Journal of Polish CIMAC
Gdansk University of Technology
The Faculty of Ocean Engineering and Ship Technology

ANALYSIS OF THE WORKING PROCESS OF AN AUTOMATED HIGH BAY RACKING SYSTEM

Bogdan Landowski

University of Technology and Life Sciences,
Faculty of Mechanical Engineering
ul. Kaliskiego 7, 85-796 Bydgoszcz, Poland
tel.:+48 52 3408495, fax: +48 52 3408495
email: lbogdan@utp.edu.pl

Andrzej Pawlikowski

Jabil Global Services Poland
ul. Fordońska 248G, 85-766 Bydgoszcz, Poland
email: apawlikowski_ando@wp.pl

Abstract

This paper analyses selected aspects of effectiveness and reliability of one of the supply chain links, i.e. an automated high bay racking system (a stacker crane). The primary purpose of the research was to determine and analyse reliability indicators as well as to assess and analyse characteristics of changes of the working process being carried out. The research was performed according to the passive experiment method in natural operating conditions. The stacker crane and the individual operations of the working process were decomposed for the needs of the research. Identification of the object and subject of the research made it possible to identify significant (for the purposes of the paper) operational states of the investigated stacker crane. The working process being carried out was identified, a model of the working process was built and the performed operations were decomposed within the extent of the research. The paper presents selected results of the research performed.

***Keywords**: automated high bay racking system, effectiveness, supply chain*

1. Introduction

This paper analyses selected aspects of effectiveness and reliability of one of the supply chain links, i.e. an automated high bay racking system hereinafter referred to as the stacker crane. The stacker crane (made by EGEMiN, Breadabaan 1201 B-2900 Schoten) is one of the material supply chain links for the storage areas of the enterprise under investigation. The object of the research is a service enterprise, specialised in repairing electronic devices (laptops, printers, scanners, switches, solar panels, AC adapters, computer screens, digital cameras, DVD players etc.). The enterprise deals with guarantee repairs, and it offers post-guarantee repairs, too.

The logistics processes in so called storage management, covering flow of material goods, creation of reserves as well as creation and processing related information require to have a specified technical infrastructure, consisting of [1, 7]:

- storage structures,
- on-site handling equipment (to transport cargo and manipulate the cargo),
- storage equipment,
- product packaging,
- computation and information technology devices as well as appropriate software.

Short series of products (i.e. laptops, screens), variety of models (about two thousand models), extensive variety of components (about six thousand) with simultaneous necessity to reduce stocks make the enterprise to use automated storage systems. The necessity to optimise personal costs (salary) and storage costs (rate of return of 1 m^2 of the warehouse) make it necessary to apply automated distribution of material, picking and packing orders.

According to the data presented by SSI SCHAFER [9] the cost of storing materials in a warehouse may reach about 40% of the total storage costs. Shortening the time to move the materials according to the principle "a product to an employee" increases productivity. Automated storage equipment may be a crucial element in the cost optimised logistics chain. This equipment is used, among other things, in the logistics subsystems in which short access time to the material being stored is required. The primary tasks of such a warehouse is to receive materials from a supplier, periodic storage, and then successive deliveries of them to satisfy the needs of the service part of the enterprise.

The primary goal was to determine and analyse selected reliability indicators as well as to assess and analyse characteristics of changes of the working process being carried out.

The stacker crane and the individual operations of the working process being carried out were decomposed for the needs of the research. The analysis of the space of the operational states of the stacker crane and the analysed working process made it possible to identify the significant (for the purposes of the paper) operational states of the investigated stacker crane.

The next stage was to perform operational investigations of the stacker crane. The obtained source data concerning the states and operational events were entered into a computer system. The statistical analysis as well as the necessary calculations and data processing were performed by applying the MS Excel programme. The paper presents selected results of the research, calculations and analyses.

2. Research object

The research object is an electronic sector enterprise which provides comprehensive design, production and services for various industrial sectors. The primary place of business of the analysed enterprise is located in St. Petersburg, Florida, USA.

