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INDUSTRIAL PLANTS

Chapter seventeen:

Transport system Automatic Guided Vehicle (AGV)

DOUBLE DEGREE MASTER IN

“PRODUCTION ENGINEERING AND MANAGEMENT”

SEAT OF PORDENONE

UNIVERSITY OF TRIESTE

Generality

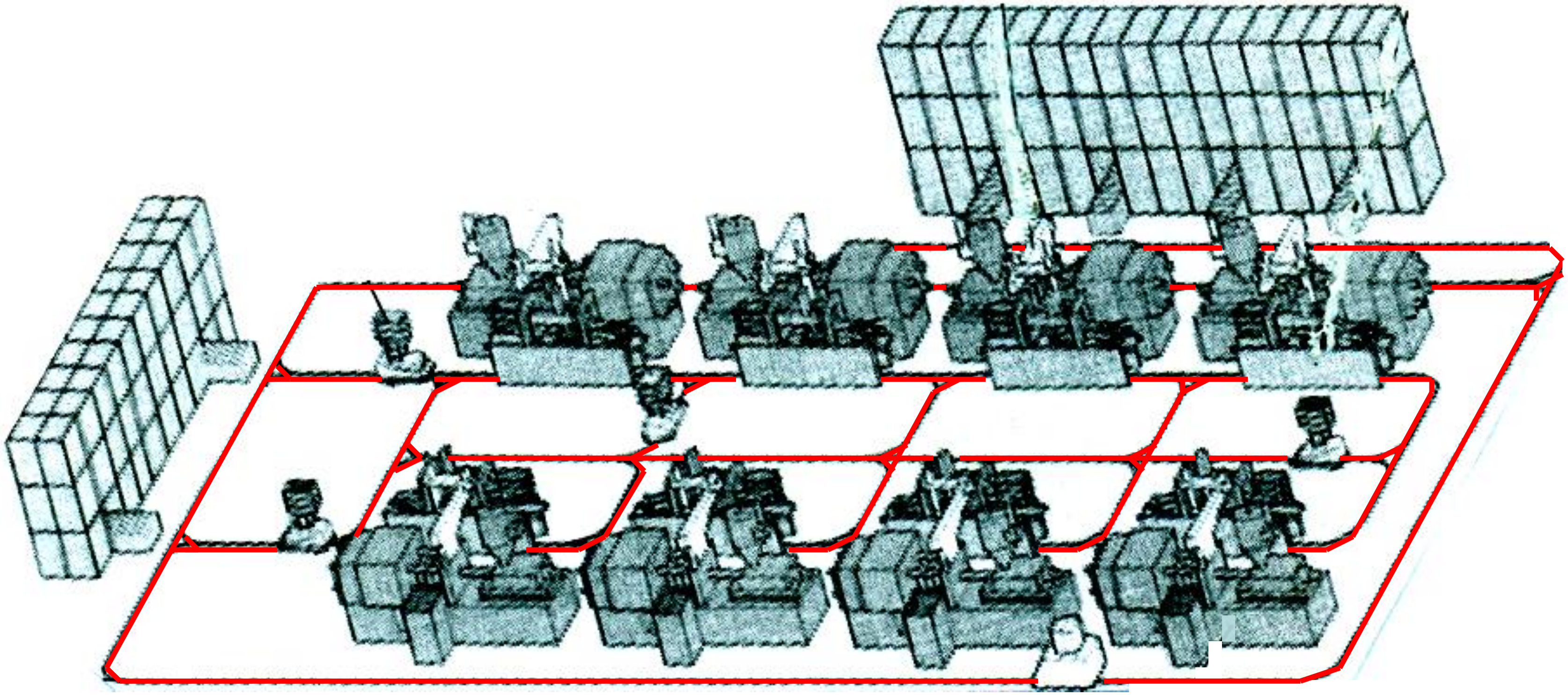
The **AGV system** identifies the trolleys or vehicles used primarily in the industrial field for the handling of products within a plant, along a series of complex paths.

These are systems that arise from the need to overcome the constraints in terms of management by the rigidity of classical industrial trucks (size, maneuverability, balance, energy costs, the presence of an operator for each machine, etc.).

The AGV systems using truck at three or four wheeled, which move in an automatic way within an establishment; from the point of view of power supply, are equipped with a system of accumulators, which makes them autonomous, which gives energy, or by an electric motor.

Generality

System AGV



Generality

There are four **basic components** of a transport system AGV:

a) vehicles or trucks at automated guide, which allow the transport;
b) a system that allows you to drive vehicles or trucks along the fixed routes;
c) a system that transmits information and load situations between vehicles or trucks and the management information system and vice versa;
d) a management information system of the AGV system, which allows the programming and optimal operation of automated transport, and control of activities.

Generality

The areas of use of AGVs in industry within the FMS (Flexible Manufacturing System) and FAS (Flexible Assemby System) are: aerospace, automotive, food, paper, electronics, pharmaceutical, healthcare, textiles etc.

Generality

The AGVs permit a number of advantages such as:

- intermittent flow of materials on variable paths;
- selective routing of loads or packages;
- simple changing of the layout;
- absence of fixed installations, apart from the magnetic stripe inground in the case of the optical guide inductive or on the floor in the case of optical guide reflected light or by laser;
- rapid change in the capacity of the movement system through the addition or subtraction of trucks;

Generality

The AGVs permit a number of advantages such as:

- fast programming of paths;
- high accuracy in positioning of the vehicle;
- good interface with the management information system of material flows;
- real time traceability of the placement of materials;
- rational and efficient use of spaces.

