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CALCULATING THE PAYBACK PERIOD OF THE IMPLEMENTATION OF AN AUTOMATED GUIDED VEHICLES - AGV IN A MANUFACTURING SYSTEM

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Abstract. Automated Guided Vehicle (AGV) systems have been frequently used as material handling equipment in the supply of assembly lines. The use of AGV systems has taken attention of practitioners and researchers. Therefore, in this article, we will present a sizing study of an AGV loop used to supply an assembly line. The study was made by a multidisciplinary team from the Faculty of Mechanics and Technology of the University of Pitesti. The Payback period calculus in the implementation of an AGV network in the supply of an assembly line workstations is essential for the implementation.
Keywords: automated guided vehicles, line supply, automatization, Payback period.

INTRODUCTION

According to the *specific work safety norms for the handling, transport by carrying and non-mechanized means and storage of materials* no. 57 art. 8 by the handling and transport process is meant “any operation of transporting or supporting a mass by one or more employees, including lifting, lowering, pushing, pulling, carrying, or moving a mass which, due to its unfavourable characteristics or ergonomic conditions, involve risks of injury or occupational illness." Therefore, when it comes to supplying workstations with raw materials, the degree of difficulty and complexity of this handling action must be considered.
Automated Guided Vehicle Systems - AGVS are the future of the handling process and efficient transport. They relieve employees of tedious transport tasks, increase handling performance, and reduce error and accident rates in the warehouse. AGVS are intended for handling and transporting materials, operating independently and autonomously, guided along a predefined path.
The AGV makes work easier, reduces damage to transported materials, increases efficiency, and reduces costs, helping to automate a production or storage facility. The AGV can be described as a means of handling that follows markers or wires on the floor or uses vision or laser to move on industrial floors for material handling, transport, or storage of products.
Since 20–50% of production costs are allocated to facility planning, cost savings in this area can significantly reduce production costs in a manufacturing unit [12]. Designing material handling systems is an important element in facility planning. It determines the material handling equipment, the form and direction of the material handling networks, and the number and location of stations [1].
Many researchers have been motivated to study various AGV related problems, in the hope of increasing their efficiency [4]. For example, Kim, Tanchoco, and Koo [6], Hirao, Tamaki and Ohno [3], Matthias, Grunow, and Günther [9], Kim, Jeon, and Ryu [5] have studied vehicle dispatching, route planning, and vehicle control problems; Arifin R and Egbelu PJ [2] have studied the problem of estimating the number of vehicles required in a system, Ko and Seo [7, 10] guide-path design problems of AGV systems, and Lee [8] the load-selection problem and/or the load drop-off problem.
In this paper

In this paper, a methodology for calculating the profitability of implementing an AGV circuit will be proposed using the Payback period indicator. This methodology is then applied to calculate the profitability of implementing an AGV circuit for the supply of workstations within an assembly line.

CALCULATION OF THE PROFITABILITY OF THE IMPLEMENTATION OF AN AGV CIRCUIT USING PAYBACK PERIOD

One of the main components of an industrial logistics system is the product handling function. Product handling costs represent a significant share of the total production cost, being 2÷3 times higher than production costs, depending on the type and volume of production and the degree of automation of the handling function.

Material handling equipment is part of the logistics system structure. As a result, the conuration of a handling system depends on:

- production diversity.
- type of handled products.
- the quantity of handled products.
- travel distances.
- type of production system served.

Calculating the efficiency of implementing an AGV circuit in a production system involves going through the following stages:

- identification of the initial data necessary for the implementation of an AGV system.
- determining the number of dollies (transport platforms) needed for a work shift and choosing their coupling system.
- determining the duration of an AGV circuit.
- determining the number of AGVs needed.
- determining the investment cost of implementing an AGV circuit.
- determination of the operator's workload – for the manual coupling systems of the dollies (transport platforms) it is necessary for manual systems for holding towed platforms.
- determining the yearly functioning cost for the considered scenarios.
- calculation of investment Payback period.

The initial data required for an AGV circuit are N_p – the number of parts on a platform (capacity of transport), Vmed - the average speed of the AGV, d - the distance of the circuit, $T_{p/d}$ - the duration of coupling-uncoupling, Ns - the number of workstations, line cycle time, circuit autonomy - calculated as the ratio between line cycle time and dolly capacity, G_{AGV} - AGV efficiency ratio.

