SIMULATION RESEARCH ON THE TOOL CYCLE IN AUTOMATED MANUFACTURING SYSTEM AT SELECTED TOOL DUPLICATION LEVELS

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Summary

The paper presents results of the research concerning impact of applied tool exchange rule on the efficiency of an automated manufacturing system. The research consider the tool duplication levels that constrain realisation of a manufacturing process. Presented study was based on the real industrial system data. The operating of the investigated system of manufacture, including tools necessary for its realisation, was modelled and programmed. Experimental research was conducted with event-driven simulation software. Various output data were collected from the experiments such as performance measures of alternative tool exchange rules.

Keywords: tool cycle, modelling and simulation, automated manufacturing, cutting tool, CNC machining centre

Symulacja procesu obiegu narzędzi w zautomatyzowanym systemie wytwarzania dla wybranych poziomów duplikacji narzędzi

Streszczenie

W artykule przedstawiono wyniki badań dotyczące oceny wpływu stosowanej reguły wymiany narzędzi na efektywność zautomatyzowanego systemu wytwarzania. Uwzględniono poziomy duplikacji narzędzi stanowiące ograniczenia podczas realizacji produkcji. Przedstawiono studium przypadku o danych z rzeczywistego systemu przemysłowego. Opracowano model i oprogramowano działanie poddanego analizie systemu wytwarzania wraz z obiegiem koniecznych do realizacji procesu obiegu narzędzi. Badania eksperymentalne wykonano z użyciem oprogramowania umożliwiającego symulację zdarzeniową. Wyniki eksperymentu przyjęto jako dane wyjściowe – miary efektywności alternatywnych reguł wymiany narzędzi.

Słowa kluczowe: obieg narzędzi, modelowanie i symulacja, zautomatyzowane wytwarzanie, narzędzia skrawające, centra obróbkowe CNC

1. Introduction

Main activities of the tool management are reduced to three levels: the tool level, the machine level and the system level [1]. Tasks of the tool level are

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strictly connected with technological aspects, i.a. the tool construction, the tool and workpiece material and the machining parameters [2]. At this level there are also taken decisions covering tool standardisation, monitoring real-time tool data as well as adaptive processes planning. At the machine level, there are determined technological capabilities of machine tools, connected i.a. with tool storing, tool switching between the storage of machine tool and its spindle, exchange of tools between the storage located by the machine (buffer tool storage) and the central tool storage, and the monitoring of conditions of the tool when machining. Typical decisions made at the machine level are the concurrent sequencing of parts and tools, the allocation of tools to tool slots of the machine tool storage and the tool exchange rules [3, 4]. At the system level, decisions concerning selection of the layout and structure of supply, storage and tool transportation systems are made. Activities at this level cover planning of tool requirements, spare tools management, allocation of tools to particular machine and scheduling of the tool exchange. As it can be noticed, the research area concerning tool cycle management covers a very wide scope of organisation and technical issues [5, 6]. Particular aspects of both general and detailed significance have been dealt by many researchers [4, 7-9]. One of the problems they have encountered, is application of computer modelling and simulation in design and investigation of the tool cycle. Developing of even the most simple model of manufacture and the reliable algorithm of its functioning is too difficult. This results from the considerable degree of complexity of such systems. On the basis of analytical computing only, selection of numerous parameters that influence the work of the manufacturing process is difficult. Thus, in research of the manufacturing process, both computer modelling and simulation have a significant meaning [10-12]. Such methods enable realization of the series of experiments covering the whole aspects of the tested system as well as analyses of the impact of particular parameters on the process throughput.

