve the organization of internal transport and modernization of existing infrastructure. Usually, this is connected with the desire to reduce or eliminate manual operations of means of transport by partial or complete automation of activities performed by machinery and devices. But it is necessary to bear in mind that, in some cases, use of simple and inexpensive manual transport resources can bring greater benefits than automated solutions. The issue of organization of internal transport infrastructure will be discussed in more detail in the next section.

3 Storage in System Production

The storage, according to information contained in [7], is defined as a functional and organization unit, which is designed to store materials and goods in a separate building storage space for use in the future. The storage process, in accordance with polish norm [8] is meant in turn a set of activities that are related to temporary: intake, storage, completing, migration, maintenance, keeping a record, controlling, and issuing of material goods. The diversity of listed activities also points out how the warehouse is organized. However, regardless of the adopted definition of storage, storage is an important link in the logistics of production. A storage space can be both a place of delivery, receipt, or goods distribution, as well as a kind of buffer, ensuring continuity of process. Managing the storage process may favorably affect the profits of the company, provided that it ensures proper management of goods flow in the warehouse. It is important to take into account that reducing the cost of storage leads to lowering logistics costs. In the absence of transparent and clear organization of material flow and warehouse management, the company is exposed to additional costs. These costs are related, inter alia, to part-filling the storage space or slow search for the desired storage space. Therefore, even during production planning, structure, and organization of warehouses should be considered.

3.1 The Structure and Organization of the Warehouses

In order to operate warehouses, various types of transport resources and equipment for the mechanization of warehouse operations are very often used. This is to avoid high costs of operating the warehouses, on the way to make the best use of storage area. In turn, organization and management of warehouses are based on modern management tools to support the activities of storage. Information systems play an important role in warehouses management, decision making and supervising work of stationary and mobile installation, devices, handling equipment, and other elements of the warehouse.

The organization of warehouses should be enough thought to get a maximum storage efficiency, determined in relation to the surface. The measure of this efficiency is generally square meter, based on which all calculations of storage costs are conducted. Thus, it appears advisable to use all three dimensions of space, to ensure the best effects of goods managing. Resource efficiency is generally recognized to one of the spatial dimensions—height. It gives the ability to store goods at high altitudes. Simultaneously maximum filling of storage space at different levels is provided. If the height of storage warehouse is between 7.6 and 40 m, then a storage warehouse is called a high storage warehouse [9].

The definition of high storage warehouse has not yet been legally regulated, but the term of this type of warehouse refers to a warehouse, where shelves create supporting structure for housing components (walls and roof). If additional storage area is supported by automatic stacker cranes, the storage is called automatic high storage warehouse. The products are stored on or in special transport units, for example, on pallets or in containers, on shelves of specialized racks. The storage area is coupled to individual storage zones by means of the conveyor system. A warehousing process usually consists of a number of subprocesses, including following zones [10]:

- receiving—space of a warehouse system for incoming material flows [11], includes the physical unloading of incoming transport, checking and updating the inventory record and also unpacking, repacking, preparing of loading units for storage and so on;
- storing—the largest surface area of warehouse for storing goods on shelves, equipped with handling road, allowing the movement of products, storage is concerned with organization of materials, held in a warehouse in order to achieve high space utilization and facilitate efficient material handling [11];
- picking—intended for the preparation of orders strictly according to customers requirements, picking products to fill customer orders is one of the most

important activities in the warehouse, due to its high contribution (about 55%) to the total warehouse operating cost [12]. It 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 disposing of the picked articles [13];

- packing—separate function within logistics, where a shipping material can be entered in a packaging dialog at any time and a handling unit can be subsequently created. All packing functions are available to pack, repack, or unpack a handling unit. A handling unit can itself manually be packaged or automatically generated upon goods receipt or in the packing zone of a warehouse and then represents a new handling unit shipping [14];
- shipping—space of a warehouse system for outgoing material flows [11], in which the transfer of control from warehouse to customers or carrier of the merchandise take place. If these transfers of control are not accomplished efficiently, safely, and accurately, the warehouse cannot possibly meet its objective of satisfying customers requirements, regardless of the quality of the other aspects of the warehouse [12].

