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DESIGN FOR A HYBRID SINGLE MULTI-LOAD AGV[1] SIMULATION SYSTEM WITH ARTIFICIAL INTELLIGENCE CONTROLLER

Abstract

This paper presents a simulation model of multi-load AGV system with artificial intelligence controller that is dedicated to be used in work transport control. The single AVG system with multi-load mean of transport is obtained assuming that the carrier capacity is big-enough to carry many lots at the single route. This model consists of a fuzzy logic and a genetic algorithms technics that minimize the total costs including transportation, setting up pick-up and/or delivery stations, and material handling devices. An example of \implementation of the model is given. The simulation experiment is conducted and the results are presented.

1. INTRODUCTION

Works transport is an important aspect of the operation of production systems, as well as other systems in which there is a movement of goods and people. Analyzing the progress and development of works transport systems we can note the growing importance of automatic guided vehicles (AGV), as an efficient and yet economical medium of transport.

A number of AGV application areas and AGV variants and types are growing fast. In production systems, depending on the profile of production, vehicles are typically used to carry parts and materials. It is estimated that in the year of 2000, in the industry, over 20 thousand various types of AGVs was used [1].

The use of AGVs is cost-effective for systems with specific transport routes. Examples of such systems are the goods distribution centers and ports, handling systems, sorting centers, etc. Such AGVs are applicable in internal (indoor) transport systems. Typically they are designed to transport of the pallets between the various pick/delivery nodes, such as the unloading ramp, storage and sorting systems, loading ramp, etc. In cargo handling systems, such as container terminals, AGVs are often used to transport goods between unloading point

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[1]AGV = Automated Guided Vehicle

(from one mean of transport e.g. from the ship), and loaded onto another mean of transport (e.g. truck) [1].

The literature contains descriptions of methods for automatic navigation and search routes, which are applied in automated transportation systems. AGV systems can produce measurable financial benefits for both ports and freight to their customers, through the implementation of orders for the transport of goods from the ships to land vehicles [3]. They found that in non-automated handling terminals, internal transport process is the process of the major cost. AGVs are also used as an unmanned transportation, running on rails in tunnels underground, such as transporting goods between the port and transshipment center a few miles away. The applications of AGVs as an unmanned underground transport people between stations are also examined [7].
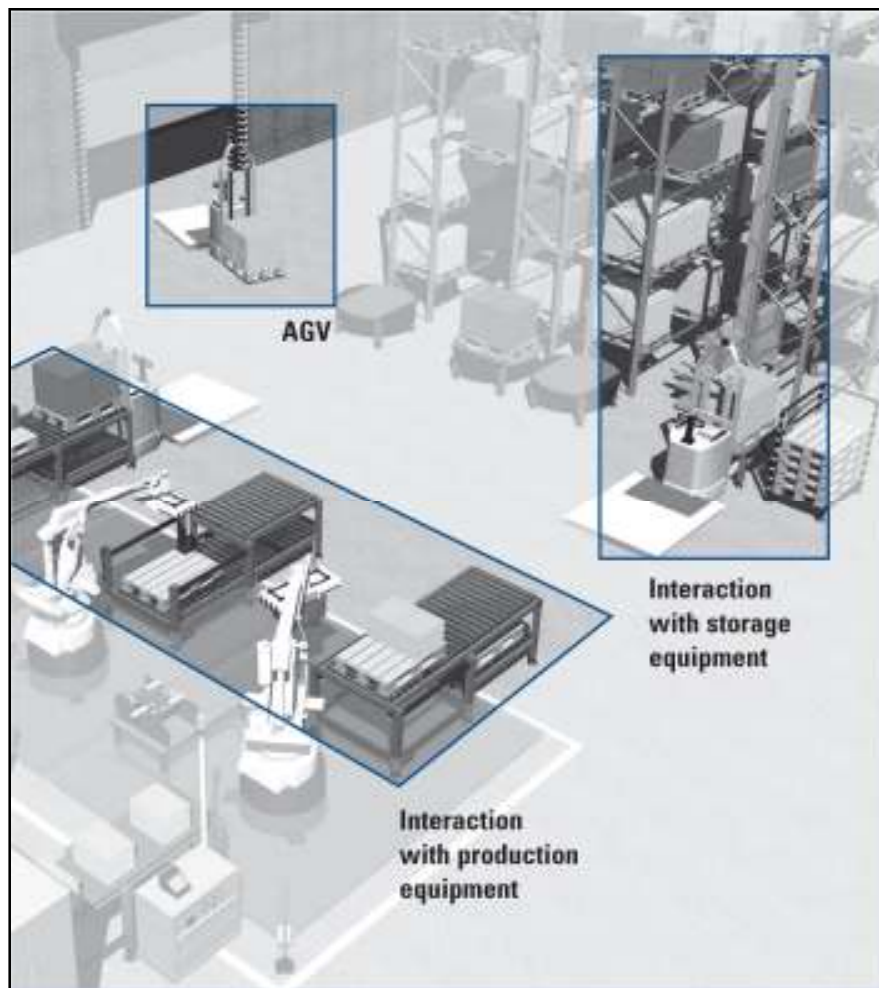

Fig. 1. Cooperation of AGV with other logistics systems (Based on Danaher Motion advertising material)

Fig. 1 shows the production system and its subsystems. The biggest differences in AGV systems applications are as follows:

- the number of vehicles involved in the AGV system,
- amount transport orders generated per unit time,
- AGV performance rate calculated as the ratio of working time to the total working time and rest time,
- the average distance that AGV has to travel during the execution of the transport orders,
- number of pick & delivery (P&D) nodes.

