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THE MODELING OF THE ASSEMBLY LINE WITH A TECHNOLOGICAL AUTOMATED GUIDED VEHICLE (AGV)

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ABSTRACT. The initial analysis of the work of the automated guided vehicle (AGV) in the assembly line was conducted. The method of defining a number of cells operated by one AGV was described. The method of the calculation of the optimal movement route and the stop spot in the initial setting was indicated. The formulas enabling to calculate the indicators of ways of the line functioning for various numbers of tasks were presented.

Key words: automated guided vehicle (AGV), assembly line, cell efficiency, demurrage time, work time.

INTRODUCTION

So called AGV trucks are one of the mainly used automatic guided vehicles. The principle of their functioning consists of the following the magnetic field created by the current flowing in the cable located in the floor of the factory through the aerials mounted on them. The topography of the cable corresponds the route of the AGV. AGVs could be equipped in platforms, rolls, forks, swivels and industrial robots and therefore they are able to cooperate with other machines. The addressing of AGVs to various branch circuits is possible (it concerns the multi-frequency vehicles) [Nieoczym 2011]. The truck has a PLC driver, which can contact with the superior controlling system by the optical connection.

The tactical and operational factors are taken into the consideration during the process of designing of AGV systems. The tactical factors [King, Kim 1999] are connected with the planning of physical elements of the system (e.g. amounts and location of receiving and dispatching points, means of transportation). The transport routes layout or the schedule of transport tasks are typical operational factors [Tanchoco 1991, King, Kim 1999]. They include also the area of the flows control, prediction and preventing of collisions and bottles necks within the transport routes or the localization of free transport means.

The operational factors are the superior ones in the process of designing of AGV systems [Koff 1997, Malmborg 2001]. The simultaneous methods [King, Kim 1999, Kom, Jea 2003] or their combinations with analytical methods [Mahadewan, Narendran 2001, Malmborg 2001] are used during the process of designing of AGV system to take into consideration so big number of decision-making variables. However, these methods are used in case of systems, which consist of a big number of vehicles, being able to transport big amounts of goods (e.g. the airport Schipol in Netherlands). The

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attempts were also made to design AGV system by planning the cells' locations simultaneously with the process of designing of the distribution system [Aiello, Enea, Galante 2002]. The minimization of the system maintenance costs was the target function. Having a big number of calls, the designing problem can be simplified and reduced to an analytical model, which is formulated as the integer model [Johnson, Brandeau 1993] and solved by the used of analytical methods.

All above-mentioned methods of the process of designing of AGV system are time-consuming and need sophisticated mathematical methods. However sometimes, there is only a need to check quickly the initial assumptions of the project, to introduce the change in the input data or to prepare a simply simulation of the system work. The correctness of the project can be verified by the use of the formulas described in this paper, which give the number of posts operated by one AGV or by making the stochastic description of the way, how the transport system operates. The proposed methodology is based on the analysis of the loads of machines and limitations of the system, such as: the capacity of production warehouses, the capacity of the warehouse of final products, the throughput of internal transportation system.

It will be assumed for the purpose of this paper, that the assembly line consists of single cells connected by the transport flow and additionally these cells are operated by the automated guided vehicle. It is used to deliver small parts to workstations and to collect the assembled sets from these workstations.

Two main issues require the solutions:

- to calculate the number of assembly cells M operated by one AGV. The higher number of operated cells, the lower total assembly costs, but at the same time the efficiency decreases due to the fact, that there are demurrages because it is necessary to wait for services as well as the AGV itself is overloaded,
- to calculate the coefficient of the line utilization η with the given number of AGVs. This issue is solved mainly at the stage of the designing process of the assembly line. If this coefficient is determined improperly, the assumed production efficiency of the line could not be achieved. In the opposite case, when the production efficiency will be higher than assumed, then the line would be not fully used and its economical efficiency would decrease.

It is assumed in the preliminary calculations that the cells cooperated within the line, have the same parameters of the reliability, such as the intensity of damages λ and the intensity of the return to the work μ. Additionally, the problem of the reliability of the AGV is ignored [Nieoczym, Gajewski 2005, Yang, Yamafuri, Tanaka, 2000].

The following designations are assumed:

k – number of cells waiting to be operated (number of tasks to be done),

N – number of automated guided vehicles,

M – number of assembly cells.