Type and performance of AGV systems

The **types of industrial applications** that allow to find different configurations of vehicles:

a) load towing

This vehicle is presented with characteristics similar to those of a small train, in which the tractor pulls the various trailers on which are placed the pieces to be moved

Type and performance of AGV systems

The **types of industrial applications** that allow to find different configurations of vehicles:

b) unit load carrier

This system enables movement of one or more cargo units (such as one or two pallets). The extreme structural flexibility dell'AGV also allows to provide for automated loading and unloading, in addition to manual, where the automatic operation of the roller conveyor or a belt or the use of telescopic forks allows the desired operation without the presence of an operator . This system allows to interface with other movement means.

The **types of industrial applications** that allow to find different configurations of vehicles:

c) light-load carrier

This system allows the movement of small units (individual pieces). Since the UdC may be of multiple and different forms, the operations of loading/unloading are manual

Type and performance of AGV systems

The **types of industrial applications** that allow to find different configurations of vehicles:

d) ***fork truck***

This system has a configuration similar to the fork lift truck and is used for the handling of the pallets with source and destination both floor that on shelves. It is used when the pavement has a good flatness and uniformity

Type and performance of AGV systems

The **types of industrial applications** that allow to find different configurations of vehicles:

e) assembly vehicle

This system is used in the automotive sector in the phases of assembly and construction of cars. It allows an easy accessibility of the operators

Type and performance of AGV systems

The **types of industrial applications** that allow to find different configurations of vehicles:

f) special vehicle

These are systems that allow applications to special handling (ad example handling unit very heavy or AGV used in special environments such as clean room)

Type and performance of AGV systems

The wire-guided vehicles AGV have speed around 50 m/minute, a maximum deviation from the path around the 4 mm and an accuracy of approach of 2 mm.

The limit on the maximum climbable gradient is 5% if the vehicle is loaded, while 10% if it is discharged.

We use three sets of accumulators.

Type and performance of AGV systems

The guidance systems are divided into:

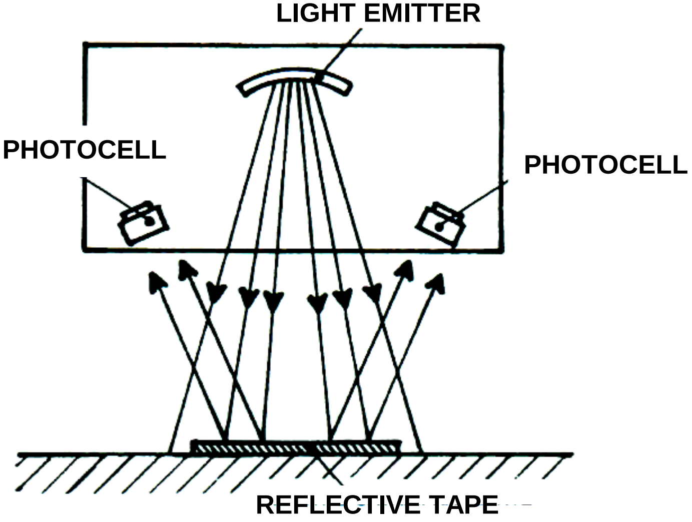
a) fixed path

They require the installation of a track on the floor (magnetic tape, photosensitive or reflective strip) or under the surface, and follow a certain path.

The automatic systems of guide for this type of route are:

- *<u>at guidance optical at reflected light</u>*

  The path is identified by the presence of reflective tapes placed on the floor which reflect the light beam that comes from vehicles. The reflected rays are picked up by suitable devices placed on vehicles



Type and performance of AGV systems

The guidance systems are divided into:

a) fixed path

The automatic systems of guided for this type of route are:

- *at guidance optical through laser*

On board the vehicle is installed a scanner transmitter/receiver of laser beams, which calculates the position of the vehicle in the plant compared to the reference reflectors placed along the perimeter of the department or establishment. In this way any extensions and modifications of the paths are much easier than the wire-guided system, making the system at guided laser more flexible

Type and performance of AGV systems

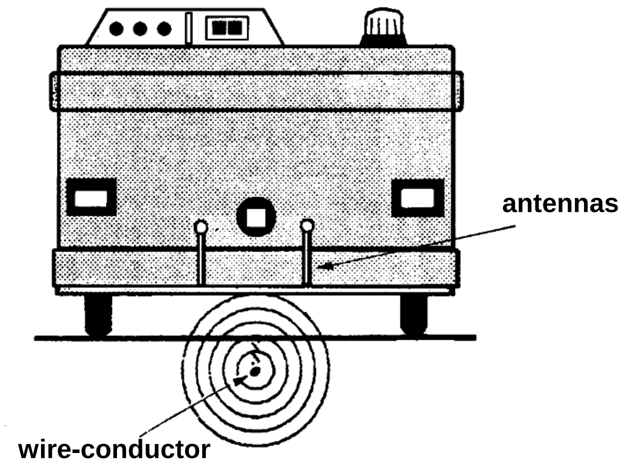
The guidance systems are divided into:

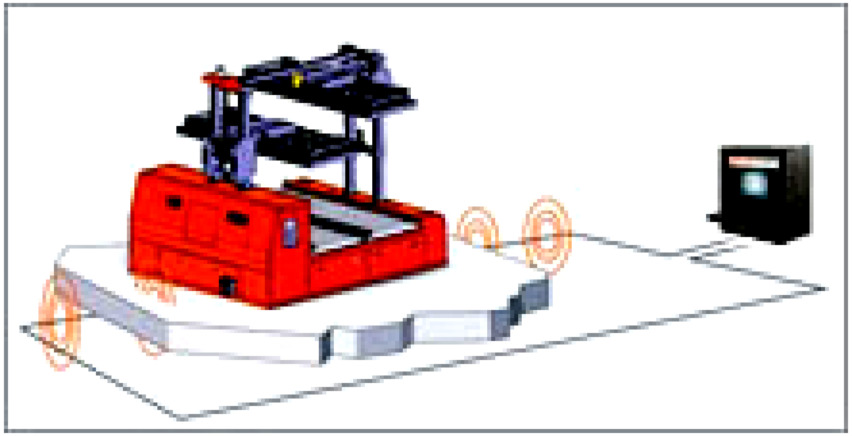
a) fixed path

The automatic systems of guided for this type of route are:

- *at guided inductive*

  Is the guidance system most used in industrial plants





Type and performance of AGV systems

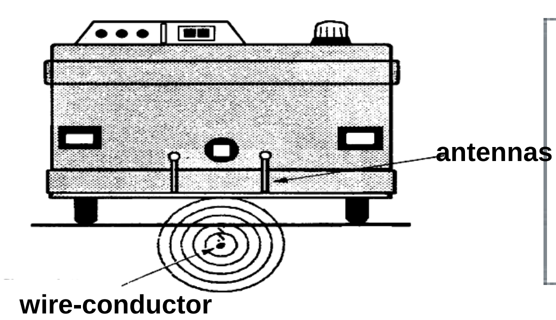
The guidance systems are divided into:

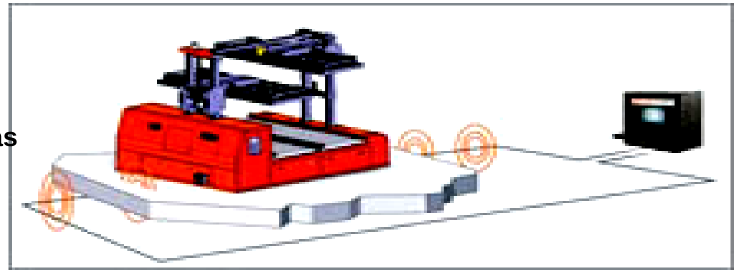
a) fixed path

The automatic systems of guided for this type of route are:

- *at guided inductive*

The inductive guidance consists of a wire conductor (copper wire section of 1.25 - 1.5 mm^2 insulated with coating in plastic) placed under the pavement within a few millimeters deep and wide groove between 10 -15 mm. The groove is then closed with a layer of spongy rubber and covered with synthetic resin. The guide inductive allows the truck to follow the magnetic field generated by current flowing through a wire buried in the floor, through a pair of antennas.





Type and performance of AGV systems

The guidance systems are divided into:

a) fixed path

The automatic systems of guided for this type of route are:

- *at guided mechanical*

  The vehicle moves on rails, so that the accuracy and approach is very high, but the flexibility of the route is reduced.

  They are suitable in those contexts in which the trajectories, on which moving vehicles, are defined and repetitive, and allow high operability due to the complete independence from the human factor and allows to perform the elementary operations of loading and unloading. The rigidity of operation is linked to the impossibility of the possible return of the rail and waste of space linked to the large radii of curvature of the rails.

Type and performance of AGV systems

The guidance systems are divided into:

a) fixed path

The automatic systems of guided for this type of route are:

- *at guided mechanical*

The guidance systems are divided into:

b) variable path

They require a map of the area in which they operate vehicles and a series of reference points that can be detected by the same. They are more flexible than guidance systems at fixed route because they choose a path.

Type and performance of AGV systems

The guidance systems are divided into:

b) variable path

The automatic systems of guide for this type of path are:

- *at guidance optical through camera*

This system involves the use of a camera with color recognition reported on a colored tape or a series of feedback colored at floor. A camera on board the vehicle recognizes the image of the tape or the feedback and allows to drive the vehicle along the route predetermined, evaluating the position. Attention to the dirtying.

Type and performance of AGV systems

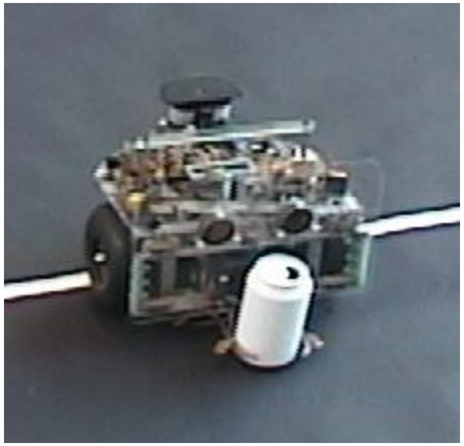
The guidance systems are divided into:

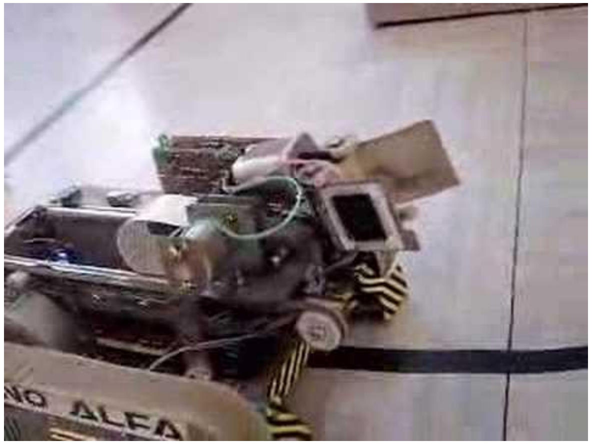
b) variable path

The automatic systems of judah for this type of route are:

- *at guidance with cartesian reference*

  The vehicle operates on a cartesian grid reference, where sensors detect the two cartesian coordinates that determine the specific location. An odometer measures the distance traveled, while a gyroscope maintaining and corrects the direction of the vehicle





Type and performance of AGV systems

The guidance systems are divided into:

b) variable path

The automatic systems of judah for this type of route are:

- *at guidance inertial*

The driving of the vehicle is obtained by a gyroscope, which measures the orientation of the vehicle in the same plane, from an odometer, which calculates the distance traveled, and from the magnetic sensors, positioned under the vehicle, which detect the presence and recognition of plaques magnetic control positioned on the floor. The information is used to determine the position of the vehicle and possibly correct it. The communications take place with the center via radio.