The characteristics of each warehouse zones indicate that virtually in every part of storage area there is a movement of the stored goods. It requires the use of various transport resources. Some simulation studies were carried out for different numbers of means of transport and for the exemplary structure of high storage warehouse. The aim of these simulations was to draw attention to the importance of ensuring proper transport infrastructure in a production system. A detailed description of researchers, together with the obtained results will be presented in this paper.

4 Simulation Researches

The organization of tasks in warehouses depends on the factors, which continually change, such as: changing the number of assortments, the number of orders, whether requirement shorter the time for order completion. On the other hand, it is important to continuously reduce costs of both production and storage and accelerating production process. Therefore, development of warehouse structure should be a properly thought-out process, supported by simulations of designed construction and based on the expected or possessed input data. Thus, warehouse management is now supported by IT systems, due to high complexity of the management and design processes.

For a defined structure of warehouse, some simulations are conducted, based on a sample system, supporting design and management of a high storage warehouse. These tests were aimed to show the impact of the number of transport resources for average time of execution, average, and maximum waiting time of orders in the system.

4.1 Simulation Parameters

A simulated warehouse is a “bag” storage system (Fig. 2), that is, with a horizontal arrangement of particular zones and with a separate receiving, storing and shipping zones. The receiving and shipping zones are adjacent to each other, but have other functions. Thus, they cannot be regarded as one receiving-shipping zone.

The analyzed warehouse consists of 480 slots, arranged in 10 shelves, each of which is composed of 6 rows and 8 levels (Fig. 3). The orders executed by the warehouse are admissions and release of the goods in full containers and each of the goods has an assigned zone (A, B, C) and a priority in the range of 1–10.

The assumed number of goods types is 6. The designation of warehouse zones was based on the ABC method with two criteria—number of orders and frequency of orders.

The goods were assigned right priorities, 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, and based on the analysis of ABC

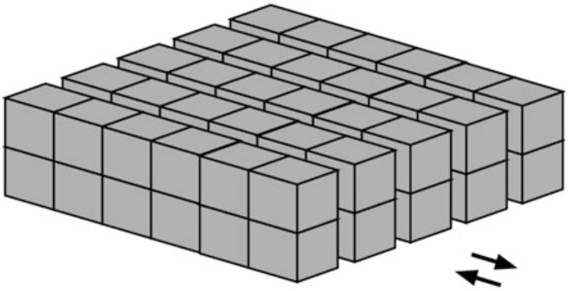

Fig. 2 A “bag” storage system

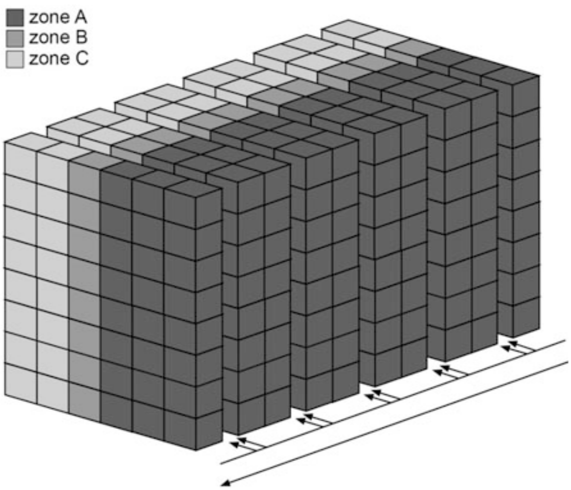

Fig. 3 The rack storage system with marked zones

Table 1 Summary of orders' priorities

Code of product	Priority of order	
	Loading	Unloading
1	6	2
2	5	1
3	5	1
4	7	3
5	5	1
6	7	3

method. Table 1 presents a summary of priorities assigned to particular types of goods. The details of the analysis will not be considered in this article.

