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METHODOLOGICAL PROPOSAL FOR AN INDOOR INDUSTRIAL AGV IMPLEMENTATION

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Abstract: The present article aims to succinctlycharacterizethe first implementationof a system of AGVs (Automated Guided Vehicles) in a factory of components for the automotive industry. Furthermore, to solidify the knowledge base upon which this article was developed, it is imperative to propose a classification approach for the different types of AGVs due to particularly heterogeneous points of view within the community. Finally, the costs between the former transportation solution, the implemented one and a third suggested by a methodological proposal for AGV implementation in an indoor, industrial context developed by the author, were compared aiming to justify the investment validity in this technology. The implementation was completed resulting in a reduction of labor costs with a payback period of 6 months and 14 days.

Key words: AGV implementation, AGV types, cost comparison, methodological proposal.

1. TYPES OF AGVs

Different sources classify AGVs in a variety of ways. Some consider that the vehicles are of a different type even if between them only the load capacity differs (AGVE, 2019). Others defines boundaries between levels of automation; if an AGV operates fully independently it belongs to one type and if it depends onmanual input, it's called a hybrid (DEMATIC, 2019). Another source argues that the navigation methods are the main criteria to distinguish between types of AGVs (Ventriglio, 2004). Each source classifies the types of AGVs according to its academic interest or financial focus.
Therefore, there's a need to come up with a broader, more objective classification approach.
Concisely, an AGV is a vehicle that transports a load from point A to B. The load capacity may vary, the vehicle may be wider or narrower, the circuit may be bigger or smaller and so forth. However, the most differentiating factor is the way each AGV loads the cargo, transports it and, finally, delivers it. Consequently, the categorization shall be based on the operating principle (Engineering 360, 2019).

1.1. Tow or tugger vehicles

These vehiclesmove the cargo by pulling one or more non-powered vehicles (Alamkhan, 2015). They are especially beneficial in cases that require the transportation of a heavy load (up to 23.000 Kg) or of a high volume of goods (Savant, 2019).
The interface between the AGVs and the load, the hitch, can be either manual or automatic and the configuration of the AGVs is generally similar to Figure 1 and Figure 2.

Fig. 1. Tow AGV with manual hitch [16]

Fig. 2. Tow AGV with automatic hitch [19]

1.2. Unit load/Heavy burden vehicles

The load is carried on the AGVs structure but the way they acquire, transport and deliver it may vary. Conveyor decks (Figure 3), lift decks (Figure 4) and robotic arms (Figure 5) are examples of how versatile these AGVs can be.
Two other subclassifications are commonly made based on the maximum load capacity. The first with a weight limit of 250 Kg (Raki, 2015) called Unit Load Vehicle

(Figure 6) and the second with a limit of 340.000 Kg (Savant, 2019) named Heavy Burden Carrier (Figure 7).

Fig. 3. Unit Load AGV with a Conveyor Deck [6]

Fig. 4. Unit Load AGV with a Lifting Deck [7]

Fig. 5. Unit Load AGV with a Robotic Arm, [5]

Fig. 6. Unit Load Vehicle [20]

Fig. 7. Heavy Burden Carrier [15]

1.3. Fork vehicles

Fork AGVs embody the most direct replacement of the classic, human operated forklifts. The maximum reach is around 6m (Alamkhan, 2015) and the load capacity limit is 2000 Kg (Savant, 2019).

These AGVs are ideal for a scenario where the loading and unloading stations have a height differential. There are models best suited for floor-to-floor transfers, where the height difference is minimal (Figure 8), and others prepared for high-bay racking (Figure 9).

It is relevant to keep in mind that different attachments can be mounted on the AGV to better suit distinct applications (Figure 10 and Figure 11).

Fig. 8. AGV floor-to-floor [14]

Fig. 9. High-bay racking AGV [8]

Fig. 10 Fork AGV: Example 1 [11]

Fig. 11. Fork AGV: Example 2 [9]

2. PRE-AGV PLANTLOGISTICS' CHARACTERIZATION

The site is plain, without ramps, doors or any other kind of barriers and the floor shows no deformations.