Type and performance of AGV systems

The guidance systems are divided into:

b) variable path

The automatic systems of judah for this type of route are**:**

- *at guidance optical through laser*

This system has been described in guidance systems to fixed path.

Type and performance of AGV systems

The transmission of commands and information are obtained through:

- **alphanumeric keyboard**, which transmits the encoded messages (path to follow, the operations of loading/unloading etc.) to the microprocessor on board the vehicle;
- **by induction**, whose information is exchanged with the vehicle is transmitted via a cable disposed under the floor. Through the modulation frequency or intensity of the current, you can send commands and information to the antennas or coils of the vehicle and vice versa;
- **infrared rays**, allowing the conversation between the sensors of the dedicated PC and the vehicles via optical pulses in the infrared range. Along the path are installed drive unit consisting of LED (Light Emitting Diode), which convert the electrical impulses of the dedicated PC in the infrared. The latter is received by the receiving unit installed on vehicles that turn them back into electrical impulses;

Type and performance of AGV systems

The transmission of commands and information are obtained through:

- **by optics**, through the use of suitable transmitters-receivers that are positioned along the optical path of the vehicles and on board of the same; in this way each vehicle receives instructions on the destination and on the operations to be performed;
- **radio waves in the UHF** (**Ultra High Frequency**), which provide continuous conversation between the vehicle and central control.

Type and performance of AGV systems

The **control system of an AGV system** is usually of type hierarchical at levels.

At the lowest level is positioned to ***control the machine of the single AGV***, realized by a microprocessor installed in the vehicle itself. The latter receives the information from the top hierarchy level and control vehicle functions (direction, speed, stops due to obstacles, etc.

At a higher hierarchical level is a ***control of department of the entire fleet of AGVs***, which are assigned tasks of fleet management (job assignment and location, management of maintenance etc.)

At the highest hierarchical level one has the general ***control system of supervision of the handling system of the plant***, which has the task to coordinate between themselves and with the production system the different handling systems.

Type and performance of AGV systems

The **management of the AGV system** is realized using the queuing theory, the numerical simulation etc. They must therefore be determined using the rules by which the entire fleet of AGVs serve a number of operating stations, taking into account any constraints (path, to meet production schedules, priorities technology, maintenance, etc.) And functions to be optimization (minimization of paths and expectations, the maximum saturation of machines, even using the trucks etc.).

Design of an transport system AGV

The design of an transport system AGV following a procedure that involves the following steps:

- knowledge of plant layout;
- choice of paths to create preferential paths of the lines as straight as possible and with large radii of curvature;
- determination of the total distance to be traveled in a given time interval (for example one shift) known the material flow;
- determination of the total journey time for a single-vehicle AGV, given the average speed (v_m = 0,4 - 0,7 m/s);
- choice of the increase of the total time to take into account the time of loading, unloading and waiting that help you calculate the total time;
- determining the minimum number of vehicles defined by the ratio between the calculated and the total time period of reference (one work shift);

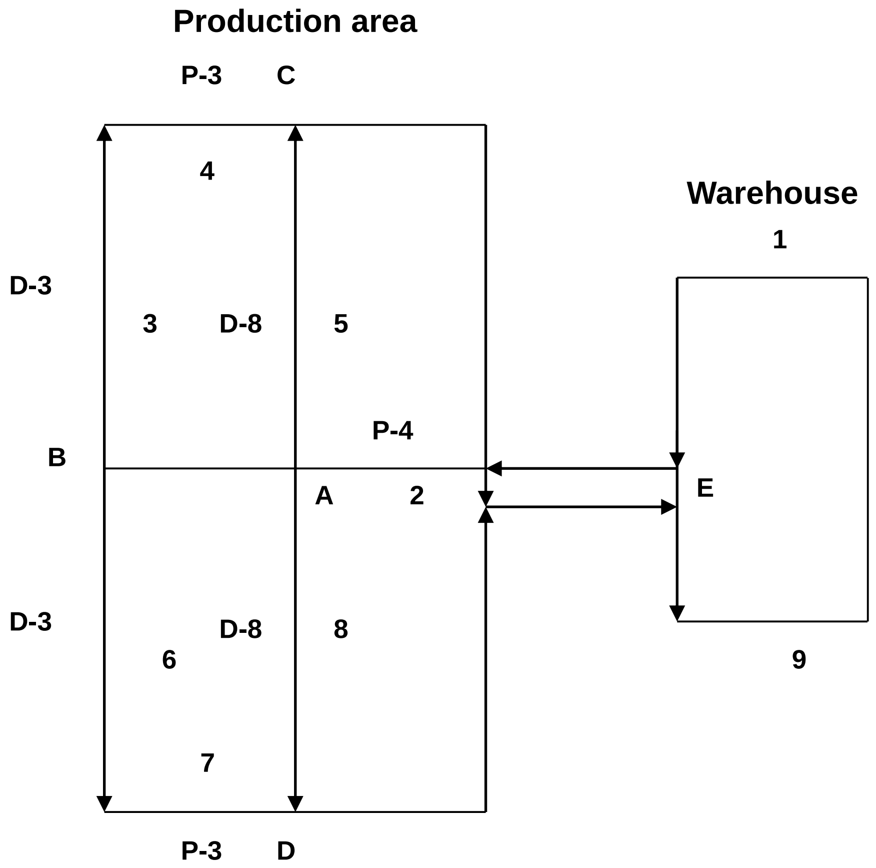
Design of an transport system AGV

The design of an transport system AGV following a procedure that involves the following steps:

- choice of the type of vehicle by referring to the average speed and peak, the acceleration and the deceleration, the maximum capacity, the maximum size compatible with the lanes to be traveled;
- conducting of the design verifications;
- refinement of the design using simulation in order to derive the performance and pinpoint bottlenecks, interference between vehicles and path failures. This step allows you to identify possible improvements to the basic solution that can translate into substantial savings even during the acquisition and installation of the AGV system.