Usually in the manufacturing systems a small number of carriers with relatively low workload are used. They support a small number of orders among several workstations that require pick-up or delivery services. In large-scale and continuous transportation systems instead of AGV the conveyors are used [1]. A contrast to the production systems supported by AGVs, are the external systems of port terminals for handling containers [2]. In this type of systems from a few dozen to 400 AGVs can be used [8, 9], which support very large amounts of transport orders. Since we're talking about open systems (outdoor), additional factors affecting their performance are the weather conditions, topography and the size of the occupied area, which factors are not taken into account in the case of closed systems (such as manufacturing or warehouse).

In many areas of AGVs implementations reported in the literature, AGVs are used for transport of parts from one position to another. Single AGV-class means of transport can be treated as a small AGV system. An AGV system can be a part of another larger system such as an intelligent, flexible manufacturing system. An example might be a complex production system consisting of a system of AGVs, automated storage system, a system to sort and search parts and a system of technological production machines [6]. The AGV system can be divided into the following elements:

- vehicles,
- transportation network,
- physical interface between the system of production and storage, and works transport control system.

The transport network is basically a network of connections (road transport) between the various pick &delivery nodes. Fully automated AGV systems are additionally equipped in the so-called the pick & delivery (P&D) stations, which act as interfaces (connectors) between the production system and transport system. In these places the parts are carried for example by the conveyor belt from the workstation to the AGV or in the opposite direction. AGVs can move between P&D nodes along the predetermined (fixed) routes, or freely. Free choice of the route is dynamic, while AGV is driving. Dynamic route selection was investigated using an artificial immune system (AIS = Artificial Immune System). AIS responded to changes, rapidly adapted to environment and drove AGVs, dispatching tasks to AGVs. They found that immune systems can be successfully implemented in controlling a fleet of autonomous AGV transporters serving the flow of materials in an automated warehouse [5].

AGV vehicles can carry one or multiple loads simultaneously. The size and weight of loads depends on many factors and are determined by the services responsible for the control of the transport system. In manufacturing systems the number of parts in a container is referred to as the lot. Transport unit (lot)can be a container or a pallet. Generally, the bigger is unit the lower is cost of transport. The bigger transport unit also means less number of AGVs.

2. PROBLEM FORMULATION

Automated guided vehicles have the sort of advantages such as centralized functions, simple over ground systems, easy construction and system atic structure. AGVs are widely applied to metal machining, car making, port freight transportation, electronic product assembling, papermaking, power plant, the ultra-nets workshop in electron industry, etc. This paper introduces some simulation researches about control of AGV.

The works transport control is essential to seek additional capacity of production systems. This fact is evidenced by the large number of publications on the subject. Currently known and used methods actually do not fully meet all the needs arising from the specificity and complexity of the various works transport systems. Among the many methods, artificial intelligence applications occupy separate position. Mechanisms of computer intelligence are specifically suited to dealing with transport issues. This statement focuses on issues related to planning and scheduling tasks for the means of transport, moving in an arbitrary way (the free choice of routes) or limited (only on designated trail paths, such as rail vehicles).

Mentioned in this paper AGV system is designed basing on two main methods: fuzzy logic (FL) and genetic algorithms (GA). FL has been implemented to design the fuzzy transportation controller. GA unit is responsible for route optimization [10].

The scope of work covers the following activities:
1. Developing an object of research and measurement methodologies by:
   a. theoretically and practically (with computer) developing the unit of control based on artificial intelligence techniques dedicated to works transport management,
   b. developing a universal and dynamic simulator of the manufacturing system, including: workstations, works transport system and the unit of control (controller).
2. Conducting simulation research with the simulator in order to verify the effectiveness of the intelligent controller.

Each P&D node (workstation) requires transport service. To transport service might have occurred, you must first decide on whether at the time given P&D node required service or not. If the answer to the first question is positive, what kind of support is needed (pick or delivery). To allow an answer to the questions mentioned above, the intelligent controller based on fuzzy logic has been designed.

In order to apply the controller, each workstation should be equipped with sensors and its own fuzzy logic unit. The sensors system along with the fuzzy logic units operate discretely, with one second sampling time. In the second time intervals fuzzy controller receives input data which, when processed, generates an output signal containing information which say if given machine requires a transport service, what kind of service it is and what its priority is.