Three production lines constitute the plant section (Figure 12) where 4 different products are made: Instrument panel A (IP A); Instrument panel B (IP B); Glove Box and Cover Driver Side (GB + CVR DS).

These products are placed in different racks, which, after reaching full capacity (Table 1), are transported by a forklift to an adjacent warehouse. Finally, at the warehouse, a second forklift correctly distributes the racks.

Table 1. Rack types and respective capacity

Rack type	Maximum capacity (units)
IP A	6
IP B	4
GB	12
CVR DS	40

The analysis of the current logistics' paradigm aims to find a new transportation solution for the 4 described products but since they are transported in racks, the relevant cycle time is the one of the racks (Table 2).

Table 2. Rack types and respective cycle time

Rack type	Cycle time (cycles/hour)
IP A	7.18
IP B	4.38
GB	5.64
CVR DS	2.96

Attending to this depiction, the transportation of products has a high profit potential on account of being a stage that doesn't add any value whatsoever to the product, hence, a minimum of resources should be allocated for it.

There are 3 aspects to be taken into consideration while inquiring about a new transportation solution.

First, the constant struggle to remain competitive in a deeply vibrant market demands a perpetual improvement on productivity. Whether by increasing the output or decreasing the input, a solution must be found. In this specific case, as it often happens in industry, the production volume (the output) is limited by the client demands, which leaves no choice left on the table but to decrease the input. The simplest way to achieve it is through automation.

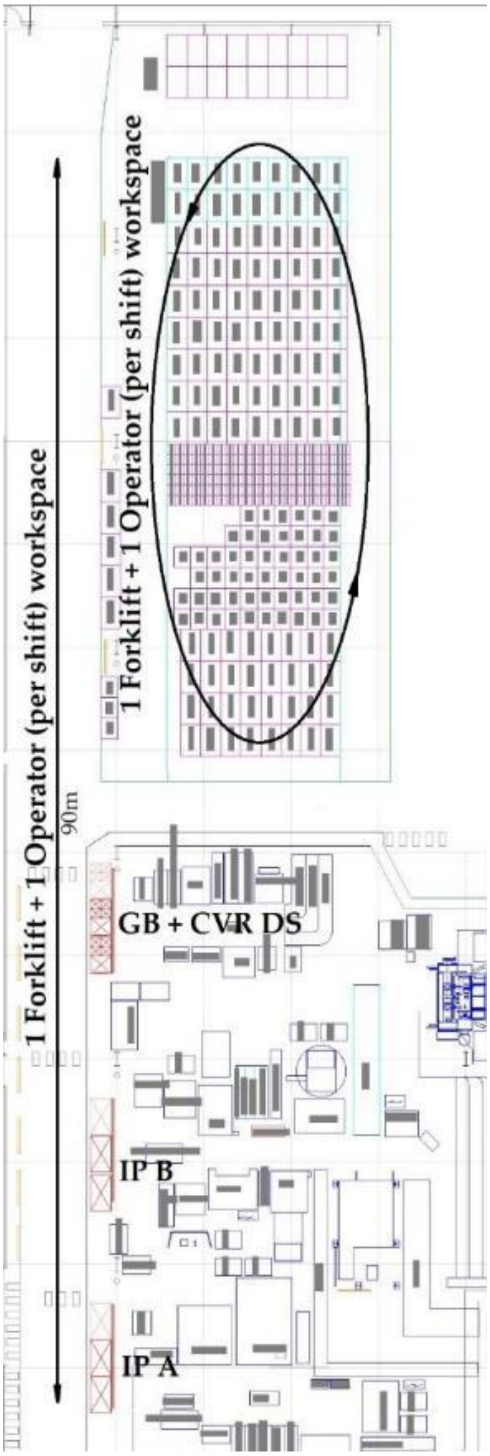

Fig.12. Plant layout section in analysis

Secondly, the fact that the product transportation is dependent on human labor necessarily introduces human error into the equation, which may translate to accidents or possible damages to the goods. The inherent human erraticity and the desire to avoid its outcomes also suggest some form of robotization.
Lastly, as the case in discussion is in the automotive industry it necessarily implies that the goods have a finite life cycle, thus the solution, along with being robotized, it must also be easily adaptable to a new context.
Taking into account the aforementioned data it is resolved the AGV (Automated Guided Vehicle) constitutes a viable candidate for the job.