Design of an transport system AGV

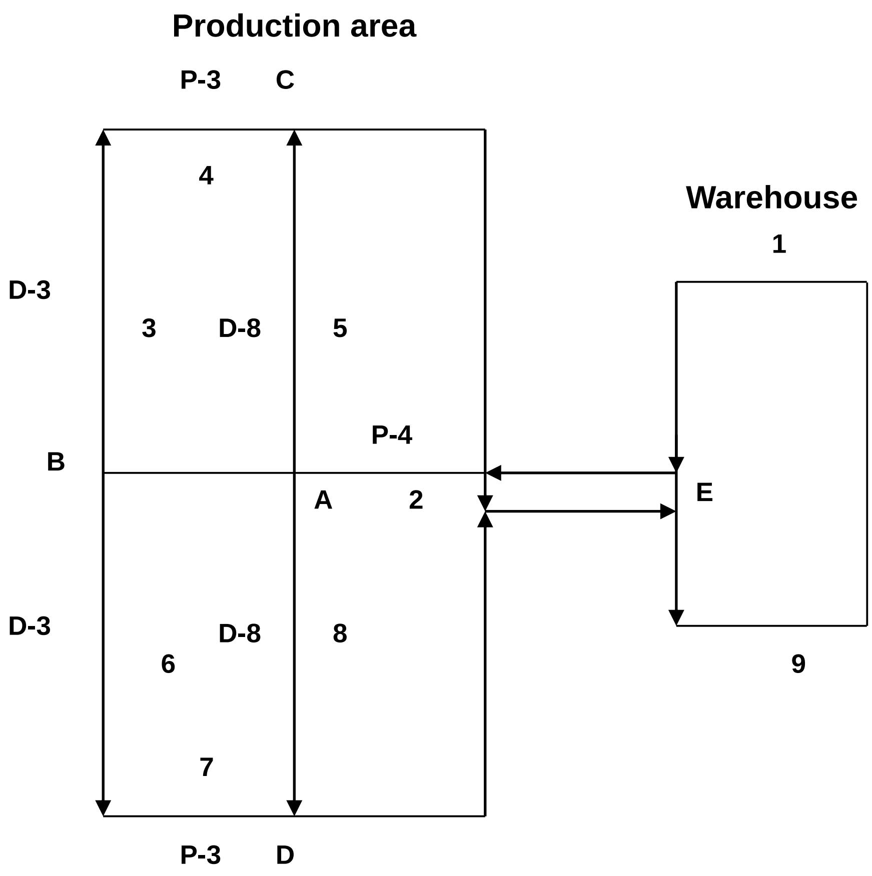
Known the layout of the plant with the position of the loading stations and unloading (numbered from 1 to 9) and the choice of preferential paths



Design of an transport system AGV

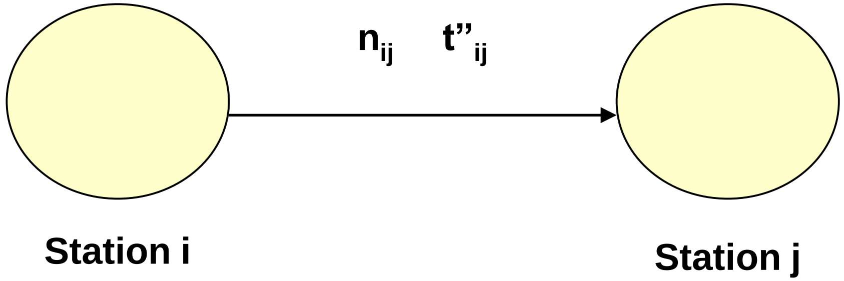
The nodes of the paths are indicated with the letters A and E, while with (D-k) are indicated the k vehicles that are downloaded into the station D during the reference duration (one work shift) or with (P-y) is indicate the y vehicles that are loaded in the station P during the same duration as the reference (one work shift).

The values k and y are known as assigned in the sheet origin-destination consequent to the flow of vehicles between the stations.



Design of an transport system AGV

With reference to the diagram of figure is denoted by:



n_{ij} = number of loads vehicles that during a work shift must be moved from station i to station j;

t''_{ij} = total time for load a vehicle in the station i, move it and download in station j.

The track is treated as a network of straight line segments and nodes corresponding to the intersection of the lines. Each segment may have of points of loading and unloading.

Each segment is divided into a number of contiguous zones, such as to allow the passage of a vehicle at a time to the area, in order to avoid collisions and to control access to the nodes.

Design of an transport system AGV

In this situation it is assumed that:

- the vehicles move in one direction along a segment;
- the vehicles can not overtake along a segment;
- the time of loading and unloading are known for each job;
- the transport times are known, known the average speed of vehicles loading and unloading;
- is known to the load to be moved from one station to another, even if it is not permitted the distribution of loads between the vehicles and therefore should be considered of the cargo units whole.