Fuzzy logic unit of the single workstation is a system where information is provided in the form of 3-element vector. Vector $\boldsymbol{W_x} = [x_1; x_2; x_3]$ contains the following elements:

x_1– Progress [%] $0 \leq x_1 \leq 100$
x_2– Pick-up time [%] $0 \leq x_2 \leq 100$
x_3– Risk $0 \leq x_3 \leq 10$

The input is 2-element vector $\boldsymbol{W_y} = [y_1; y_2]$. It contains the following elements:

y_1– Delivery $\quad\quad -1 \leq y_1 \leq 1,$ when $\quad y_1 > 0$ then Delivery
y_2– Pick-up $\quad\quad\quad -1 \leq y_2 \leq 1,$ when $\quad y_2 > 0$ then Pick-up

The need for pick or delivery service of given workstation occurs when the output value is greater than zero. The higher is the value, the higher is the priority of the transportation service notified by given workstation. Inputs and outputs of the fuzzy controller are shown in Fig.2. Risk range from 0 to 10 is estimated in real time, on the basis of deviations from the ideal terms of use, which are recorded at each pick &delivery station at the moment. The risk is calculated in intervals of seconds, like the other output parameters of the system.
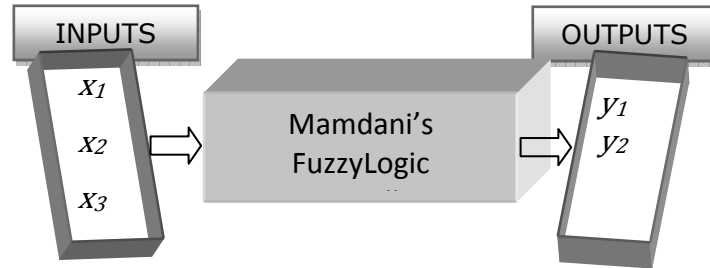

Fig. 2.Inputs and outputs of the fuzzy logic controller

The formula, which is determined by the risk of delivery, can be expressed as equation (1). Risk depends on the number of the remaining parts after last transportation service for given workstation. It is a dynamic parameter, so important is the moment of its registration.

$$R = 10 \cdot \left(1 - \frac{l_p}{2p_t}\right) \tag{1}$$

$$R(l_p, p_t) = \begin{cases} 0 & dla & R < 0 \\ R & dla\ 0 \leq R \leq 10 \\ 10 & dla & R > 10 \end{cases} \tag{2}$$

where: R – delivery risk,

l_p– the number of parts remaining to be processing with the current lot at the time of delivery [pc],

p_t– number parts in the lot [pc].

Fig.3 presents the spatial relationship between the two selected input variables, and the delivery and pick-up outputs. Irregular shape of both surfaces indicates a complex mapping function. Hence, it can be concluded that describe these relationships using a mathematical formula would be a difficult task. This fact explains the benefit of using fuzzy logic to solve problems related to the processes of decision-making control.

Fig. 4shows allocation of the work stations within manufacturing system zone. Switching station is the node with coordinates (0,0). The coordinates of P&D nodes are summarized in Table 1. As you can see, all workstations are apart far enough to allow free access to any position on all four sides.

The research was conducted for the manufacturing system consisting of 20 workstations with various technological parameters. Simulation system with an intelligent controller has been developed using Matlab with Simulink and Stateflow tools.