3. AGV ANDPOST-IMPLEMENTATION PLANT LOGISTICS' CHARACTERIZATION

Four tow AGVs with automatic hitch (JBT, 2019) were implemented to satisfy the production lines' takt time.

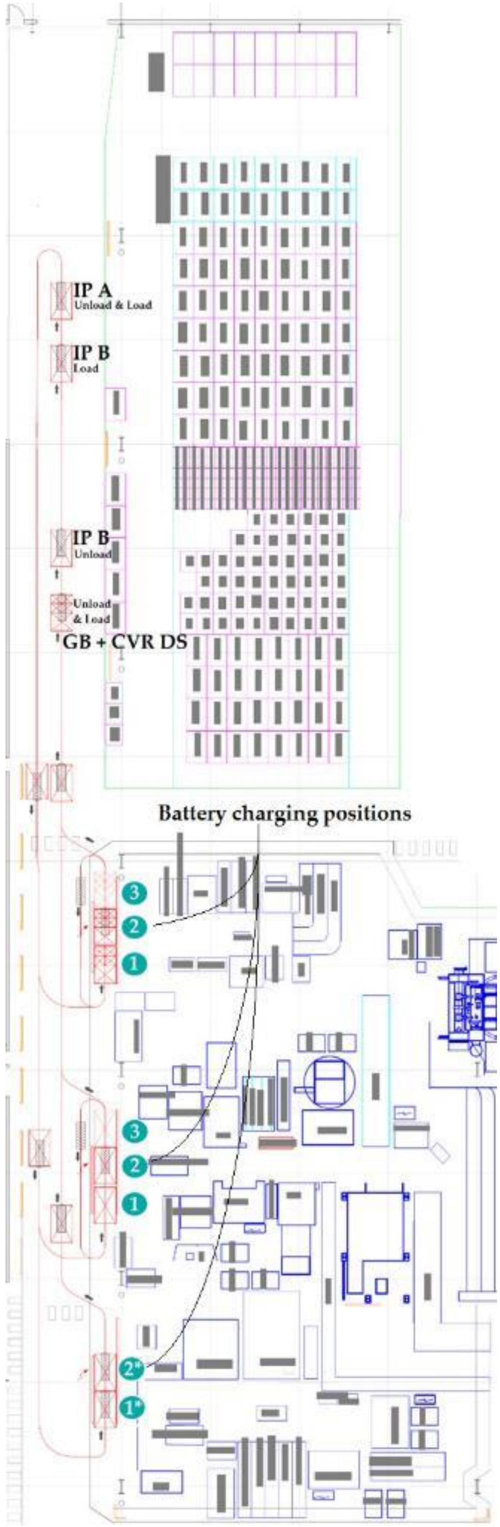

Fig.13. Layout of the implemented AGV circuit

Moreover, due to the design of the racks they could not be towed, consequently, an interface element between the racks and AGVs was designed.
The circuit is defined by a fixed path and confines the AGV within it by passive tracking, using magnetic tape (MHI, 2012).
Commands are transmitted to the vehicle by programmable RFID tags placed along itspath and by 3 start buttons, through radio waves, each in one of the production lines.
In each of the production lines lies a charging station (position 2 or 2* shown in Figure 13) that allows the AGVs to replenish its batteries by opportunity charging.
The AGVs are unidirectional, consequently there's only one 180°safety sensor at their frontend that slows down the AGV if a body enters the warning zone or stops it completely if the danger zone is crossed.