2. Research framework

The object of research was the automated manufacturing system. It was designed to manufacture diversified part mix on three milling-boring machining centres. The studies covered the workpiece spectrum comprising of 62 different parts (prismatic parts, bodies), and data applying to parts and tools were acquired from real process plans. During the investigation, production jobs are defined as a quantity of palletized and fixtured parts. Such a pocket was completely processed by a single machining centre. All machining centres are of similar process capability. They can perform all the processes required with every part type in the work list. This enables allocation of any job to any machine. Jobs are assigned to machines and then sequenced according to the user set priorities, whereas tool allocation and flow are determined by the work schedule i.e. Advanced Planning and Scheduling (APS) heuristic with minimum work in process (WIP) rates. Jobs are loaded principally under push paradigm in such a manner as to ensure the workload balance across machines included in a system whilst meeting user's set priorities and objectives. The sequence of throughput dictated by job allocation rules establishes the sequence and timing of the tool set exchange activity. The tools are assigned to particular machines dynamically and gradually when the progress of production is being realised The analysis is carried out with the number of tool duplicates equal to the number of machines (TDL = 3) and variable tool duplication level determined for each individual tool type based on calculations presented, e.g. by Mohamed [9].

The three exchange rules are considered:

- CTE (Complete Tool Exchange): complete set of tools has to be returned when the machine tool has finished processing of a particular job.
- PTE1 (Partial Tool Exchange v.1): when the machine tool has finished processing a particular job all tools needed for a subsequent job remain in the local tool storage of the machine. All redundant tools have to be returned.
- PTE2 (Partial Tool Exchange v.2): when the machine tool has finished processing a particular job, all tools needed for some subsequent jobs in the work list remain in the local tool storage of the machine. All redundant tools have to be returned.

3. Modelling the part and tool flow in automated manufacturing system

System was modelled with the Witness® software by Lanner Group. In the model of a part flow, there were specified elements connected with the semi-finished and finished products storage system, the parts transportation and handling system, and components of individual machining centres. These model elements, related to one of the centres are presented in Fig. 1. Information covering the job list, lot sizes and arrival times are included in partfiles, whereas data related to the technological process (processing time, setup time, batch size etc.) were imported with the function *If Type Return Value*.

In each machining centre, the queue of realisation of machining jobs was maintained in accordance with previously assigned sequence. It was provided by the sequence rule in the form of *Sequence /failure_option location1*, *location2 {,location3...}*. Each location is in the format: *{element_name} location_name {(index_exp)} {at position_exp} {with labor_name {#labor_qty}} {using Path} {#element_qty}*. There was also applied *Wait failure_option* , the effect of which was that the machining centre waited until input of palletized parts was possible. The sequence is strictly maintained that the one obtained using Advanced