Design of an transport system AGV

Indicating with:

t_i = loading time in the station i;

u_j = discharge time in the station j;

t'_{ij} = travel time to load a vehicle to go from the station i to station j;

The total time to load a vehicle in the station i, move it and download it at the station j, is expressed by the relation:

$$t''_{ij} = t_i + u_j + t'_{ij}$$

The movement between the station i and the station j is realized by selecting the path with less travel time.

Design of an transport system AGV

Indicating with:

$\sum_j n_{ij}$ = number of vehicles needed at the station i to move the material in the work shift as the number of vehicles exiting the station i and arriving at every station j

$\sum_i n_{ij}$ = number of vehicles arriving at the station j in work shift equal to the sum of all vehicles starting from the various stations i arrive at station j

In the event that the work stations do not have the interoperational buffers, the flow of vehicles entering must equal those in output, while when they are present may occur a certain difference between the flow of vehicles incoming and outgoing. Is possible that to start or end of each round there are empty trips in order to rebalance the system to initial conditions predisposing for the production of the next turn.

Design of an transport system AGV

The total time for the activity of transport relating to a work shift, net of empty trips of rebalancing of the system at the beginning and end of the shift is expressed by the relation:

$$\sum_i \sum_j n_{ij} \cdot t_{ij}^{''}$$

If you consider the trips empty of rebalancing of the system at the beginning and end of shift, you should consider an increase in time that indicates with ΔH. The total time H is therefore:

$$H = \sum_i \sum_j n_{ij} \cdot t_{ij}^{''} + \Delta H$$

Denoting by h the period of availability of a vehicle AGV in one work shift, it determines the minimum number of vehicles Y given by the relation:

$$Y = \frac{H}{h}$$

which approximates to the next upper number.

Design of an transport system AGV

The net flow of vehicles in the station i - NF (i) - is given by (with the minus sign indicating the flow of materials exiting from the station i for go to the stations j and with a plus sign indicanting the flow incoming into the station i from the stations j):

$$NF(i) = -\sum_j n_{ij} + \sum_j n_{ji} + f_i - g_i$$

with f_i and g_i indicate the vehicles available from the station i at the beginning of the shift and those required at the station i at the end of the shift.

It seems evident that must be, as far as possible, the following relationship:

$$\sum_i NF(i) = 0$$

Design of an transport system AGV

Therefore it is a relocate optimally the vehicles made redundant in the work station i, in the case where NF (i)> 0, to meet the demands of the other work stations j that have NF j (j) <0.

Assuming:

$$a(i) = \begin{cases} NF(i) & se\ NF(i) \geq 0 \\ 0 & se\ NF(i) < 0 \end{cases} \qquad b(i) = \begin{cases} NF(i) & se\ NF(i) < 0 \\ 0 & se\ NF(i) \geq 0 \end{cases}$$

and having denoted by:

ts_{ij} = time of the shortest path from the workstation i to the j when the vehicle is empty;

xs_{ij} = number of trips to empty vehicle that should be made from the workstation i to the j during one work shift for requirements for rebalancing the system

Design of an transport system AGV

The total travel time of vehicles along the route during a work shift is expressed by the relation:

$$\Delta H = \sum_i \sum_j x_{ij}^s \cdot t_{ij}^s = S$$

You can determine the set of values of variable xs$_{ij}$ that minimize the objective function S with the boundary condition:

$$\sum_j x_{ij}^s = a_i$$

$$-\sum_j x_{ji}^s = -b_i$$

$$x_{ij}^s \geq 0$$

The problem is typical of linear programming in which the variables have integer values.

Design of an transport system AGV

Is required the knowledge of the handling time of the vehicle empty from a node closest to the work station on a segment that departs from that node or from a starting node at an end node if there are work stations along the following or from work stations or another, most recently, from one workstation to the terminal node.

Design of an transport system AGV

They are assigned the average time between the transfer of the layout areas analyzed without considering the time of loading/unloading from the origin-destination table.

From	To	Time (s)
A	B	52
A	5	80
A	8	56
B	3	52
B	6	52
5	C	48
8	D	48
3	4	144
6	7	132
C	E	210
D	E	210
4	C	48
7	D	36
E	9	126
9	1	166
1	2	180
2	A	40

Design of an transport system AGV

In the absence of interference phenomena between the vehicles, you can determine the minimum time for moving the vehicle between the workstations on the shorter routes, the origin-destination table (From/To) shows the values measured in seconds:

From	To								
Station	1	2	3	4	5	6	7	8	9
1		180	324	468	330	324	456	276	660
2	648*		144	288	120	144	276	96	480
3	696	876		144	948	1188	1056	972	696
4	552	732	876		852	876	912	828	384
5	540	732	876	1020		1044	912	828	384
6	672	852	996	1140	972		132	948	504
7	540	720	864	1008	840	864		816	372
8	552	732	876	1020	852	876	1008		384
9	168	348	492	498	498	492	624	444	

* The paths to reach by workstation 2 at the 1 are four: 2-A-B-3-4-C-E-9-1, 2-A-B-6-7-D-E-9-1, 2-A-5-C-E-9-1 e 2-A-8-D-E-9-1 and the times of handling are respectivelòy: 838 s, 814 s, 670 s e 648 s. The minimum time of handling is related to the fourth path and equal to 648 s.