85

Tab. 1.Coordinates of P&D nodes of the manufacturing system

Node No.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Coordinate x	0	16	33	39	44	5	16	5	16	38	6	14	22	39	6	43	6	14	22	36	43
Coordinate y	0	43	43	43	43	35	35	28	29	28	19	19	19	19	12	12	5	5	5	5	5
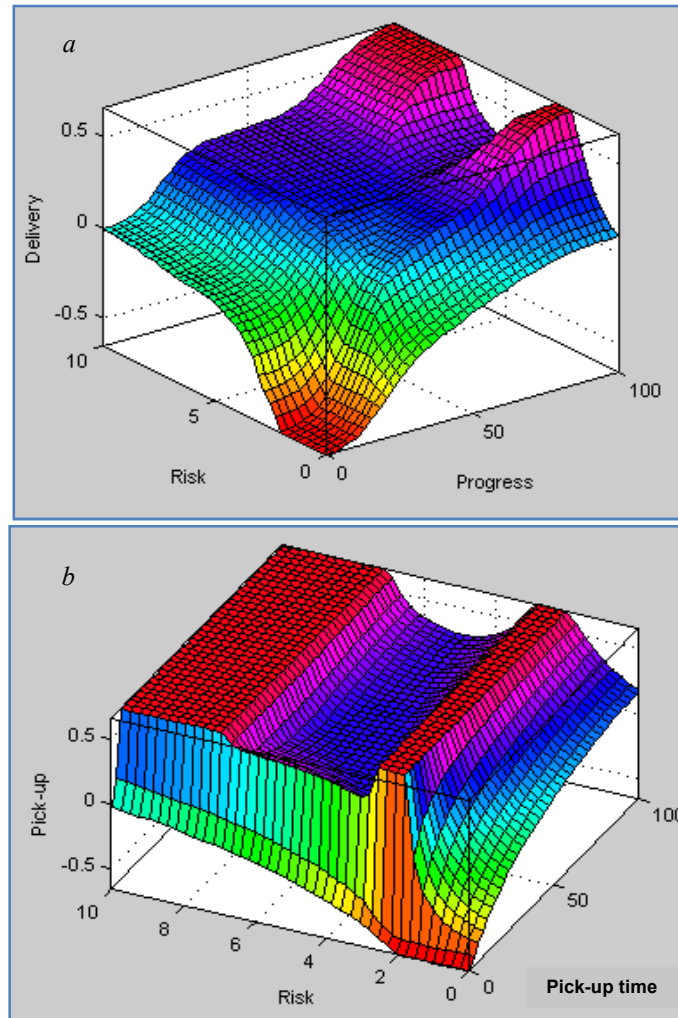
Fig. 3.Impact of **Progress** and **Risk** for **Delivery** *a*) and impact of **Pick-up time** and **Risk** for **Pick-up** *b*)
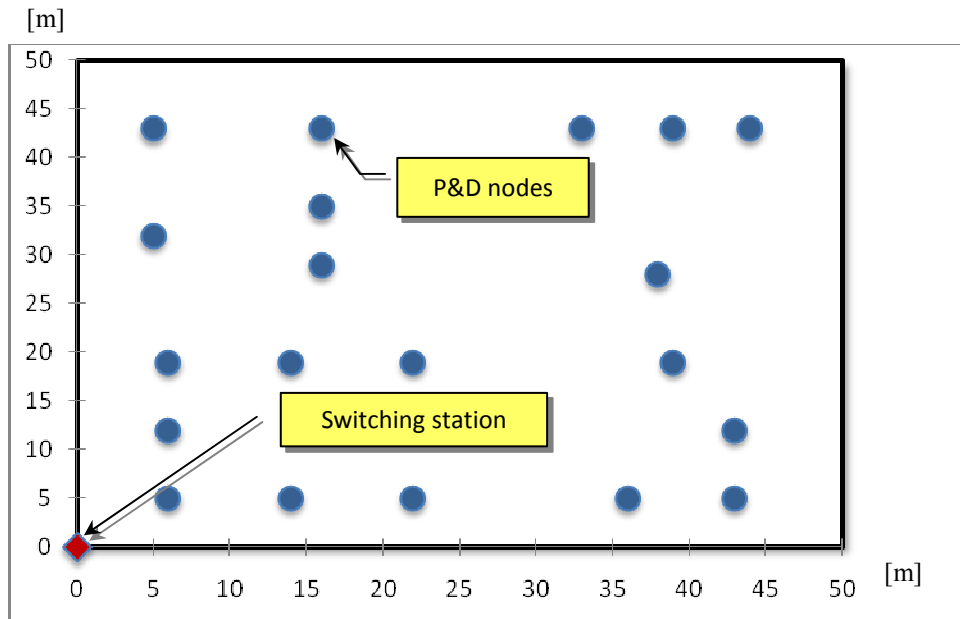
Fig. 4.Topology of the manufacturing system

3. RESULTS OF RESEARCH

As a result of simulation, performance of the transportation system controlled by fuzzy logic unit and genetic route optimizer was verified. Thus, a wide range of data has been collected, so that you can review the efficiency of intelligent transportation system controller.

Due to the large amount of information and restrictions in relation to the volume of this work, it is impossible to present detailed results from all workstations. Therefore, the results recorded below examine the work of one, the chosen workstation within an 8 hour shift. The analyzed workstation has the number 9 in Tab. 1.

Simulated time is 8 hours (28800 seconds). Fig.5 presents the delivery times for the workstation No. 9 during the simulation. The horizontal axis is the axis of time from 0 to 28800 seconds. The vertical axis maps the delivery, while 0 means no supplies in given second of simulated time, and 1 means the supply of parts (one lot or more lots).

From Fig.5 we learn that during the work shift seven deliveries occurred. It is not known how many parts (lots) was brought by the mean of transport in each delivery but this information can be read from a chart presented in Fig.9 which is discussed later in this chapter. Fig. 6 presents an analogous situation as the graph of Fig.5 but this time it comes to transport operations involving the pick-up parts from the workstation No. 9. As you can see, during a simulated shift pick-up was held seven times, exactly as the number of deliveries. Also, we see that the pick and delivery took place at different times (not simultaneously). Information on the number of incoming parts is shown in Fig. 11.