During simulations as transport resource a forklift is adopted, because it is the most commonly used mean of transport. A forklift, after completing its assigned order, remains in place and is waiting for the next job assignment.

Below other simulation parameters are presented and they relate to the access time of forklifts to warehouse locations, times are contractual units of time [c.u.t]:

- access time to the shelves between two consecutive shelves: 12 × No. shelves;
- access time to the row, specifying time it takes to go the way between adjacent rows: 3 × No. row;
- access time to the level, specifying time needed to overcome a distance of lifting the loading units between levels: 4 × No. level;
- time of loading/unloading, so the manipulation time of postponed and downloaded good from the slot: 2.

The time needed to transport goods between loading and unloading zone is 35 [c.u.t].

There are adopted four following criteria (in a hierarchy according to the shown order), allowing to select the method that defines the order of orders execution and location in warehouse:

- minimum time of order execution;
- minimum priority order—it is assumed that the lower the priority, the more important is the order;
- minimum waiting time of order;
- maximum waiting time of forklift.

The simulation was performed for 333 jobs, the first order falls on 28.10.2016, at 7.00 a.m. and the last on 10.30.2016 r., at 6.45 a.m. It was assumed a work carried out 24-h a day and three shift arrangements. The number of the forklift, used in this simulations, is varied in the range of 1–15.

4.2 The Results of Researches

For the adopted structure of high storage warehouse and set of simulation parameters several tests were conducted. Those researches were aimed to select the effective number of means of transport.

The simulation results carried out with a different number of transport, are shown in Table 2.

The data contained in Table 2 are also presented in the form of three following charts and a chart, presenting a comparison of all received data.

4.3 The Analyzes of Results

As it to be expected, the increase in the number of transport resources significantly influences reduction of average waiting time of order (Fig. 4)—using maximum available number of forklifts, it can be observed more than 56 times reduction of average waiting time of order in relation to use only one mean of transport. Based on Fig. 5, it can be concluded that in most cases maximum waiting time of order decreases with increasing of the number of used transport resources, but this decline is not as gradual as in the case of average waiting time of order—there is no characteristic trend. When changing the number of forklifts with 1, the largest differences in time are for the number of resources equal to 9 and 10, and 12 and 13. The maximum waiting time of order for 10 forklifts is reduced by 381 [c.u.t] in

Table 2 Summary of simulation results for a particular number of transport resources

Number of transport resources	Average execution time (c.u.t)	Average waiting time (c.u.t)	Maximum waiting time (c.u.t)
1	60.71	534.69	1411.00
2	55.68	392.19	1422.00
3	57.66	295.00	1315.00
4	58.97	237.94	1316.00
5	60.47	194.71	1317.00
6	61.61	154.26	1301.00
7	64.55	121.65	1287.00
8	66.26	88.96	1222.00
9	68.65	61.33	1047.00
10	70.04	45.57	666.00
11	70.41	33.32	578.00
12	71.19	25.66	505.00
13	71.80	17.20	229.00
14	71.46	12.10	197.00
15	71.31	9.42	197.00

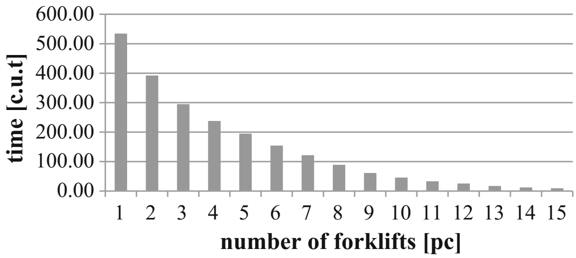

Fig. 4 The average waiting time of order for a particular number of used forklifts