Design of an transport system AGV

If it is considered for simplicity, the equality between the travel time for a vehicle load and the time for the shortest path when the vehicle is to go from the unloading station of the work i to the j:

$$\mathbf{t'_{ij} = ts_{ij}}$$

It can therefore be noted in the table from/to the number of travel of vehicles for work shift, which is equal to the number of load units (UdC):

From	To								
Station	1	2	3	4	5	6	7	8	9
1		-	3	-	8	3	-	8	-
2	-		-	-	-	-	-	-	4
3	-	-		-	-	-	-	-	-
4	-	-	-		-	-	-	-	3
5	-	-	-	-		-	-	-	-
6	-	-	-	-	-		-	-	-
7	-	-	-	-	-	-		-	3
8	-	-	-	-	-	-	-		-
9	-	-	-	-	-	-	-	-	

Design of an transport system AGV

The net flows NF (i) for each workstation, which will match the movements of empty vehicles for rebalancing at the beginning or end of work shift, are:

Number station	1	2	3	4	5	6	7	8	9	Totale
Total To	0	0	3	0	8	3	0	8	10	32
Total From	22	4	0	3	0	0	3	0	0	32
NF(i)	-22	-4	3	-3	8	3	-3	8	10	

Applying the simplex method, it is possible to determine one of the possible solution:

Station From	3	5	9	9	6	8
Station To	4	1	2	1	7	1
NF(i)	3	8	4	6	3	8

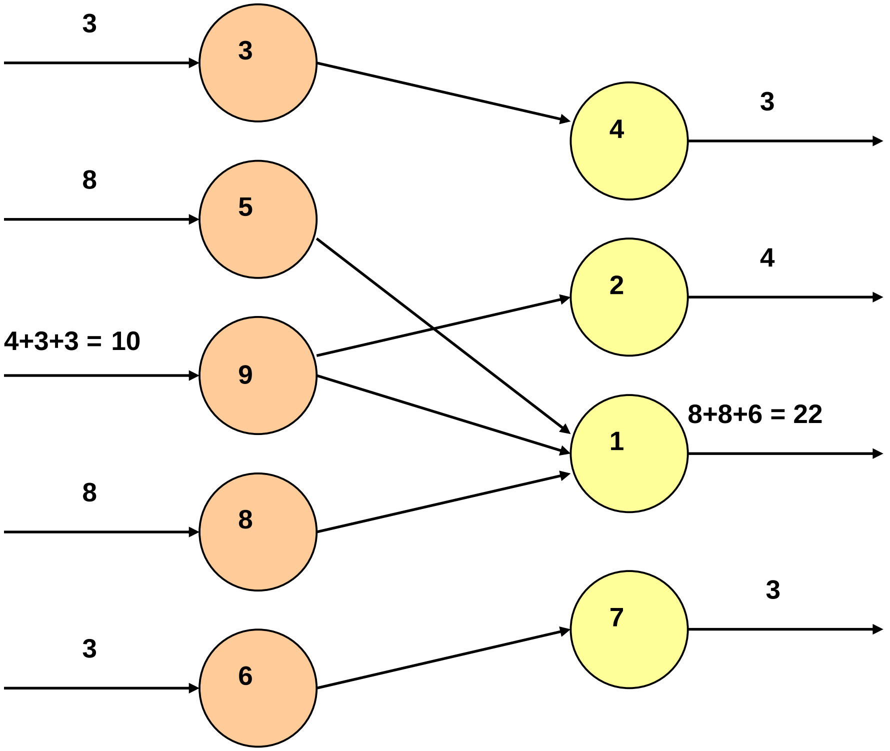
Design of an transport system AGV

To which corresponds the following table From/To:

Da	A								
Stazion e	1	2	3	4	5	6	7	8	9
1		-	-	-	-	-	-	-	-
2	-		-	-	-	-	-	-	-
3	-	-		3	-	-	-	-	-
4	-	-	-		-	-	-	-	-
5	8	-	-	-		-	-	-	-
6	-	-	-	-	-		3	-	-
7	-	-	-	-	-	-		-	-
8	8	-	-	-	-	-	-		-
9	6	4	-	-	-	-	-	-	

Design of an transport system AGV

To which corresponds to the following scheme with the flow of trucks empty:



Design of an transport system AGV

If the problem presents a higher number of unknowns, the manual solution of the linear programming problem with the simplex method is impractical. Using appropriate software programs that help solve the objective function:

$$S = \sum_i \sum_j t_{ij}^s \cdot x_{ij}^s = 0 \cdot x_{11}^s + 180 \cdot x_{12}^s + 324 \cdot x_{13}^s + ... + 624 \cdot x_{97}^s + 444 \cdot x_{98}^s + 0 \cdot x_{99}^s$$

The problem therefore considered 81 unknowns xs_{ij} of which 9 definitely null (xs_{ii})

Design of an transport system AGV

The relations of constraint that express the availability of empty vehicles are:

$$
\begin{cases}
x_{11}^s + x_{12}^s + x_{13}^s + x_{14}^s + x_{15}^s + x_{16}^s + x_{17}^s + x_{18}^s + x_{19}^s = 0 \\
x_{21}^s + x_{22}^s + x_{23}^s + x_{24}^s + x_{25}^s + x_{26}^s + x_{27}^s + x_{28}^s + x_{29}^s = 0 \\
x_{31}^s + x_{32}^s + x_{33}^s + x_{34}^s + x_{35}^s + x_{36}^s + x_{37}^s + x_{38}^s + x_{39}^s = 3 \\
x_{41}^s + x_{42}^s + x_{43}^s + x_{44}^s + x_{45}^s + x_{46}^s + x_{47}^s + x_{48}^s + x_{49}^s = 0 \\
x_{51}^s + x_{52}^s + x_{53}^s + x_{54}^s + x_{55}^s + x_{56}^s + x_{57}^s + x_{58}^s + x_{59}^s = 8 \\
x_{61}^s + x_{62}^s + x_{63}^s + x_{64}^s + x_{65}^s + x_{66}^s + x_{67}^s + x_{68}^s + x_{69}^s = 3 \\
x_{71}^s + x_{72}^s + x_{73}^s + x_{74}^s + x_{75}^s + x_{76}^s + x_{77}^s + x_{78}^s + x_{79}^s = 0 \\
x_{81}^s + x_{82}^s + x_{83}^s + x_{84}^s + x_{85}^s + x_{86}^s + x_{87}^s + x_{88}^s + x_{89}^s = 8 \\
x_{91}^s + x_{92}^s + x_{93}^s + x_{94}^s + x_{95}^s + x_{96}^s + x_{97}^s + x_{98}^s + x_{99}^s = 10
\end{cases}
$$