Intervals at which the P&D operations took place were similar but not identical. This demonstrates the lack of problems that could face a mean of transport and the capacity reserve of the carrier.
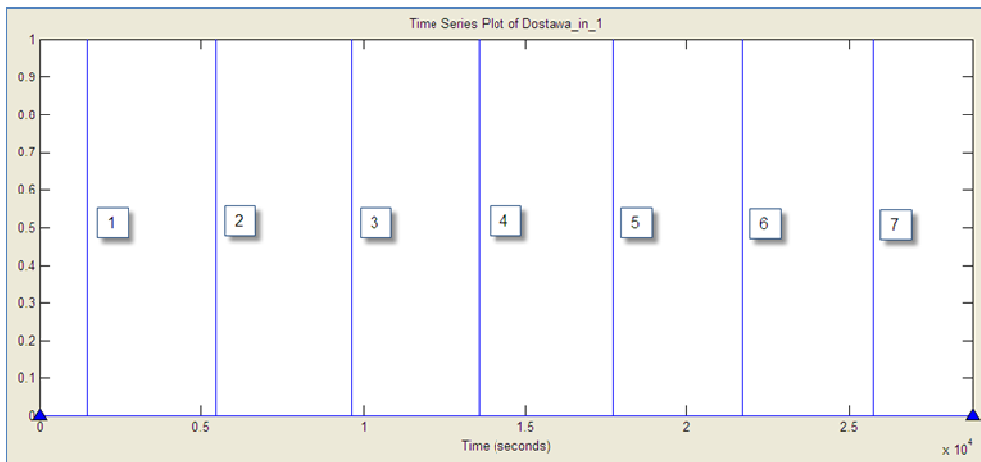

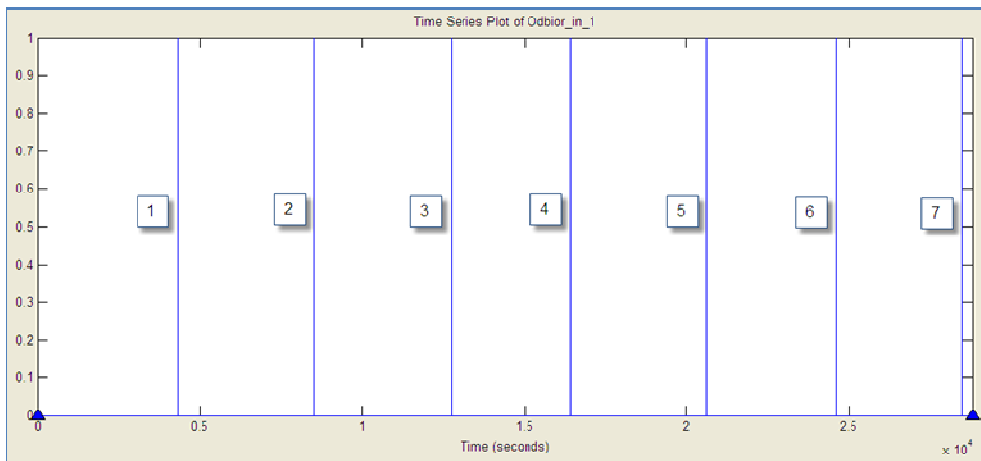Fig. 5.Delivery services during simulation for workstation No. 9

Fig. 6.Pick-up services during simulation for workstation No. 9

Fig.7 presents the output value of Delivery - one of the two fuzzy controller output signals in workstation No. 9. Because at the start of the simulation the stock before processing was   pieces with the risk of   , the delivery output value was negative. With the subsequent decreasing of the stock level (on the inlet side of workstation) the value of delivery was increasing. In a short time it has exceeded the level of 0, and began to adopt positive values, which was the signal to start requests of delivery of next lot (or lots).

88

From that moment the workstation of No. 9 was included in the queue positions requiring transportation service in next loop of the carrier. Shortly afterwards, when the value of the delivery went up to 0.2 the lot was delivered (delivery 1). In the Fig. 7, this moment is shown as a sharp drop vertical line in the value of delivery. Soon, the level of 0.19 of the indicator has dropped below the level of -0.6. At this point the stock of new parts was so large that the value of the Delivery was at the same low level for some time. However, since the stock of new parts was gradually decreasing, finally the value of the Delivery began to grow again.

This cycle was repeated seven times. It may be noted that Fig.7 corresponds to Fig.5 in terms of deliveries and delivery times. If you analyze the part of the waveform of Fig.7 that go over the level of zero, you can read the waiting times for delivery from the moment of sending the first request of delivery. This moment coincides with the time when the curve of the graph crosses level of zero.
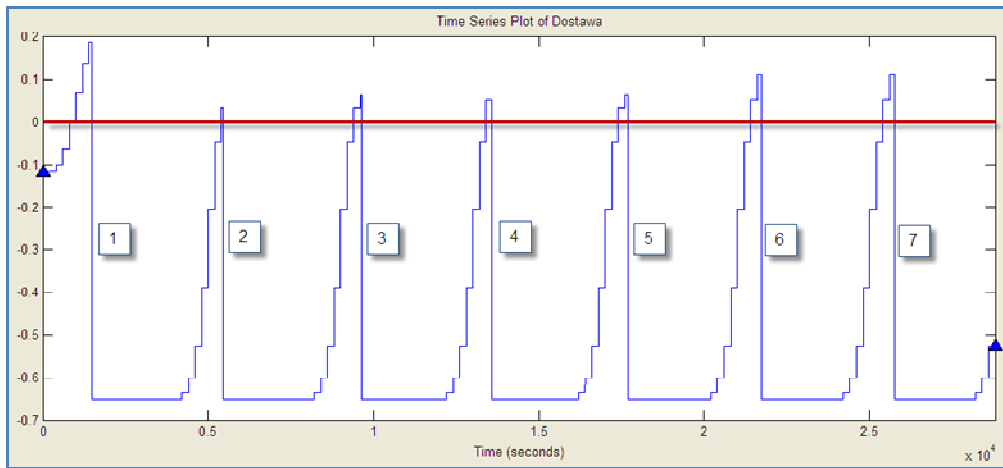