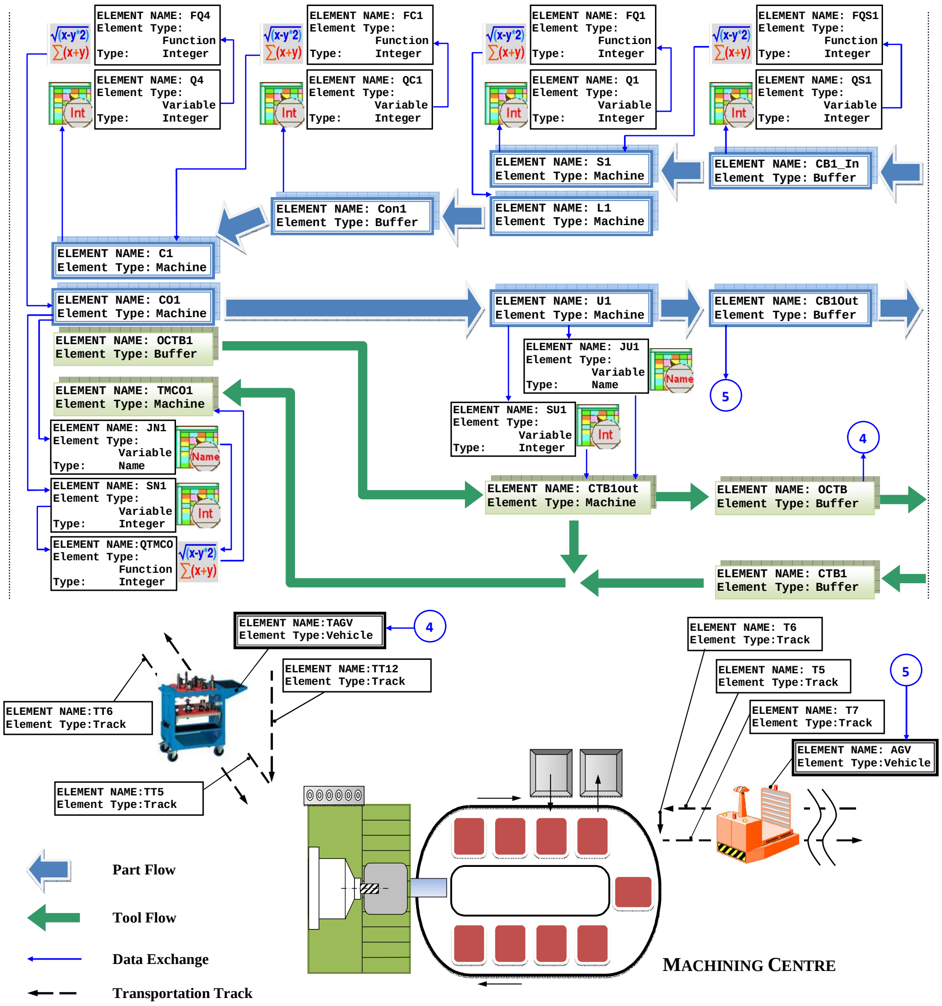

Fig. 1. Diagram of a programmed model of the manufacturing station based on a milling-boring machining centre

Planning and Scheduling (APS) heuristic with minimum work in process (WIP) rates. Supplying the machining centres with tools required to process parts of a particular type went on accordingly to one of the assumed rules of the tool exchange. The rule applied here was *Match/qualifier part_name from location_name(location_index) #(part_qty)*, which provided the load of tools to the machine tool storage from the buffer tool storage. The tools were delivered to the buffer storage, which was located in the machining centre, by the use of the special manufacturing tool trolleys. In the model of the tool cycle, there were specified a central tools storage and a tools transportation system (Fig. 2). To increase the usage of particular tools in the central tool storage, priorities were taken into consideration. The top priority was given to tools that were in the system.