4. CIRCUIT MODEL

The circuit is not the same in the 3 production lines. In IP B and GB + CVR DS:
-Rack in position 2 being loaded;
-AGV with an empty rack arrives to position 1, leaves it and moves on to position 2;
-AGV charges its batteries in position 2 waiting for the rack to be fully loaded;
-Rack in position 2 is filled and the start button pressed which causes the AGV to take the full rack to position 3;
-It leaves the rack there and loops around back to position 1;
-The AGV takes the empty rack to position 2;
-It leaves the empty rack at position 2, moves on to position 3 securing the fully loaded rack and heads on to the warehouse;
-Repeat the cycle.
Whereas in the IP A production line:
-AGV charges its batteries in position 2* waiting for the rack to be loaded;
-AGV with an empty rack arrives to position 1* and stops due to the action of the security laser;
-Rack in position 2* is fully loaded and the start button pressed causing the AGV in this position to begin its way to the warehouse;
-The AGV in position 1*, no longer detecting a body ahead of him, moves by default to position 2*;
-Repeat the cycle.
The 4 AGVs operate exclusively in their own route without any permutation. Taking into account the cycle time, circuit length and AGV speed, one AGV was assigned to GB + CVR DS, one to IP B and the two remaining to IP A.

5. COST CALCULATION

5.1 Pre-AGVs – Operators and forklifts

The operators have a total cost of 11.8€/hour and the forklifts 600€/month. It is also important to consider the possibility of labor strikes that entail an increase of the labor costs. However, this shall not be taken into account for the cost calculation:

$$\begin{aligned} &11.8€/\text{hour x 8hours x 3shifts x251days/year} + \\ &+600€/\text{month x 12months} = 78283.2\ €/\text{year} = \\ &= 6523.6€/\text{month} \end{aligned} \quad (1)$$

There are however, 2 operators and 2 forklifts, which means the monthly cost is:

$$6523.6€/\text{month x } 2 = 13047.2€/\text{month} \quad (2)$$

5.2 Implemented tow AGVs with automatic hitch

Both the AGVs and the forklifts are electric powered, ergo the energetic consumption and environmental impact of either will be disregarded in the calculations. The implemented solution keeps 1 of the operators and forklifts while adding four AGVs with a unitary cost of 273€/month over a period of 60 months. During this period, the AGV supplier guarantees its maintenance.
The PLC controller, radio communication system, automatic hitch, tags and RFID tag reader, magnetic tape, safety lasers, batteries, four battery charging stations, start buttons, SIGAT software and cable have a fixed cost of 24.674€. In order to allow this type of AGV to tow the racks it was necessary to construct 10 platforms to serve as an interface between them (6 in use and 4 as a backup) each with a cost of 825€. Other costs arose from plant layout adaptation adding up to 2047€.
Fixed investment:

$$24674€ + 825€ \text{ x } 10 + 2047 = 34971\ € \quad (3)$$

Monthly AGV cost:

$$\begin{aligned} &273€/\text{month x 4AGVs x 12months} = \\ &= 13104€/\text{year} = 1092€/\text{month} \end{aligned} \quad (4)$$

Total monthly cost:

$$\begin{aligned} &1092€/\text{month} + 6523.6€/\text{month} = \\ &7615.6€/\text{month} \end{aligned} \quad (5)$$

5.3 Forklift AGVs (alternative)

Based on the methodological proposal for an indoor, industrial AGV implementation, it was determined forklift AGVs (Savant, 2019) would be a more suitable candidate than the tow AGVs. Thus, assuming that:

-Forklift AGVs are acquired by leasing over a period of 60 months;
-Unitary monthly cost is 2.5 times superior than tow AGVs;
-Double the AGVs are implemented;
-Fixed investment of 100.000€ to put in place heavy duty shelves for the racks.
Total monthly cost:

$$700€/month \times 8AGVs \times 12months = \\ = 67200€/year = 5600€/month \quad (6)$$

Implementing forklift AGVs would allow an automation of the total process thence the absence of salaries in the total monthly cost.

6. COST COMPARISON BETWEEN THE THREE TRANSPORTATION SOLUTIONS

It is reminded that the leasing is over a period of 60 months. After that, for maintenance cost simulation, it is stipulated that there will be a monthly cost of 50% of the leasing's (Figure 14).