THE DETERMINATION OF THE NUMBER OF CELLS OPERATED BY ONE AGV

Two coefficients are used in the calculations:

- coefficient of the time of the work of AGV on the assembly line:

$$\eta_t = \frac{T_{obs}}{T} \qquad (1)$$

where: T_{obs} – service time of the assembly line by AGV,

T – total work time of the assembly line in the given period of time (e.g. one shift).

– coefficient of the efficiency of the cell:

$$\eta_c = \frac{Q_R}{Q_{nom}} \tag{2}$$

where: Q_R – real efficiency of the assembly cell taking into account the damages and blockings,
Q_{nom} – nominal efficiency of the assembly cell.

Assuming, that the efficiency of each cell is equal [Gujnar, Sanders 1994, Yang, Yamafuri, Tanaka, 2000], it can be written:

$$Q_R = \sum_{k=0}^{M} (M-k)P(M,t)\frac{Q_{nom}}{M} \tag{3}$$

where: *P(M,t)* – the probability of serving of assembly cells in given time *t*.

Substituting this to the formula (2), it is obtained:

$$\eta_c = \sum_{k=0}^{M} (M-k)\frac{P(M,t)}{M} \tag{4}$$

$$\eta_t = \sum_{k=1}^{K} P(M,t) = 1 - P(0,t) \tag{5}$$

where: *P(0,t)* – the probability, that there is no task to do by AGV in given time *t*.

If the assembly cells have the same values of parameters λ and μ, then the average number of repaired cells in the time interval *(0,t>* is described as follows:

$$\overline{n_{rem}} = \mu\eta_t t \tag{6}$$

and the average number of cells, which will be damaged in the time interval *(0,t>* [Gujnar, Sander 1994]:

$$\overline{n_{uszk}} = \lambda\sum_{k=0}^{M} (M-k)P(M,t)t = \lambda\eta_c\, M\, t \tag{7}$$

If the assembly processes are considered in sufficiently long intervals, there is a relationship:

$$\overline{n_{rem}} = \overline{n_{uszk}} \tag{8}$$

As a result, it will be:

$$\eta_c = \frac{\eta_t\, \mu}{M\, \lambda} \tag{9}$$

It means, η_c depends on ratio $\frac{\mu}{\lambda}$.

The maximal value of the efficiency coefficient η_c at the assumed value $\frac{\mu}{\lambda}$ can be found by the use of the iterative method and substituting the consecutive value of cells' number *M*.

THE DETERMINATION OF THE COEFFICIENT OF THE USE OF AUTOMATED GUIDED VEHICLE

The location of the AGV as an initial position should be determined after the calculation of cells' numbers operated by one AGV. This position should be chosen so, that the distances among the cells covered by the AGV should be minimized.

It is assumed, there are $M = (S_1, S_2, ...S_M)$ cells of different coefficients of the reliability located along the assembly line. The location of each of them is described by the coordinate x_i and the initial location of the AGV is characterized by the coordinate y (Fig. 1).

The time of work of a work cell is:

$$T = T_{op} + T_{obsl} + T_{oczek} \quad (10)$$

where: T_{op} – time of the technological operation at the workstation of the assembly cell,

T_{obsl} – service time by the AGV,

T_{ocz} –waiting time for the AGV.

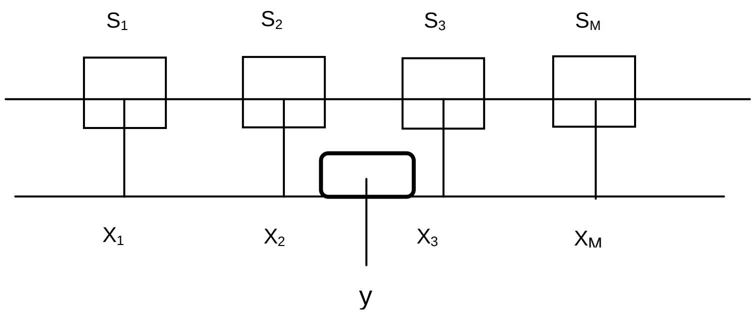

Fig. 1. The diagram of allocation of assembly cells and the location of AGV
Rys. 1. Schemat rozmieszczenia komórek montażowych i położenia sterowanego automatycznie wózka

The waiting time T_{oczek} - the time needed for the AGV to cover the distance between the initial location and the cell, needed to be operated:

$$T_{oczek} = \frac{|x_i - y|}{v} \quad i = (1...M) \quad (11)$$

where: y – location of the AGV in the initial position,

v – velocity of the AGV.