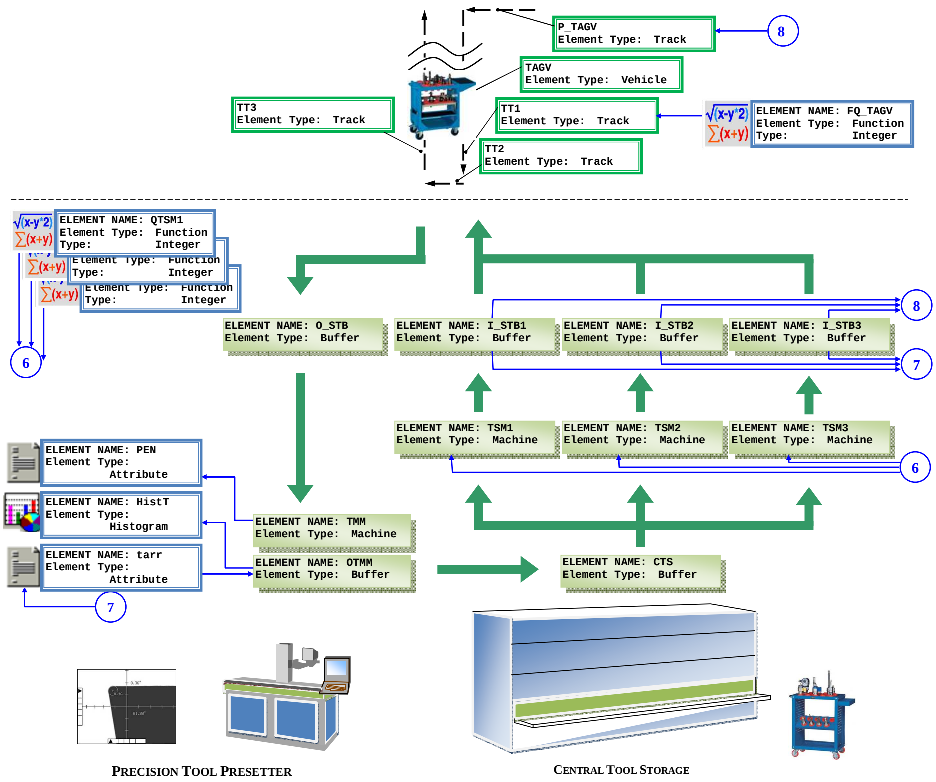

Fig. 2. Diagram of a computer model of machining tools cycle elements

The station for tools maintenance and pre-setting worked in the cycle described by a uniformal distribution, whereas tool trolley and vehicle (part transportation device) were driving with the speed described by the triangular distribution. In such a way, i.a. working and idle transfers were taken into account. To request a tool trolley to load tools at one track and unload them at another, the *Call* action was applied. Follow the *Call* action with a *VSearch* action, which creates a list of tracks that the model must search for a tool trolley and vehicle that can satisfy the request. If a transportation device cannot satisfy the request immediately, the model stores the request and the list in the device's demand list so that the tool trolley or the vehicle can satisfy it later.

4. Simulation studies and experimental results

Three tool exchange rules and two tool duplication levels have been extensively studied in the industrial layout and for a given production process characteristics, using simulation programmed in the Witness® software package.

The following additional assumptions are made for the need of performed simulation studies:

- cycle times, compound of machining time, part handling and set-up time while queuing are as provided in related process plans,
- work list for the determined production period remains unchanged during it,
- tool storages capacity and the tool life are considered as a limitation,
- tool exchange time is assumed to be included into related machine set-up times.

In the simulation all the machines use the sets of tools as demanded by jobs assigned to them. Simulation modelling and analysis is conducted under defined scenarios and consequently with the use of methods outlined in the previous section.

Applying the Partial Tool Exchange rule for duplication level equal to the number of machines resulted in shortening of the manufacturing cycle (Fig. 3). Machining centres do not have to wait for delivering tools from the central tool storage. The number of exchanged tools was smaller, and consequently the time was shorter. The results acquired for variable tool duplication system indicate a significant impact on the limited number of copies on the elongation of the manufacturing cycle, independently of the applied tool exchange rule.

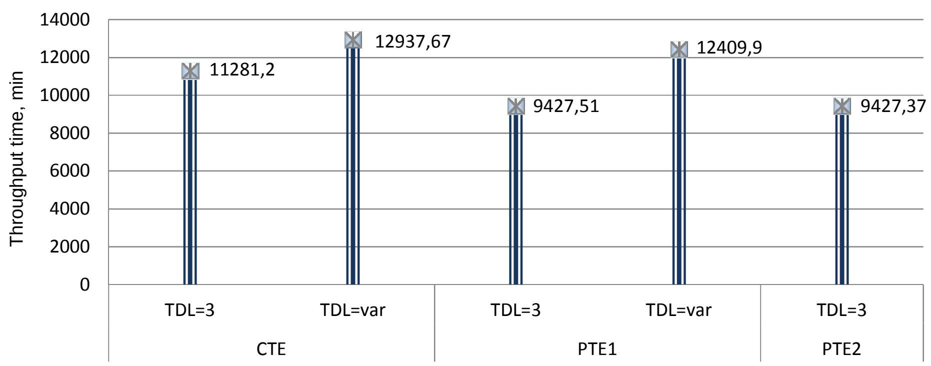

Fig. 3. Throughput time obtained for considered tool exchange rules and tool duplication levels

The extreme case was the model blockage during simulation of the second version of Partial Tool Exchange rule. It arose from mutual blockage of manufacturing centres. Let's consider the following case. There are given tools T1 (TDL = 2) and T2 (TDL = 2), which are the tools included in tool sets needed for processing three various types of parts being processed or just awaiting for processing in manufacturing centres. MC1 requests demand for tool T1, which is in tool storage MC2 and MC3, whereas MC2 requests demand for tool T2, which is in tool storage MC3 and MC1. Then, mutual blockage of tools takes place, which results from too small number of copies of one of tools. In real conditions, an arbitrary decision complementing the tool set has to be taken. In this paper, such an action was not undertaken due to discretion of such a decision that would interfere the research methodology.