The analysed division of the enterprise employs some 650 people now. The area of the facility is about 21,500 square meters, divided into halls designated as A, B, C, D. Each of them is equipped with an incoming warehouse, a service hall, an outgoing warehouse. Logistics solutions:

1. Automated warehouse of components for all the projects.
2. Separated incoming warehouse and outgoing warehouse (finished goods) for the specific project.
3. Access to the warehouses through loading docks.
4. Global storage programme – Xelus Parts Planning (planning the components for 1 to 3 months; preparing the stock of components for new models with appropriate advance).
5. Advanced IT system, integrated service, storage and accounting programme enables to check the repair status in real time via WWW site.
6. Global agreement with the courier company UPS, DHL:
    a) all the parcels are insured,
    b) simplified complaint procedure,

c) fixed time of deliveries of parcels to the division: at 8:00 a.m., collection of parcels at 8:00 p.m. (road transport / air transport),
d) guaranteed time of delivering parcels, at the latest within 24 hours.

The investigated stacker crane is an automatically controlled, single aisle rail guided stacker crane, intended to store small components.

A typical rail guided stacker crane is made of the following parts:

- a beam connected with the traction assembly to move the stacker crane along the racks and power rail fixed to the warehouse flooring,
- a post connected with the traction beam and equipped with the parts fixing it to the rack structure in its upper part,
- trolley moving vertically with a catch (tray) for cargo (container),
- electric driving and controlling system.

The stacker crane (Fig. 1, Fig. 2) consists of a working aisle in which a single-mast trolley moves guided by steel rails, and on both side of the aisle racks are installed. The order picking and packing as well as the container handling area, equipped with conveyors, is positioned at the beginning of the racking system. The stacker crane leaves the cargo taken from the rack at this place. Then the conveyor takes a container to the operator (warehouse operative) and after completing the operator's task (for instance taking one item of the order) the container, after scanning the code, is moved back the rack place. The equipment is controlled by the computer programme based on the WMS (Warehouse Management System) which registers location of all the materials in the warehouse, and records them on real time basis.

The structudre of the equipment is designed to handle cardboard boxes, steel trays or containers as cargo carriers. Materials (electronic components) are stored in containers. The stacker crane is equipped with a set of sensors allowing, from the operator's place, to interact with the environment – performance of a transport task. The executive elements are motors: for the X axis (along the movement aisle), for the Z axis (vertical movement – lifting the tray) and for the Y axis (trolley with the tray – inserting a contained into the racking system). The operator controls, by means of the computer system, the operations "Bring", "Send back"(this operation consists of scanning the tray code and sending the tray back) as well as the operation "Transport" (organizational changes in the warehouse), however picking and packing all the product groups takes place according to the ABC rule (the operator in the electronic register finds an index of the component ordered by a technician).

The basic tasdk of the stacker crane is to receive materials from a supplier, periodic storage, and then successive deliveries of them from the warehouse to satisfy the needs of the service part of the enterprise.

Fig. 1. View of the stacker crane from the operator's side (own work)

Fig. 2. View of the telescopic platform (own work)

3. Selected research results

The research was performed according to the passive experiment method in natural operating conditions.

The selected results of the research presented herein refer to 17 selected exemplary so called working days. The working process being carried out was identified, a model of the working process was built and the performed operations were decomposed within the extent of the research. The following operations of the working process were distinguished and analysed:

- Bring (Fig. 3 shows decomposition of the operation),
- Send back – including scanning the tray number,
- Transport,
- Reject.

The selected research results presented herein refer mainly to the random variables denoting:

- the number of the analysed primary operations and their components,
- the duration of the distinguished operational states of the stacker crane.

The sum of all the correct and incorrect operations, within the time interval under investigation, was 11,448, of which wrong operations amounted to 3,978 and represent about 35% of all the operations.