The number of dollies needed per shift is determined as following:

$$N_c = \frac{N_m}{N_p}$$

Where:

N_c = number of dollies/ shifts;
N_m = number of products/ shifts;
N_p = numbers of parts/ dolly.

The coupling system of the dollies to the AGV can be manual – done by an operator or automated. The duration of coupling-uncoupling for an automated systems is 0.5 minutes and for a manual system is 0.64 minutes.

The circuit duration is calculated as following:

$$D_c = \frac{d}{V_{med}} + (T_{p/d} * N_s) \quad (1)$$

Where:

D_c = circuit duration
d= circuit distance
V_{med} = AGV average speed
$T_{p/d}$ = coupling-uncoupling duration

N_s = number of workstations on the circuit

The number of AGVs is determined as following:

$$N_{AGV} = D_c / A_c / G_{AGV} \qquad (2)$$

Where:

D_c = circuit duration

A_c = circuit autonomy

G_{AGV} = AGV efficiency ratio

After determining the number of AGVs needed to transport the dollies it is calculated *the investment cost,* that is made of cost of the AGVs and the cost of implementation.

In the case of the manual coupling-uncoupling systems *the cost of operator work* in relation to the *operator workload* must be determined with the following formula:

$$C_{op/an} = T_{a\,op} * N_e * C_{op} \qquad (3)$$

Where:

$C_{op/an}$= yearly cost for operator work [€]

$T_{a\,op}$= total workload/ operator [%]

N_e= number of work shifts/ day

C_{op}= yearly cost for an operator [€]

$$A_{op} = T_p * \frac{N_c}{N_{ech}} * N_p$$
$$A_{op} = Td * \frac{N_c}{N_{ech}} * N_p \qquad (4)$$

Where:

A_{op}= workload operator/ shift

T_p = duration of coupling activity for a dolly

T_d = duration of uncoupling activity for a dolly

N_c = number of dollies/ shifts

N_{ech} = number of minutes/ shifts

N_p = numărul de prinderi

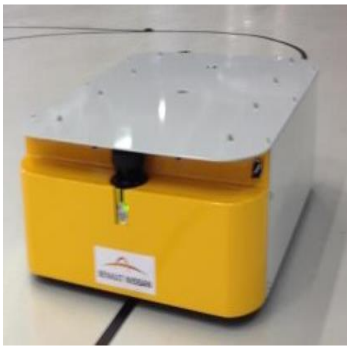
The Payback period for the investment in the implementation of an AGV circuit for the supply of an assembly line can be determined with the following formula:

$$PB = \frac{\text{Investment cost}}{\text{Functioning cost}_{\text{initial}} - \text{Functioning cost}_{\text{after implementation}}} \qquad (5)$$

THE CAS STUDY: PAYBACK PERIOD CALCULUS OF THE IMPLEMENTATION OF AN AGV CIRCUIT IN AN ASSEMBLY LINE

The case study takes place on an assembly line that is supplied with parts from a logistics preparation area. The parts are arranged, on dollies, in the order of entry into manufacturing. The dollies are transported in the assembly line with the help of an electric tractor, driven by a logistics operator, and the calculation of the profitability of the implementation of an AGV circuit for the supply of the workstations within the assembly line is desired.

The improvement of the flow of the supply of parts to the workstations is done by replacing the existing means of transport with an AGV, ure 1, whose coupling-uncoupling system of the dollies can be manual or automatic, the characteristics being presented in Table 1.



. 1. AGV

Table 1. AGV characteristics

Dimensions [mm]	Length	950
	Width	750
	Height	273
Capacity [kg]	Boarded	1100
	Towed	1600
Speed [m/min]	0 - 40	
Autonomy [h]	10 - 25	

The initial data needed for the implementation of the AGV circuit are presented in Table 2.

Table 2. Initial data of the assembly line

Dolly capacity	V_{med} [m/min]	d [m]	$T_{p/d}$ manual	$T_{p/d}$ automated	N_s	Line cycle time [min]	Circuit autonomy	AGV efficiency
60	20	94	0,64	0,5	2	0,76	45,6	0,9

Depending on the number of products to be made per shift, the number of dollies to be transported for each workstation is determined (Table 3).