Table 1. The system productivity for the considered cases

Value	**System productivity [piece/h]**				
	CTE		**PTE1**		**PTE2**
	TDL = 3	**TDL = var**	**TDL = 3**	**TDL = var**	**TDL = 3**
Mean	5,127	4,486	6,132	4,681	6,132
SD	7,0324	6,8469	7,2103	5,8992	7,3425
Min	0	0	0	0	0
Max	32	32	33	32	38

In other cases, applying the variable level of duplication caused extending the production period with regard to results obtained for the level of duplication equal to three. The productivity of the system was also substantially lower in these cases. However, maximum values were obtained for partial tool exchange (Table 1). The level of utilisation of the means of transport of the part is presented in Fig. 4-5. As it can be noticed, the highest share of the

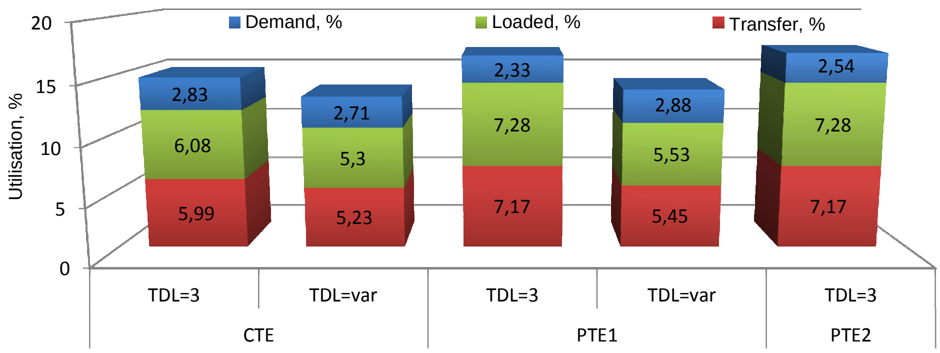

Fig. 4. Utilisation of the part transportation device in a system according to the selected tool exchange rules and selected tool duplication levels

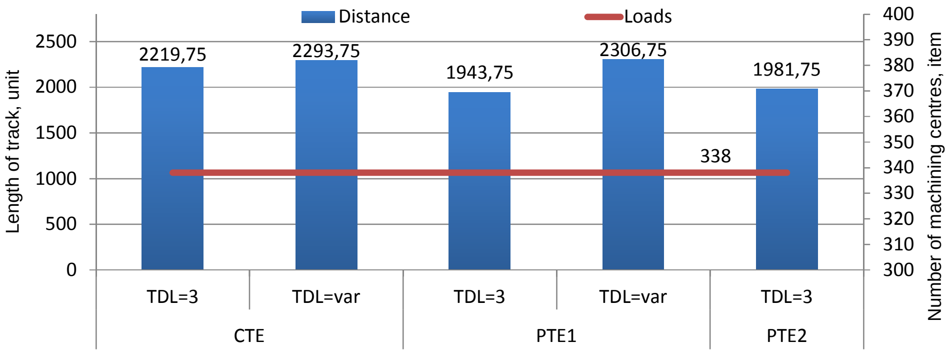

Fig. 5. Length of tracks covered by the vehicle referred to the total number of machining centres loads

loading/unloading, as well as the transport of parts in the utilisation of the vehicle appeared for both versions of the PTE rule and the level of duplication TDL = 3. However, for the constant value of the number of loadings, the track covered by the part transportation device was the longest for CTE and PTE1 v.2 at the variable level of the tools duplication. Differences in the length of the covered tracks by the vehicle result mainly from the changing sequence of the parts processing and various places of parking after loading/unloading.

The level of utilisation of individual machining centres was ranging within the limits of values met in industrial practice (Table 2). There was also obtained very good workload balance across machine tools included in a system. This indicates correctly made previous scheduling of production jobs with the application of the APS rule. Utilisation of machining centres in cases of the application of the partial tool exchange rules was about 10% higher comparing to the complete tool exchange. The percentage share of set-ups changed in a wide range from about 9% to over 20%. Apart from the contribution of the number of exchanged tools in set-ups, a diversified number of parts introduced to machining in the fixture was significant. The fixtures were uniparts for large parts (bodies) and multiparts for small products (the maximum capacity of the fixture was 16 parts). This resulted in diversifying the labour intensity of assembling and dismounting products in the fixture, and therefore in increasing the share of set-ups in general utilisation of the machine.