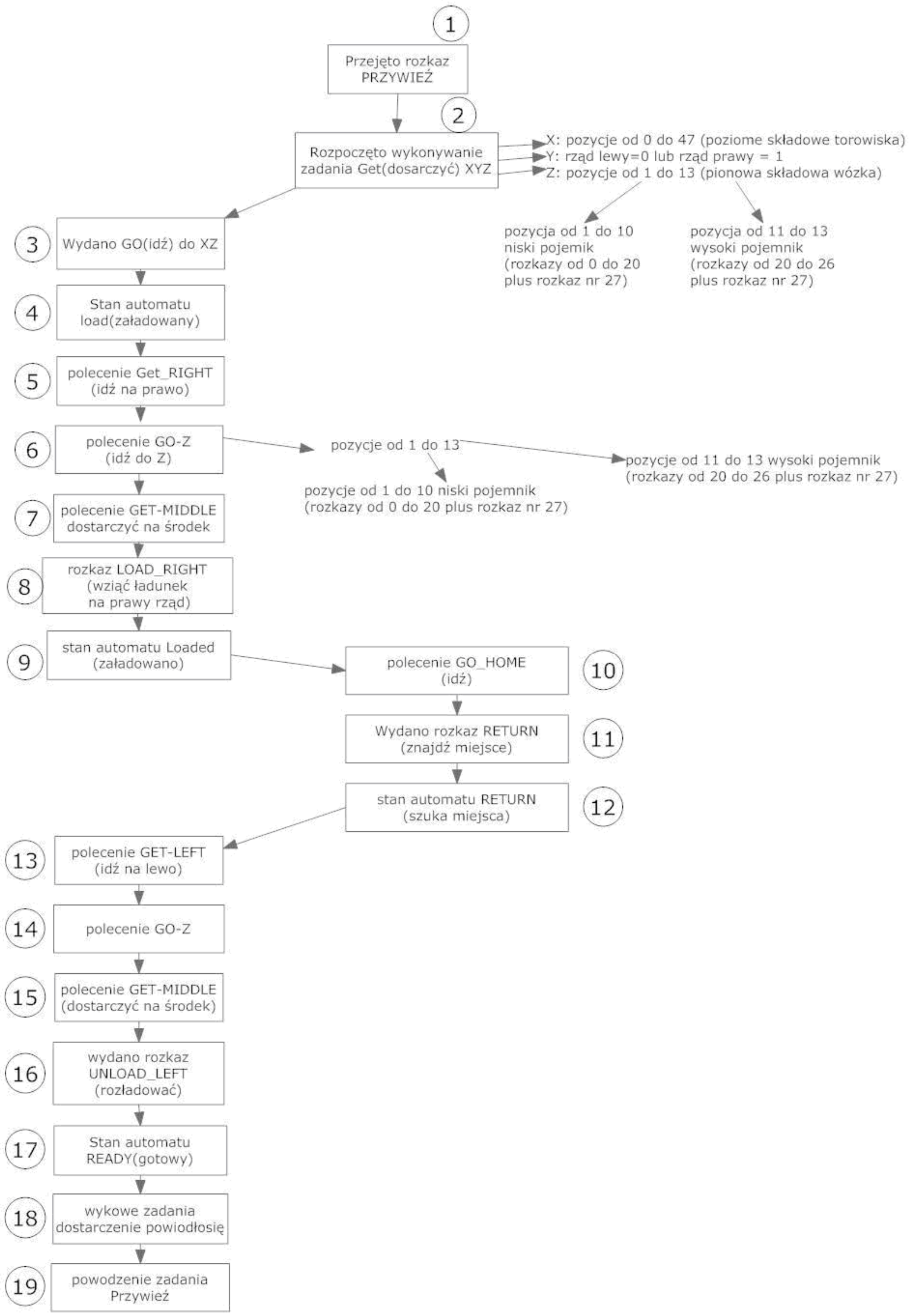

Fig. 3. Decomposition of the command Bring (own work)

The codes and abbreviations used later on in the paper (including the ones in the tables and on the diagrams) stand for:

- B1 – error code: Error! Performance of the command Bring,
- B2 – error code Error! Coordinates XYZ outside the range,
- B3 – error code Error! Number of the tray outside the range,

- B4 – error code Error! Failed to read the file with the shelf base,
- B5 – error code Error! Performance of the command MAN,
- B6 – error code Error! Performance of the command Send back,
- O-1 – code of the operator 1,
- O-2 – code of the operator 2,
- O-3 – code of the operator 3,
- O-4 – code of the operator 4.