Assuming the extreme situation, when the AGV is at the cell, which should be operated but the cell is damaged. The service time of this cell is longer by the time T_{rem} needed to repair this cell.

$$T_{i\,obsl} = T_{i\,rem} + T_{i\,obs\,efekt} \quad (12)$$

It should be assumed additionally, that on the average, there are $\lambda_i T$ damages of i cell during T time of the line work. The time needed to repair this cell is equal to:

$$T_{i\,rem} = \lambda_i\, T\, \frac{1}{\mu_i} \quad (13)$$

The average total time to restore the readiness of the line for the work is equal to:

$$T_{rem} = T \sum_{i=1}^{M} \frac{\lambda_i}{\mu_i} \tag{14}$$

and the coefficient of the utilization of the AGV at the line is:

$$\eta = \frac{T_{op}}{T_{op} + T_{obs} + T_{oczek}} \tag{15}$$

Therefore, the location of the AGV in the initial position and its route affects the value of the η coefficient. This coefficient reaches the maximal value with the given values of λ and μ, when the value of the expression $|x_i - y|$ is minimal. The value of the following function should be calculated to find optimal values of *y*:

$$f(y) = \sum_{i=1}^{M} |x_i - y| . \tag{16}$$

The results of the function (16) with the assumptions, that:

– the distances between cells are the same and equal to *l*,

– there are *M*=4 cells in the operated zone,

are presented at the figure 2.

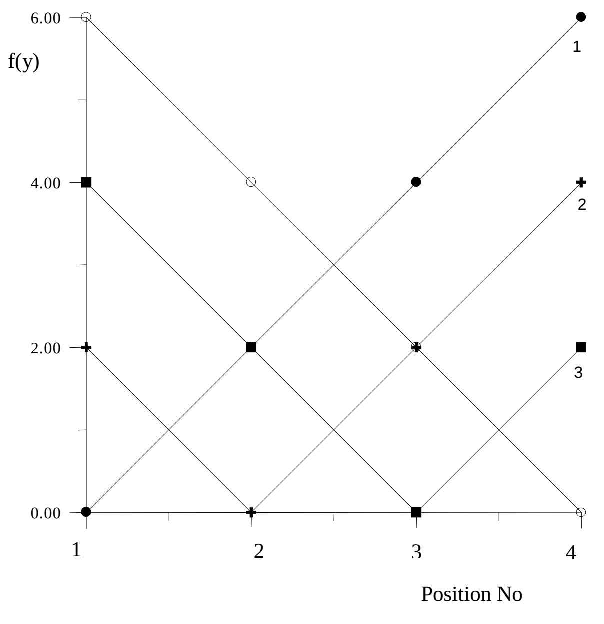

Fig. 2. The diagram of the dependence of the stop spots of the AGV on the route covered in the time of service of *M*=4 assembly cells. The AGV stop at the cell: 1 – first, 2 – second, 3- third, 4- fourth.
Rys. 2. Wykres miejsca postoju wózka sterowanego automatycznie od przebytej drogi w czasie obsługi M=4 komórek montażowych. Postój wózka przy komórce: 1 - pierwszej, 2 - drugiej, 3 - trzeciej, 4 - czwartej

The method, shown by King and Kim [1999] of the determination of the AGV location in the initial position by the analysis of covered route in left and right directions from this position, seems to be unjustified due to its complexity. The proposed method is very simple and the graphical way of the presentation of results of the function allows to determine the optimal routes.