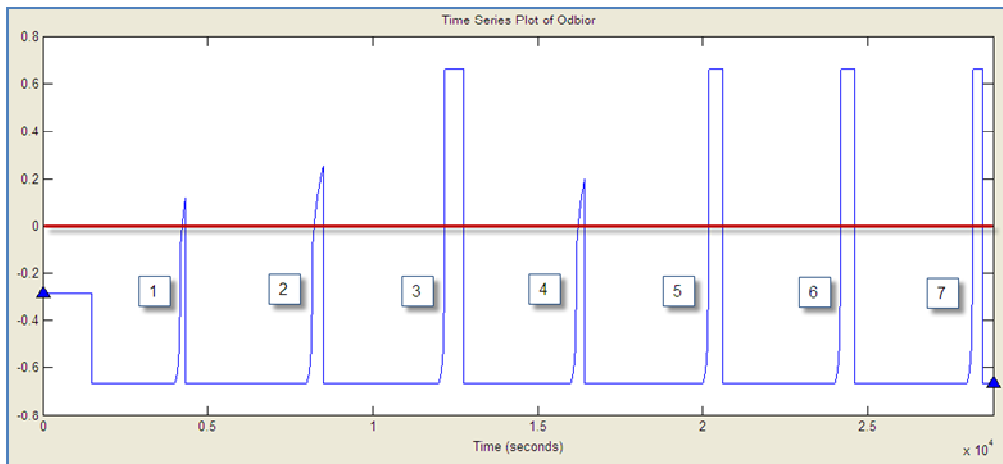Fig. 7. Output delivery values for workstation No. 9

Fig. 8. Output pick-up values for workstation No. 9

Fig. 8 presents value of the output signal of fuzzy controller of machine No. 9, for the Pick-up parameter. At the beginning of simulation output value delivery is negative (less than 0.2). Then you see a drop in signal level at right angles to the level below (-0.6). This is due to reduction in risk, which is a newly converted during each delivery (Fig. 13.). In Fig. 9 in the same second, when the value of the parameter Pick-up was decreased (Fig. 8.), first delivery to the workstation No. 9 was recorded.

Fig. 9 blue line indicates the size of buffer stocks of parts before processing. The vertical long lines reflect the deliveries. The dashed line indicates the average level of stock before processing, and the red lines indicate the minimum and maximum level of stock. Clearly, the stock level is maintained at an average of about 22 pieces, which is the amount slightly greater than the base lot quantity   . In case of workstation No. 9   parts.
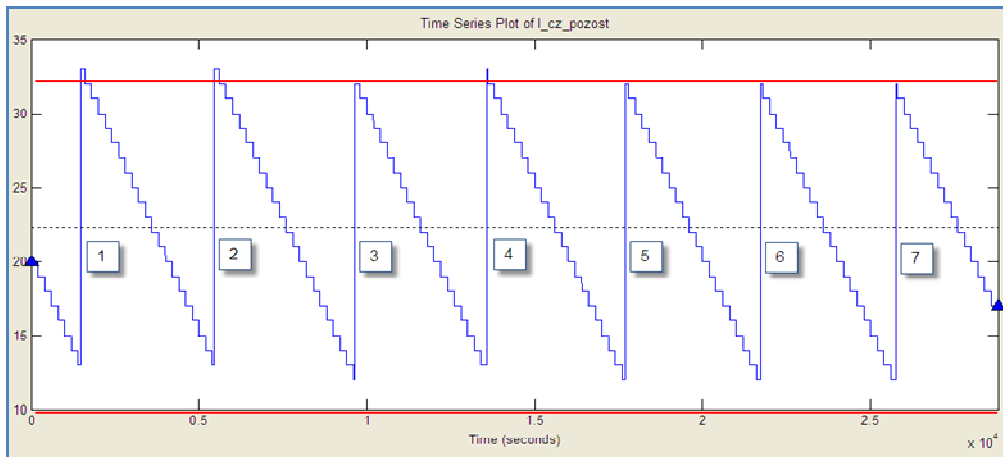