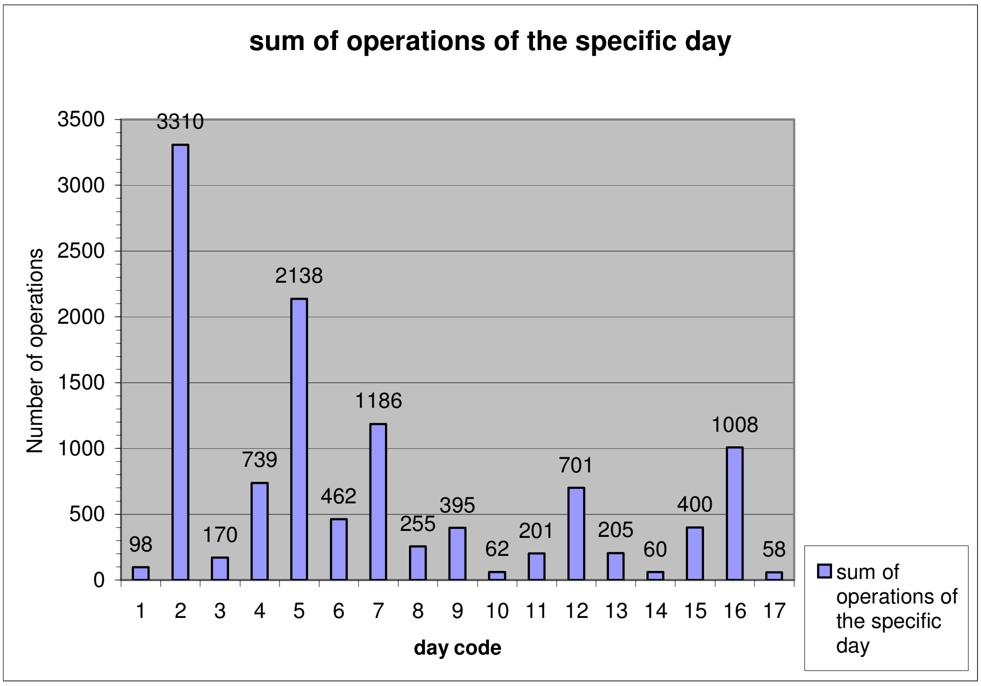

Fig. 4. Number of operations (own work)

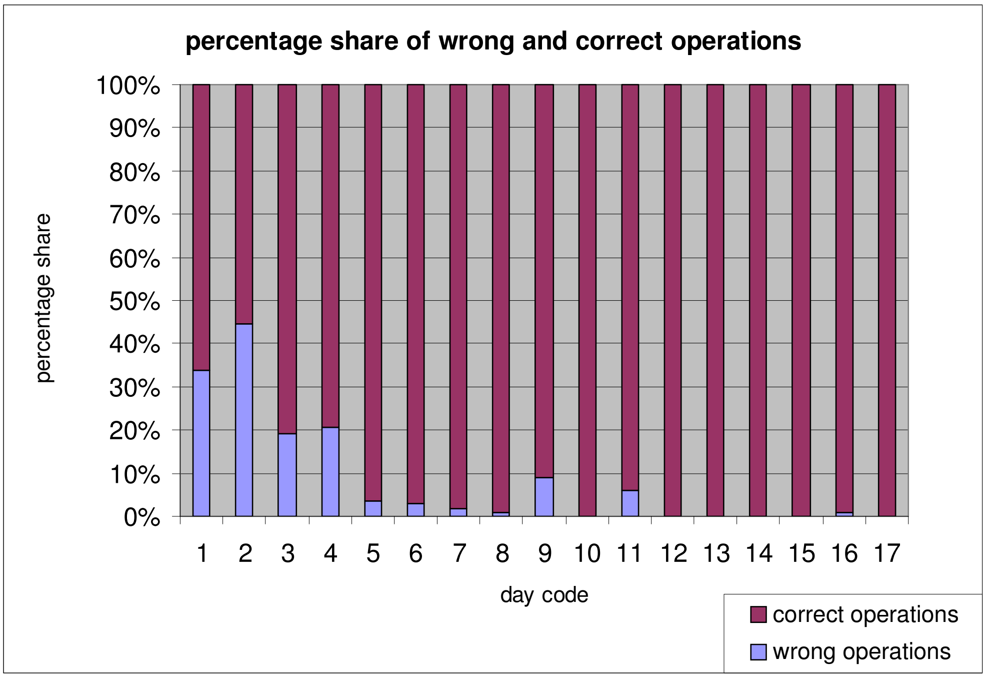

Fig. 5. Percentage share of wrong and correct operations in total number of the operations (own work)

The paper presents selected results of the research concerning duration of the analysed operations of the working process and their components later on. The following designations were applied:

- T_1 – duration of wrong operations (duration of the state S1 – operational state, in which the object wrongly performs the working process operations),
- T_2 – duration of correct operations, (duration of the state S_2 – operational state, in which the object correctly performs the working process operations),
- $T_{2/1}$– duration of the operations correctly performed, designated as “others” – starting the controller work, initiation of the object work, changing the server status, ending the controller work (duration of the state S_{21} – operational state (sub-state of the state S_2), in which the object correctly performs the working process operations designated as “others”),
- $T_{2/2}$– duration of correctly performed operation Scanning the tray (duration of the state S_{22} – operational state (sub-state of the state S_2), in which the object correctly performs the operation Scanning the tray of the working process),
- $T_{2/3}$– duration of correctly performed operation Send back (duration of the state S_{23} – operational state (sub-state of the state S_2), in which the object correctly performs the operation Send back of the working process)
- $T_{2/4}$– duration of correctly performed operation Bring (duration of the state S_{24} – operational state (sub-state of the state S_2), in which the object correctly performs the operation Bring of the working process)
- $T_{2/5}$– duration of correctly performed operation Transport (duration of the state S_{25} – operational state (sub-state of the state S_2), in which the object correctly performs the operation Transport of the working process)
- $T_{2/6}$– duration of correctly performed operation Reject (duration of the state S_{26} – operational state (sub-state of the state S_2), in which the object correctly performs the operation Reject of the working process),

where:

$$T_2 = \sum_{i=1}^{6} T_{2/i} \tag{1}$$

- T_3 – waiting time to perform the task (duration of the state S_3 – operational state, in which the object waits for performance of the task).

Moreover, values of the following indicators were determined:

W_1 – effectiveness indicator:

$$W_1=T_2/(T_2+T_3) \tag{2}$$

W_2 – readiness indicator:

$$W_2=(T_2+T_3)/(T_1+T_2+T_3) \tag{3}$$

The selected results of the research are presented in the figures from 4 to 6 and in the tables from 1 to 3.

Tab. 1. Percentage share of duration of the analysed states (own work)

Day code	**State code**		
	S_1	S_2	S_3
1	0.099	0.077	0.825
2	0.077	0.232	0.691
3	0.004	0.227	0.769
4	0.002	0.159	0.841
5	0.021	0.680	0.299
6	0.122	0.063	0.815
7	0.021	0.087	0.892
8	0.000	0.046	0.954
9	0.068	0.034	0.898
10	0.000	0.005	0.995
11	0.005	0.076	0.919
12	0.000	0.081	0.919
13	0.000	0.022	0.978
14	0.000	0.005	0.995
15	0.000	0.053	0.947
16	0.021	0.047	0.932
17	0.000	0.991	0.009
Sum	0.025	0.145	0.83

Tab. 2. Types of errors (own work)

	Error code						
Day code	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**Sum**
1	34				16		50
2	709	41	2156				2906
3	76		1	8			85
4	372	1					373
5	102		4	2		48	156
6					100		100
7	42				9		51
8			2				2
9	35				102	21	158
10							
11	16				35		51
12							
13							
14							
15							
16	20				26		46
17							
Sum	1406	42	2163	10	288	69	3978

Tab. 3. Values of the selected indicators (own work)