Design of an transport system AGV

The relations of constraint that express the availability of empty vehicles are:

$$\begin{cases} x_{11}^s + x_{21}^s + x_{31}^s + x_{41}^s + x_{51}^s + x_{61}^s + x_{71}^s + x_{81}^s + x_{91}^s = 22 \\ x_{12}^s + x_{22}^s + x_{32}^s + x_{42}^s + x_{52}^s + x_{62}^s + x_{72}^s + x_{82}^s + x_{92}^s = 4 \\ x_{13}^s + x_{23}^s + x_{33}^s + x_{43}^s + x_{53}^s + x_{63}^s + x_{73}^s + x_{83}^s + x_{93}^s = 0 \\ x_{14}^s + x_{24}^s + x_{34}^s + x_{44}^s + x_{54}^s + x_{64}^s + x_{74}^s + x_{84}^s + x_{94}^s = 3 \\ x_{15}^s + x_{25}^s + x_{35}^s + x_{45}^s + x_{55}^s + x_{65}^s + x_{75}^s + x_{85}^s + x_{95}^s = 0 \\ x_{16}^s + x_{26}^s + x_{36}^s + x_{46}^s + x_{56}^s + x_{66}^s + x_{76}^s + x_{86}^s + x_{96}^s = 0 \\ x_{17}^s + x_{27}^s + x_{37}^s + x_{47}^s + x_{57}^s + x_{67}^s + x_{77}^s + x_{87}^s + x_{97}^s = 3 \\ x_{18}^s + x_{28}^s + x_{38}^s + x_{48}^s + x_{58}^s + x_{68}^s + x_{78}^s + x_{88}^s + x_{98}^s = 0 \\ x_{19}^s + x_{29}^s + x_{39}^s + x_{49}^s + x_{59}^s + x_{69}^s + x_{79}^s + x_{89}^s + x_{99}^s = 0 \end{cases}$$

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By eliminating the xs_{ij} null and using the simplex method, we obtain a solution:

Station From	3	5	9	9	6	8
Station To	4	1	2	1	7	1
NF(i)	3	8	4	6	3	8

which corresponds to the minimum value of the objective function:

$S = \Delta H = 11.748$ s

Assuming the time of loading of the work station 1 (t_1) and of the work station 2 (t_2) and the time of loading of the work station 9 (u_9) same and equal to:

$t_1 = t_2 = u_9 = 300$ s

and all other times t_i and u_j equal to 1200 s, we obtain the total time for the activity of transport for the shift, net of empty rebalancing of the system at the start and at th eend of shift, that is equal to:

$$\sum_i \sum_j n_{ij} \cdot t_{ij}^{''} = 55.380 \ s$$

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Obtainable from the sum of the values:

i=1	da	i=1	a	j=3	$t''_{13} = t_1 + u_3 + t_{13} = (300 + 1200 + 324) = 1824 \; s$	$n_{13} = 3$	$3 \cdot 1824 = 5472 \; s$
	da	i=1	a	j=5	$t''_{15} = t_1 + u_5 + t_{15} = (300 + 1200 + 330) = 1830 \; s$	$n_{13} = 8$	$8 \cdot 1830 = 14640 \; s$
	da	i=1	a	j=6	$t''_{16} = t_1 + u_6 + t_{16} = (300 + 1200 + 324) = 1824 \; s$	$n_{13} = 3$	$3 \cdot 1830 = 5472 \; s$
	da	i=1	a	j=8	$t''_{18} = t_1 + u_8 + t_{18} = (300 + 1200 + 276) = 1776 \; s$	$n_{13} = 8$	$8 \cdot 1776 = 14208 \; s$
i=2	da	i=1	a	j=9	$t''_{29} = t_2 + u_9 + t_{29} = (300 + 300 + 480) = 1080 \; s$	$n_{13} = 4$	$4 \cdot 1080 = 4320 \; s$
i=4	da	i=4	a	j=9	$t''_{49} = t_4 + u_9 + t_{49} = (1200 + 300 + 384) = 1884 \; s$	$n_{13} = 3$	$3 \cdot 1884 = 5652 \; s$
i=7	da	i=7	a	j=9	$t''_{79} = t_7 + u_9 + t_{79} = (1200 + 300 + 372) = 1872 \; s$	$n_{13} = 3$	$3 \cdot 1872 = 5616 \; s$

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Assuming the duration of the shift equal to 26,100 s, and assuming you choose the AGV with the same autonomy of service, you get the minimum number of trucks needed using the relation:

$$Y = \frac{H}{h} = \frac{55380 + 11748}{26100} = 2{,}57$$ that is approximates at 3

The problem analyzed is static, but one must consider the dynamic aspect in that it must consider the behavior of the system over time. Recourse must be had in this case to a model developed with a simulation program, which must have the rules of precedence of the orders of movement of vehicles and the sequence in which the stations are reached by vehicles trying to avoid the occurrence of phenomena of locking of the outflow lines or interference between vehicles at intersections.

A specific approach can be found in the literature to which we refer.