THE COEFFICIENTS USED TO DETAIL DESCRIPTION OF THE FUNCTIONING OF THE LINE WITH THE AUTOMATED GUIDED VEHICLE

In the case of the flexible manufacturing system, there is often the need to change the assembled sets and therefore various tasks fulfilled by the AGV. The following formulas, which take into consideration such changes and are based on the theory of mass operations [Nieoczym, Gajewski 2005, Nieoczym 2002], can be created:

- the probability, that there are *k* tasks to be done in *t* time on the line and the number of tasks is smaller than the number of AGVs:

$$P(M,t) = \frac{M!}{(M-k)!\,k!}\left(\frac{\lambda}{\mu}\right)^k P(0,t) \quad 1 \le k \le N \tag{17}$$

- the probability, that there are *k* tasks to be done in *t* time on the line and the number of tasks is bigger than the number of AGVs:

$$P(M,t) = \frac{M!}{(M-k)!\,N!\,N^{k-N}}\left(\frac{\lambda}{\mu}\right)P(0,t) \qquad N \le k \le M \tag{18}$$

- the average number of cells waiting to be operated:

$$M_{oczek} = \sum_{k=N+1}^{M} \frac{(k-N)\,M!}{N^{k-N}\,N!\,(M-k)!}\left(\frac{\lambda}{\mu}\right)^k P(0,t) \quad N \le k \le M \tag{19}$$

- the probability, that there are no tasks to be done in *t* time on the line by AGVs (*k*=0):

$$P(0,t) = \left[\sum_{k=0}^{N} \frac{M!}{k!\,(M-k)!}\left(\frac{\lambda}{\mu}\right)^k + \sum_{k=N+1}^{M} \frac{M!}{N^{k-N}\,N!\,(M-k)!}\left(\frac{\lambda}{\mu}\right)^k\right]^{-1} \tag{20}$$

- the average number of cells being operated:

$$M_{obsl} = \sum_{k=1}^{N} \frac{M!}{(k-1)!\,(M-k)!}\left(\frac{\lambda}{\mu}\right)^k P(0,t) \qquad 1 \le k \le N \tag{21}$$

$$M_{obsl} = \sum_{k=N+1}^{N} \frac{kM!}{N^{k-N}\,N!\,(M-k)!}\left(\frac{\lambda}{\mu}\right)^k P(0,t) \qquad N \le k \le M \tag{22}$$

– the coefficient of waiting time for a cell:

$$\frac{M_{oczek}}{M} = \frac{(M-1)!}{N!} \sum_{k=N+1}^{M} \frac{k-N}{N^{k-N}(M-k)!} P(0,t) \tag{23}$$

– the service coefficient of a cell:

$$\frac{M_{obsl}}{M} = \frac{1}{M} \sum_{k=1}^{M} k \, P(M,t) \tag{24}$$

SUMMARY

The presented paper can be regarded as a preliminary analysis of the work of the automated guided vehicle. The assumption, that the coefficients λ and μ of operated cells are of the same value, is the reason for that. The next part of the researches should be the determination of the scheduling of tasks and routes of AGVs in case, when the idle time is bigger than an assumed value, during which the AGV can wait for a cell to be returned to the work.

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MODELOWANIE LINII MONTAŻOWEJ Z TECHNOLOGICZNYM WÓZKIEM STEROWANYM AUTOMATYCZNIE

STRESZCZENIE. W artykule przeprowadzono wstępną analizę pracy wózka sterowanego automatycznie. Opisano metodę określenia liczby komórek obsługiwanych przez jeden wózek. Wskazano sposób obliczenia optymalnej trasy ruchu i miejsca postoju w położeniu wyjściowym. Zamieszczono wzory do obliczenia współczynników funkcjonowania linii przy różnych ilościach zadań.

Słowa kluczowe: wózek sterowany automatycznie, linia montażowa, wydajność komórki, czas uszkodzeń, czas pracy.

DIE MODELIERUNG VON MONTAGELINIE MIT DEM TECHNOLOGISCHEN FAHRERLOSEM TRANSPORTFAHRZEUG (AGV)

ZUSAMMENFASSUNG. Der Artikel präsentiert eine vorläufige Analyse der Arbeit von dem fahrerlosen Transportfahrzeug. Der Weg der Bestimmung der Anzahl der Zellen, die durch einen AGV unterstützt sind, wurde beschreibt. Die Methode zur Berechnung der optimalen Route für den Verkehr und des Parkplatz in die Ausgangsposition wurden angezeigt. Die Formeln für die Berechnung von der Koeffizienten der Arbeitsweise der Linie mit verschiedenen Mengen der Aufgaben wurden gegeben.

Codewörter: fahrerloses Transportfahrzeug, Montagelinie, Leistung von der Zelle, Verlustzeit, Arbeitszeit.

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