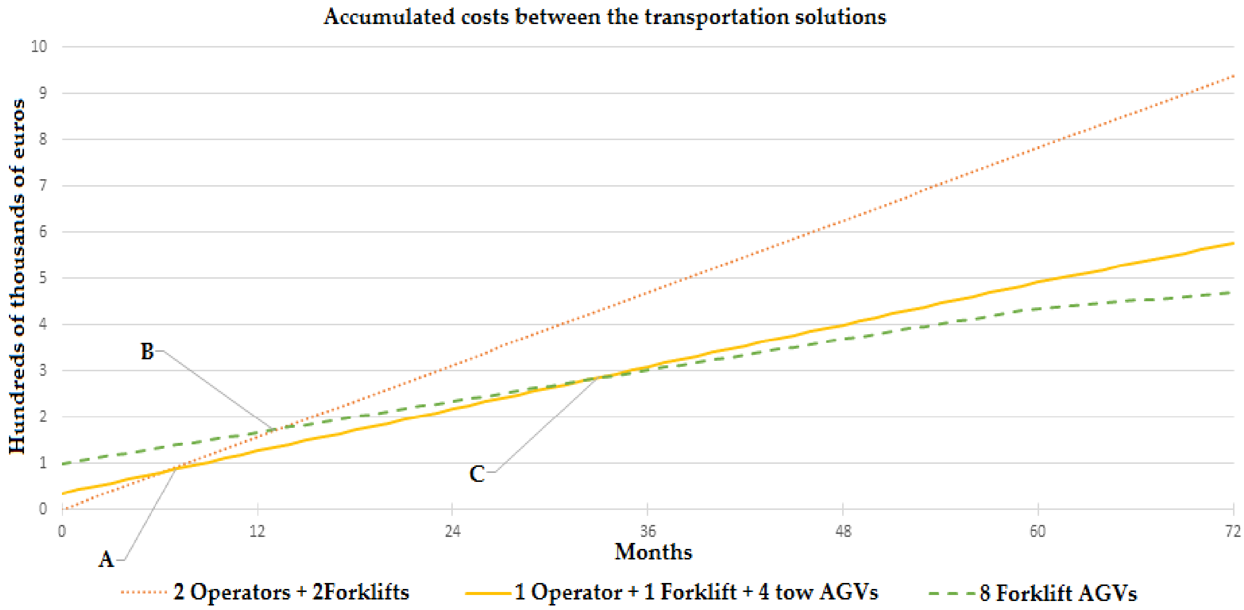

Fig.14. Accumulated costs between the three transportation solutions over a period of 6 years

7. METHODOLOGICAL PROPOSAL FOR AN INDOOR, INDUSTRIAL AGV IMPLEMENTATION

This proposal is the outcome of months of research on the topic but mostly of the hands-on experience from planning and executing AGV implementations.
While carrying out an AGV implementation there are a myriad of details that should be taken into account and developing a methodology that would work infallibly for every possible case would constitute a megalomaniac task.
Point A (6.44; 84004) 6.44 months = 6 months, 14 days.
The implementation of the 1 Operator + 1 Forklift + 4 Tow AGVs option will start generating profit after the 6 months and 14 days over the nonautomated solution.
Point B (13.43; 175196) 13.43 months = 13 months, 13 days.
The implementation of 8 forklift AGVs would generate profit after 13 months and 13 days over the nonautomated solution.
Point C (32.26; 280672) 32.26 months = 32 months, 8 days.
The implementation of 8 forklift AGVs would generate profit after 32 months and 8 days over the 1 Operator + 1 Forklift + 4 Tow AGVs option.

Assuming the plant keeps the AGVs in operation one year after the expiration of the leasing (six in total), the savings of the less profitable solution (the implemented one) will be 365,386.2€ and the gain from the most long-term financially attractive option would be 469,798.4€.
Consequently, the proposal in the form of a flowchart is potentially expandable in every decision moment.
On the flowchart, the red path symbolizes the decisions made during the implementation and the green segments express alternatives that would have been more adequate.
The Figure 15 suggests that bidirectional or omnidirectional AGVs would have been preferable than unidirectional. For the tow AGVs it would decrease the cycle time almost 2 minutes by eliminating the need of the loops in IP B and GB + CVR DS production lines. As for the forklift AGVs, were they implemented, it would have been a necessary condition.
Figure 16 first emphasizes that the forklift AGVs' working principle best suited the project requirements and secondly, that the redundancy solutions were too conservative and that an additional AGV should have been purchased.