Table 3. Determining the number of dollies per shift

N_p, [pcs]	N_m, [pcs]	N_c, [pcs]
60	540	9

The circuit duration for each dolly coupling system is shown in Table 4 and the number of AGVs is shown in Table 5.

Table 4. Cycle duration

D_c	
Manual	Automated
5,98	5,70

Table 5. Number of AGVs

N_{AGV}		Total N_{AGV}	
Manual	Automated	Manual	Automated
0,14	0,13	1,81≅ 2	1,77≅ 2

Investment cost, Table 8, which consists of the total cost of the AGV, Table 6, and the implementation cost, Table 7. The implementation cost consists of the route painting cost, the cost of the TAGs, and the cost of the pick-up/drop-off station.

Table 6. AGV cost

	Manual	Automat
AGV Price [€]	9700	
Battery [€]	600	
Charger [€]	550	
Dolly coupling mechanism [€]	450	
Automated coupling station [€]	0	2000
Hook (D=50 mm), [€]	280	
Actioning console (wired), [€]	475	
WEGA box (wireless), [€]	990	
Total AGV cost [€]	**13045**	**15045**

Table 7. Implementation cost

	Qty	Price [€/unit]	Manual	Automat
Paint	185	16	2960	
TAGs	30	7	210	
Automated docks	0 - 2	3000	0	6000
Implementation cost [€]			3170	9170

Table 8. Investment cost

	Manual	Automated
Number of AGV	2	2
AGV cost [€]	13045	15045
AGV system total cost [€]	26090	30090
Implementation cost [€]	3170	9170
Total investment [€]	29260	39260

In the case of manual coupling systems, the workload of the operator will be determined. The operator workload per shift for coupling/uncoupling of the dolly is calculated in Table 9.

Table 9. Operator workload to coupling/ uncoupling of dollies

T_p , [min]	T_d, [min]	N_c , [buc]	N_{ech} , [min]	N_p	A_{op}, coupling [%]	A_{op}, uncoupling [%]
0.35	0.29	9	435	2	1.45	1.20

Table 10 shows the operator's total workload per shift, and it's cost per year for the manual coupling system.

Table 10. Operator total cost per year

$T_{a\ op}$, [%]	N_e, [min]	C_{op}, [€]	$C_{op/year}$, [€]
18,55	3	14000	7791

The results of the analysis of the efficiency of the implementation of an AGV circuit for the supply of workstations within the assembly line will be centralized in the following Table, and the Payback period of the investment will be calculated.

Table 11. Results Synthesis

Functioning cost	Initial situation	Proposed scenarios	
		Manual coupling	Automat coupling
$C_{op/an}$ [€]	18170	7791	-
$C_{tr/an}$ [€]	3388	-	
Yearly battery change [€]		1200	1200
Total yearly functioning cost [€]	21558	8991	1200
Yearly gain in functioning cost [€]	-	12567 (-58%)	20358 (-94%)
Total investment [€]	-	29260	39260
Payback period [ani]		**2,32**	**1,92**

CONCLUSIONS

In this paper, a method for calculating the profitability of an automation proposition is presented. The porpoise being to show a method for an easy evaluation of 2 scenarios from the technical point of view, from the economic point of view (implementation cost and functioning cost) and the calculus of an indicator that can help the decision-making process.

In the case study we can see how we can compare 2 automation scenarios using AGV systems, starting from an initial situate of an assembly line supply done with an electrical tractor and operator. After the

technical description, we can see the calculus of the equipment needed depending on the characteristics of the assembly line: number of dollies, number of AGVs etc.
There are calculated 2 types of costs: the cost for the implementation of each scenario and the yearly functioning cost. The yearly functioning cost is compared with the cost in the initial situation. In our case study we can see that both scenarios are less expensive in the yearly functioning cost (with 58% and with 94%). Comparing the investment cost we can see that the fully automated scenario is with 34% more expensive than the manual coupling version.
Using the Payback period calculus allows us to chose between the two scenarios comparing the yearly functioning gain with the initial investment in the same industrial system hypothesis. This very useful indicator shows us that the second scenario even if it has a higher implementation cost, considering its yearly functioning cost allows for a return in investment of 1.9 years, lesser from the 2.3 years of the first scenario.
This methodology is very useful when comparing complex scenarios in an evolving industrial environment that demands a constant reduction in manufacturing prices with a minimum of initial investment.

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