As it hab been mentioned earlier, the processing time of the measurement and tool pre-setting station was sampled from uniformal distribution. Number of realised operations conducted by tool presetter in the framework of the defined exchange rule was approximately the same. However, applying version 2 of PTE rule caused the reduction in the number of these operations comparing to CTE, and twofold comparing to PTE v.1. The station was reduced proportionally to these values (Fig. 6).

Table 2. Machining centre utilisation in a system by the total production cycle

		CTE		PTE1		PTE2
		TDL = 3	TDL = var	TDL = 3	TDL = var	TDL = 3
MC1	Busy, %	59,86	52,2	71,63	54,42	71,63
	Setup, %	10,9	9,51	13,05	9,91	13,05
MC2	Busy, %	59,79	52,13	71,54	54,35	71,54
	Setup, %	13,79	12,03	16,5	12,54	16,51
MC3	Busy, %	59,09	51,53	70,71	53,72	70,71
	Setup, %	17,37	15,15	20,79	15,79	20,79

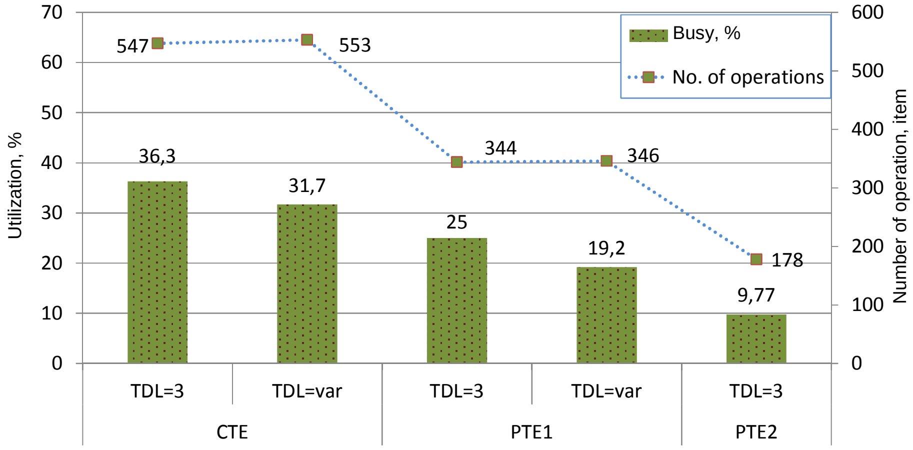

Fig. 6. Utilisation and relevant number of performed operations of the measurement and the tool pre-setting station

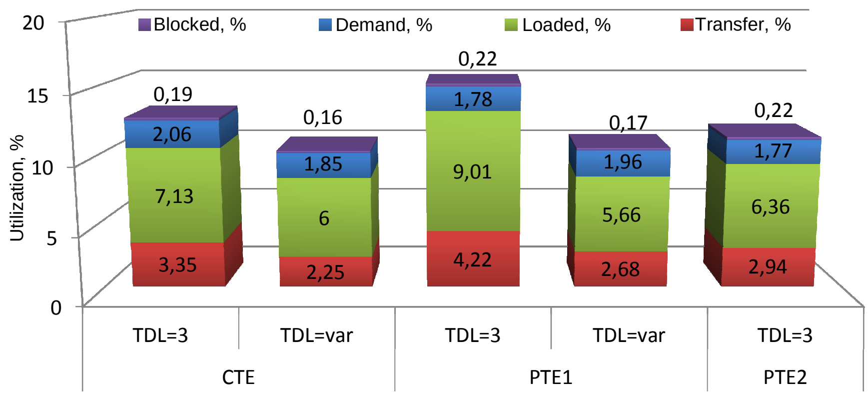

Fig. 7. Utilisation of the tool trolley according to the selected tool exchange rules and selected tool duplication levels