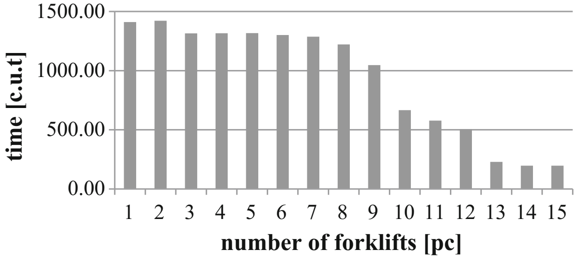

Fig. 5 The maximum waiting time of order for a particular number of used forklifts

relation to the time for 9 forklifts. In contrast, for 13 resources maximum waiting time, compared to the time for 12 resources, is shorter by 276 [c.u.t]. For 13 and more forklifts, there are none or small changes in maximum waiting time of orders. On the other hand, Fig. 6 represents a general upward trend in average time of orders executions with an increase of the number of forklifts. By average execution time is understood time elapsed, since the emergency of order in the system until completion of the order.

The summary of the results, presented in the Fig. 7, can thus be used to predict that the most effective number of forklifts for analyzed high storage warehouse is 13. This number was chosen due to several important observations. Namely, differences in average waiting times of orders and average times of execution of orders for the number of resources greater than 13 are definitely smaller, and in turn, maximum waiting time is significantly smaller than in the case of a smaller number of forklifts. It should be however noted that in the conducted tests the focus was mainly on the relationship between the number of used forklifts and the time

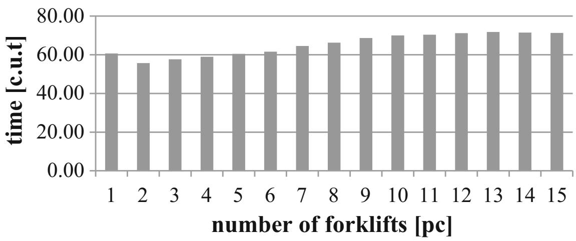

Fig. 6 The average execution time of order for a particular number of used forklifts

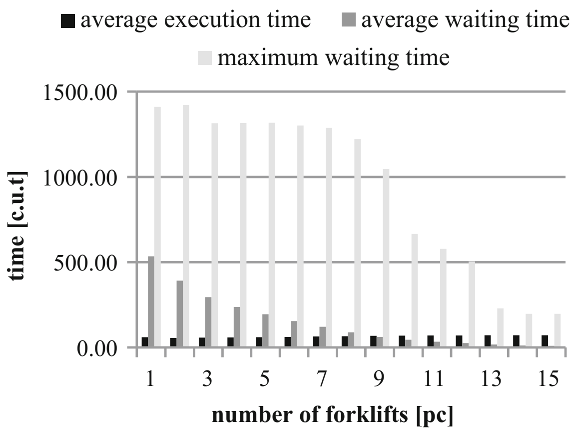

Fig. 7 A summary of the results

parameters. If the carried out analysis would be completed by additional analysis of purchase and maintenance costs, the most effective number of forklifts should be reduced to 10. This choice was made in view of the fact that average execution time for 13 resources is slightly different in relation to average time occurring for the 10 forklifts. While Fig. 5 demonstrates that reducing the number of forklifts below 10 significantly increases maximum waiting time of orders.

The chosen fragments of the Gantt charts for 10 and 13 forklifts, showing when these means of transport were occupied, are presented in Figs. 8 and 9. The Figs. 10 and 11. show the percentage occupancy of this warehouse for 10 and 13 forklifts.