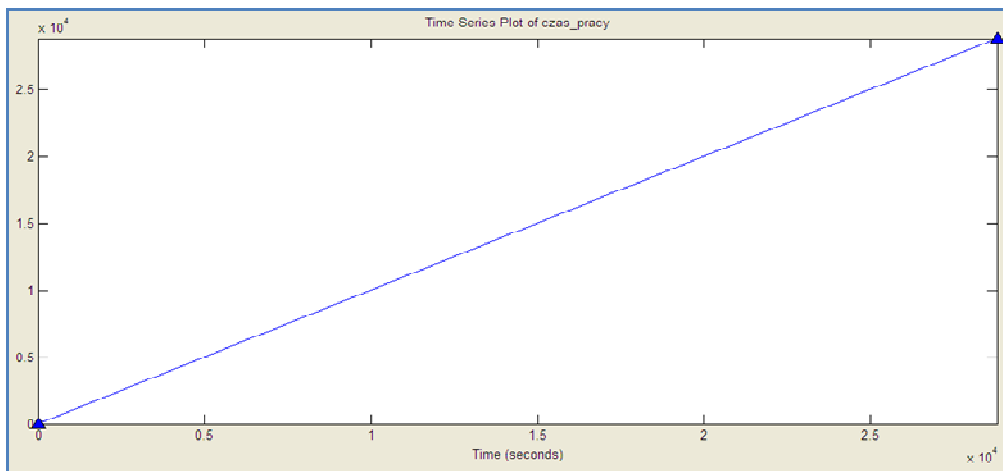Fig. 9. Stock level before processing in workstation No. 9

Fig. 10. Work time of the workstation No. 9 (increasingly)

90

Fig. 11 presents the general level of buffer stock in the workstation No. 9 after processing. The long vertical lines (drops) are equivalents of individual pick-up services. The average level of stocks after processing was about 12 pieces, which was below the average level of stock before processing. This situation is appropriate because the purpose of keeping higher stock level at the input of the workstations to ensure continuity of manufacturing process.
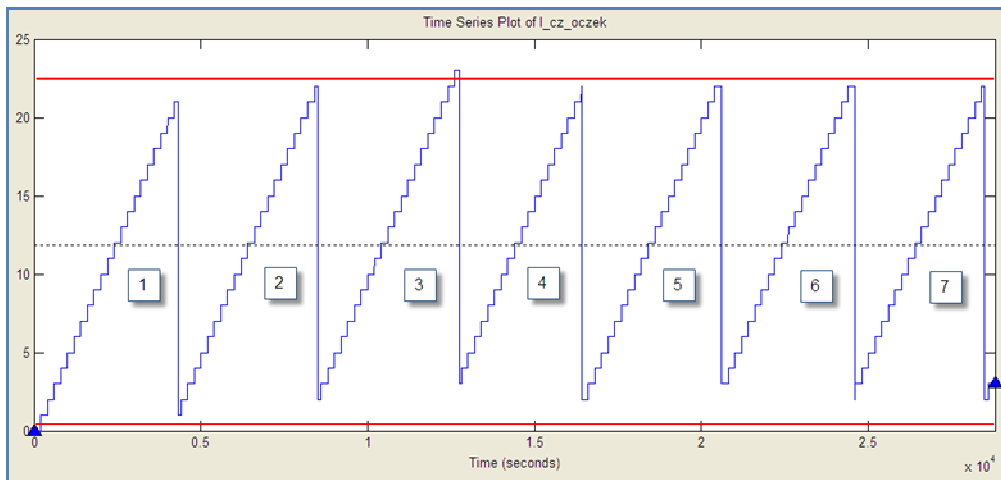

Fig. 11. Stock level after processing in workstation No. 9

Stock level after processing is not a critical parameter, and causes only the freezing of capital (not manufacturing stops). Therefore, this stock should be as small as possible. Maximum output buffer in workstation No. 9 oscillated about a level of 23 parts. A minimum level was close to zero only upon first pick-up service. Then the stock fell to 1 pc. This was due to the fact that the initial value for the risk parameter was set to 5, and after the first delivery the risk decreased considerably. Therefore, a priority of pick-up services was also reduced, which resulted in a slight increase in the average stock levels.

It should be taken into account that the means of transport takes only parts whose quantity is the base lot [   ] multiplicity – thus leaving a number of parts after the pick-up service. Fig. 12 presents the waiting times to receive lots after processing. The number of pick-up transactions (7 pick-ups) corresponds to Fig. 11. As can be seen, waiting times were relatively short, suggesting a surplus capacity of the carrier. In general, the pick-up services took place after the waiting period of less than 600 sec. Only the Pick-up No. 3 made it necessary waiting for the lot more than 700 sec.
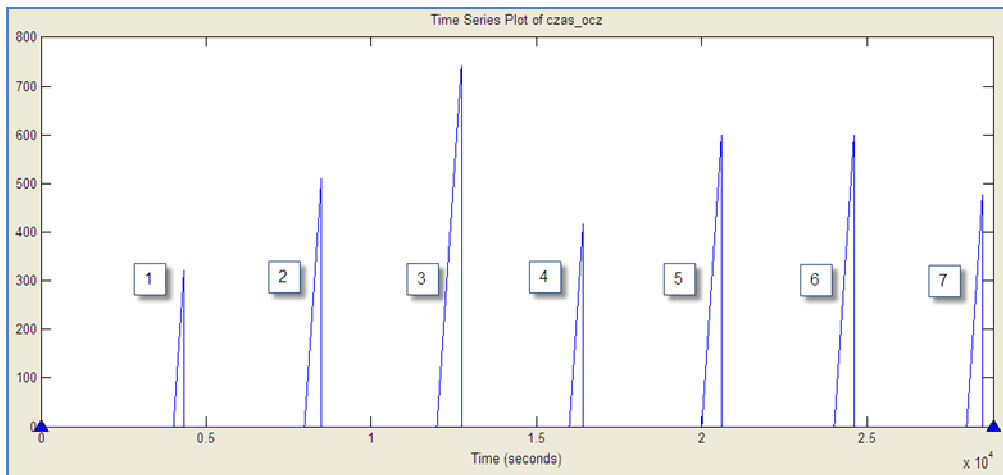
Fig. 12. Lot   waiting times to be picked-up from workstation No. 9