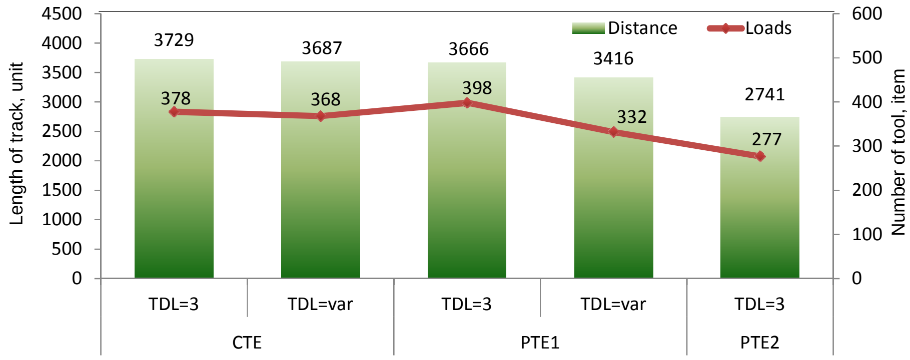

Fig. 8. Length of tracks covered by the tool trolley and received number of tool load/unload instances

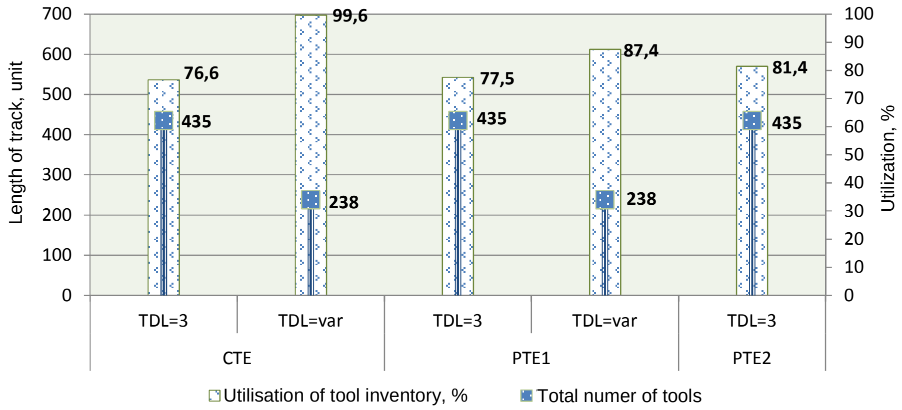

Fig. 9. Total number of tools in the system and utilization of tool inventory for considered tool exchange rules and tool duplication levels

Theoretically, the complete tool exchange should cause the highest load of the means of transport. However, analysing the obtained results from Fig. 7-8, it can be noticed that such a tendency does not exist. The highest load appeared for TDL = 3 and v.1 of the partial tool exchange, but the values obtained in other cases were close. However, the loads/unloads number was the smallest for v.2 of partial tool exchange and TDL = 3. In this case, the distance covered by a cutting tool trolley was about 25-35% smaller than in other cases. The cause of such divergences are the operations whose job is collecting the used tools from machining centres. For example, in the case of partial tool, fewer tools were transported, what increased the load of the tool transport system.

Considering the resources of available tools in the system it can be stated that, as expected, the best system exploiting appears for the change able level of duplication (Fig. 9). The total number of tools in the system was in this case the smallest. In other cases utilisation of the tool resources was about 75%, which from the practical point of view, proves making good initial assumptions.

5. Conclusions

The main purpose of this paper was describing the relation between the accepted level of tools duplication and acquired effectiveness of the automated manufacturing system. The results were referred to the accepted and defined rules of the tools exchange. Models of the flow of tools in the automated manufacturing system were described. Programming the number of procedures enabled to perform simulation experiments.

As it can be noticed, accepting the level of the duplication of tools different from the one equal to the number of machines in the system, worsens measures selected in the research performance. However it should be noticed that the number of used tools is nearly twofold smaller, and their utilisation is at the very high level (87-99%).

The question not answered yet is how to establish individual tool duplication levels (in the paper, the algorithm presented in [11] was adopted). It should result from some kind of compromise between the frozen capital in tools and the effectiveness of the system acquired from the tool usage.

“This research work was financed by the funds for research in 2009÷2012 as a research project”.

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Received in March 2012