Day code	State code				Indicator code		State code					
	S1	S2	S3				S2/1	S2/2	S2/3	S2/4	S2/5	S2/6
	Summary duration						Summary duration					
	T1	T2	T3	Suma			T2/1	T2/2	T2/3	T2/4	T2/5	T2/6
	hours:minutes:seconds				W1	W2	hours:minutes:seconds					
1	0:07:34	0:05:53	1:03:12	1:16:39	0,09	0,90	0:05:53	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00
2	0:36:17	1:49:51	5:27:08	7:53:16	0,25	0,92	1:49:51	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00
3	0:01:16	1:20:02	4:30:42	5:52:00	0,23	1,00	1:20:02	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00
4	0:00:59	1:13:45	6:30:58	7:45:42	0,16	1,00	1:13:45	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00
5	0:08:33	4:33:08	2:00:08	6:41:49	0,69	0,98	3:54:08	0:03:32	0:17:59	0:15:15	0:01:21	0:00:53
6	0:47:06	0:24:27	5:14:28	6:26:01	0,07	0,88	0:15:27	0:00:44	0:03:10	0:05:06	0:00:00	0:00:00
7	0:08:33	0:36:14	6:10:56	6:55:43	0,09	0,98	0:00:44	0:00:38	0:02:57	0:31:55	0:00:00	0:00:00
8	0:00:00	0:07:34	2:35:59	2:43:33	0,05	1,00	0:00:00	0:00:11	0:00:52	0:06:31	0:00:00	0:00:00
9	0:12:19	0:06:14	2:43:54	3:02:27	0,04	0,93	0:00:20	0:00:24	0:02:39	0:02:51	0:00:00	0:00:00
10	0:00:00	0:01:47	5:25:13	5:27:00	0,01	1,00	0:00:00	0:00:05	0:00:27	0:01:15	0:00:00	0:00:00
11	0:01:16	0:20:00	4:01:15	4:22:31	0,08	1,00	0:16:52	0:00:27	0:00:59	0:01:42	0:00:00	0:00:00
12	0:00:00	0:18:06	3:24:02	3:42:08	0,08	1,00	0:00:03	0:01:26	0:07:22	0:09:15	0:00:00	0:00:00
13	0:00:00	0:05:19	3:55:37	4:00:56	0,02	1,00	0:00:00	0:00:25	0:02:08	0:02:46	0:00:00	0:00:00
14	0:00:00	0:01:44	5:43:30	5:45:14	0,01	1,00	0:00:00	0:00:05	0:00:29	0:01:10	0:00:00	0:00:00
15	0:00:00	0:23:59	7:04:59	7:28:58	0,05	1,00	0:06:12	0:00:48	0:04:53	0:12:06	0:00:00	0:00:00
16	0:13:29	0:30:12	9:57:15	10:40:56	0,05	0,98	0:05:42	0:02:00	0:10:25	0:12:05	0:00:00	0:00:00
17	0:00:00	1:13:29	0:00:42	1:14:11	0,99	1,00	1:12:26	0:00:05	0:00:25	0:00:33	0:00:00	0:00:00
Sum	2:17:22	13:11:44	75:49:58	91:19:04	---	---	10:21:25	0:10:50	0:54:45	1:42:30	0:01:21	0:00:53

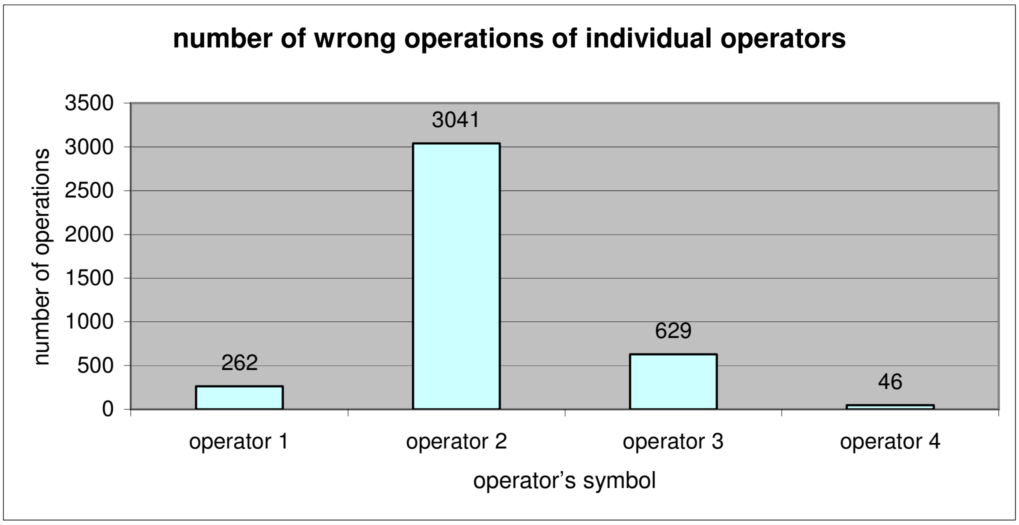

Fig. 6. Number of wrong operations, split into the specific operator (own work)

4. Summary and final conclusions

A stacker crane and the working processes being performed in a real operating system were decomposed for the needs of the paper. On the basis of the research it was found that the EGEMiN post stacker crane was characterised by the following values of duration of the analysed states during the time interval under investigation:

- S_1 – 2 hours 17 minutes 22 seconds (performance time of wrong operations), which represents 3% of the total working time of the stacker crane;
- S_2 – 13 hours 11 minutes 44 seconds (performance time of correct operations), which represents 14% of the total working time of the stacker crane;
- S_3 – 75 godzin 49 minutes 58 seconds (waiting time to perform the task), which represents 83% of the total working time of the stacker crane.