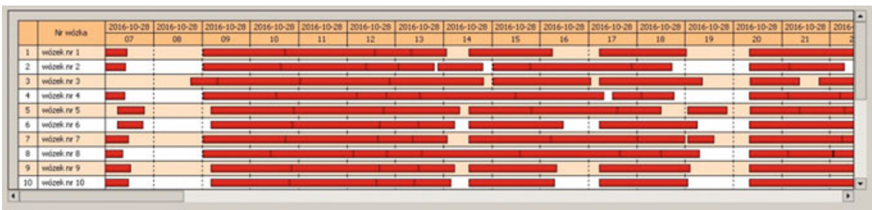

Fig. 8 Fragment of the Gantt chart for 10 forklifts

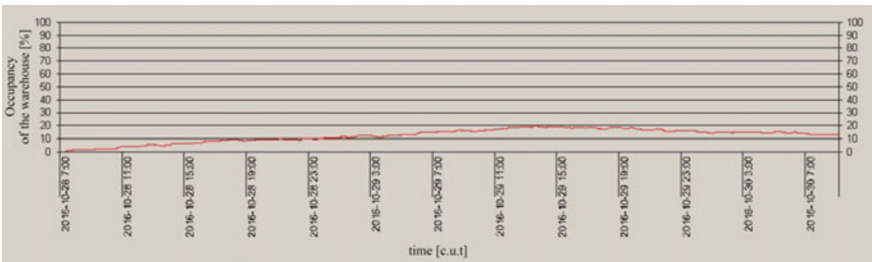

Fig. 9 Percentage occupancy of the warehouse for 10 forklifts

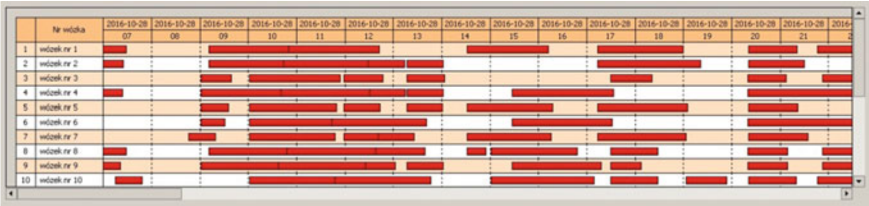

Fig. 10 Fragment of the Gantt chart for 13 forklifts

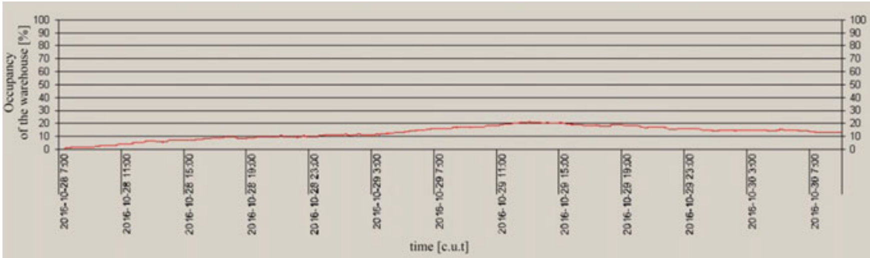

Fig. 11 Percentage occupancy of the warehouse for 10 forklifts

5 Conclusions

The development of material flow in the manufacturing system is one of the most important stages of production planning. The analysis should be submitted to both transport path occurring within factories and external transport infrastructure, ensuring the distribution of finished goods and deliver them to the customer in a timely manner. The use of applications and systems supporting design flow of goods, organization, and management of storage space are an essential convenience for the qualified personnel. In addition, it reduces the likelihood of errors already at the stage of emerging prototypes. The possibilities of an exemplary supporting system designed to simulate the operation of a user-defined high storage warehouse and the benefits of its use were presented in this paper. The results of the investigations were subjected to statistical analysis in order to select the most effective number of transport resources. The increase in the number of forklifts is associated with an increase in the cost of transport resources purchase and their subsequent operation. It has been taken into account in the considered analysis. At the time of determining the number of means of transport, one more aspect should be also included. Namely, more resources require appropriate organization of transport paths so as to avoid crossing paths and ensure collision–free transport. This indicates that use of systems and applications, designed to simulate, only support decision making, so this decision should be supported by additional analysis of the results obtained from these systems.

Acknowledgements This work has been supported by Polish Ministry of Science and Higher Education under internal Grants BK-213/RAu1/2016 for Institute of Automatic Control, Silesian University of Technology, Gliwice, Poland.

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