Although it was theoretically possible, but during simulation there was not a case that the mean of transport picks-up more than one lot. This information can be read from Fig. 11 where each falling vertical line in the following pick-up service is equal to 20 parts, so it is equal to   . The top and bottom red horizontal lines (Fig. 11.) indicate the minimum and maximum stock levels after processing in the workstation No. 9.
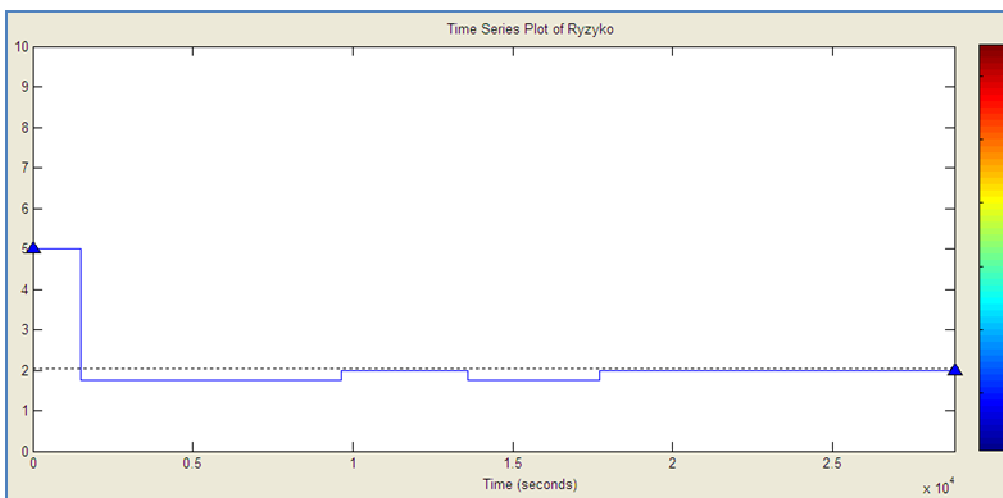

Fig. 13. Risk level in workstation No. 9 during simulation

Fig. 13 illustrates the risk level during the simulation, corresponding to the workstation No 9. The initial value of risk was 5. After the first delivery, during which it turned out that the waiting time for the transport operation is short, the risk has fallen to below 2. Then it wavered slightly, but did not exceed level 2.It means that during the simulation there was no need to

deliver parts for the processing of more than one lot. Because of this, the stock of parts before processing keeps low and constant level. The Risk parameter certainly would be higher if the utilization of the carrier was stronger.

4. CONCLUSION

The results confirmed that the intelligent controller, using fuzzy logic rules and genetic algorithm optimization can operate efficiently in large AGV systems. It is proved by the fact that during simulation the intelligent controller was able to efficiently and continuously operate the system consisting of 20 workstations, while the works transport control systems based on linear programming algorithms have been unable to effectively control systems up to 15 P&D nodes (with one AGV) [4].

In the simulation it was found that the system does not need to optimize the route consists of more than 13 nodes in a single loop. Obtaining such a small, maximum number of nodes in a single loop (13 nodes) in 20-nodes system, was possible through an efficient transportation dispatching method.

Dispatching procedure was implemented through fuzzy inference system by the method of Mamdani. The innovative element was the introduction of an additional Risk factor in determining the P&D urgency. The results of experiment confirmed the validity of introducing parameter of Risk, as well as the correctness of its original function (1).

Developed controller allows solving several problems simultaneously. First, it decides about the time of notification by the P&D node for transport service request. Secondly it optimizes the carrier's route. Thirdly, it keeps the level of risk associated with P&D delays. At last fourthly –the controller takes specific prevention activities against manufacturing process breakdown (e.g. it speeds up or slows P&D demand and decides on the size of delivery to ensure adequate buffer stocks). The controller is dynamic (working in real time with one second discretization).

Because of the intelligent controller optimization method based on genetic algorithms, it is possible to carry out research towards the development of advanced heuristic simulation techniques. These techniques should lead to shorter time of calculations performed by the control mechanism of the vehicle dispatching in large AGV transportation systems, taking into consideration collision avoidance, traffic congestion and delays.

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