The sum of all the correct and incorrect operations, during the time interval under investigation, was 11,448, of which wrong operations amounted to 3,978, which represents about 34.7% of all the operations. The nominal time of the operator's work (warehouse operative) is 136 hours, the actual time of work of the stacker crane is 91 hours 19 minutes 4 seconds, which represents about 67.1% of the nominal time of the operator's work.

The total duration of the operations Bring, Send back (including the tray scanning), Transport, Reject as well as other operations (changing the server state, starting the controller work, ending the controller work, etc.), represents 14% of the working time of the equipment. The duration of the state of the object waiting to perform the tasks Bring, Send back (including the tray scanning), Transport, Reject represents 83%, and of the wrongly performed operations is 3% of the object working time. The average value of the analysed effectiveness indicator W_1 of the stacker crane in the time interval under investigation was 17%.

It was observed that the operator designated with the code O1, performed wrong operations much more frequently than the other operators. The percentage share of the errors caused during the work of the operator designated with the code O1, in the total number of wrongly performed operations is 76.4% of wrong operations for the time interval under investigation. Additional investigation of the reasons for performing wrong operations by the operator designated with the code O1 should be considered.

Liquidation of the investigated fixed asset (the EGEMiN stacker crane) should be considered due to low level of use (the ratio of the effective working time of the stacker crane to the time of the operator's work <the shift duration>).

It seems that the elaborated method to analyse the operation and maintenance process of the analysed stacker crane, performed in the research object, the element of which is the compiled set of the patterns of the spreadsheets (containing, among other things, calculation formulas for automatic determination of values of the analysed indicators) is a useful tool to assess effectiveness and readiness of the investigated EGEMiN stacker crane. By using the created pivot tables of the MS Excel programme it is possible to obtain data from the files of the controlling programme of the stacker crane (Log module) and process them automatically in order to obtain results in the form of a set of the indicators and a presentation of the results in a graphical form.

The results of the performed work as well as the remarks and observations made when identifying the research object and subject and when performing the research work were handed over to the decision makers of the analysed enterprise. Their effect was an introduction of changes to the work organisation, modification of the operating process of the investigated stacker crane and modification in the enterprise management subsystem.

References

[1] Abt S., *Systemy logistyczne w gospodarowaniu. Teoria i praktyka logistyki*, Wydanie II, Wydawnictwo Akademii Ekonomicznej, Poznań 1997.

[2] Aldag R. J., Stearns T. M., *Management*, South Western Publishing Co., Cincinnati 1987.

[3] Blokus-Roszkowska A., Kołowrocki K., Kwiatuszewska-Sarnecka B., Soszyńska J., *Modelowania niezawodności i bezpieczeństwa złożonych systemów i procesów*, Problemy

niezawodności systemów XXXV Zimowa szkoła niezawodności, Wydział Transportu Politechniki Warszawskiej, Szczyrk 2007.

[4] Bukowski L., *Prognozowanie niezawodności i bezpieczeństwa systemów zautomatyzowanych*, Problemy niezawodności systemów XXXI Zimowa Szkoła Niezawodności, Wydział Transportu Politechniki Warszawskiej, Szczyrk 2003.

[5] Coyle J. J., Bardi E.,, Calvinato J. L., *Transportation*, West Publ. Co., New York 1990.

[6] Dokumentacja techniczno-ruchowa CRC, EGEMIN, Holandia 1993.

[7] Fijałkowski J., *Transport wewnętrzny w systemach logistycznych - wybrane zagadnienia*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2000.

[8] Krawczyk S., *Zarządzanie procesami logistycznymi*, PWE, Warszawa 2001.

[9] Malanowska I., Fajfer P., *Zastosowanie nowoczesnych technologii dla zwiększenia efektywności zarządzania magazynem*, E-mentor nr 2 (39)/2011 (www.e-mentor.edu.pl/artykul/index/numer/39/id/833).

[10] Woropay M., Knopik L., Landowski B., *Modelowanie procesów eksploatacji w systemie transportowym*, Biblioteka Problemów Eksploatacji, Bydgoszcz-Radom 2001.