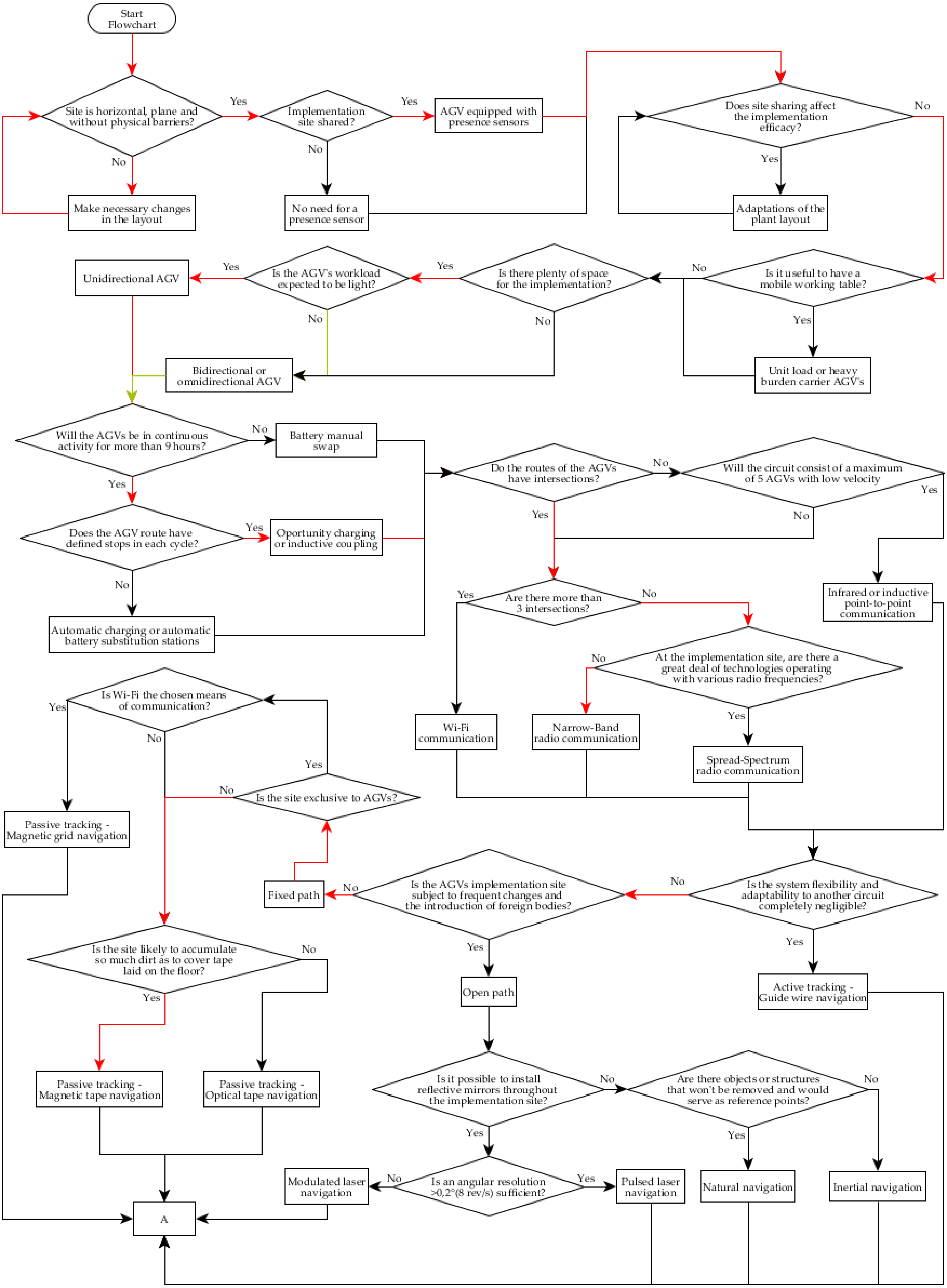

Fig. 15. Site conditions, workload, battery charging, communication methods, trajectories and navigation, [11]

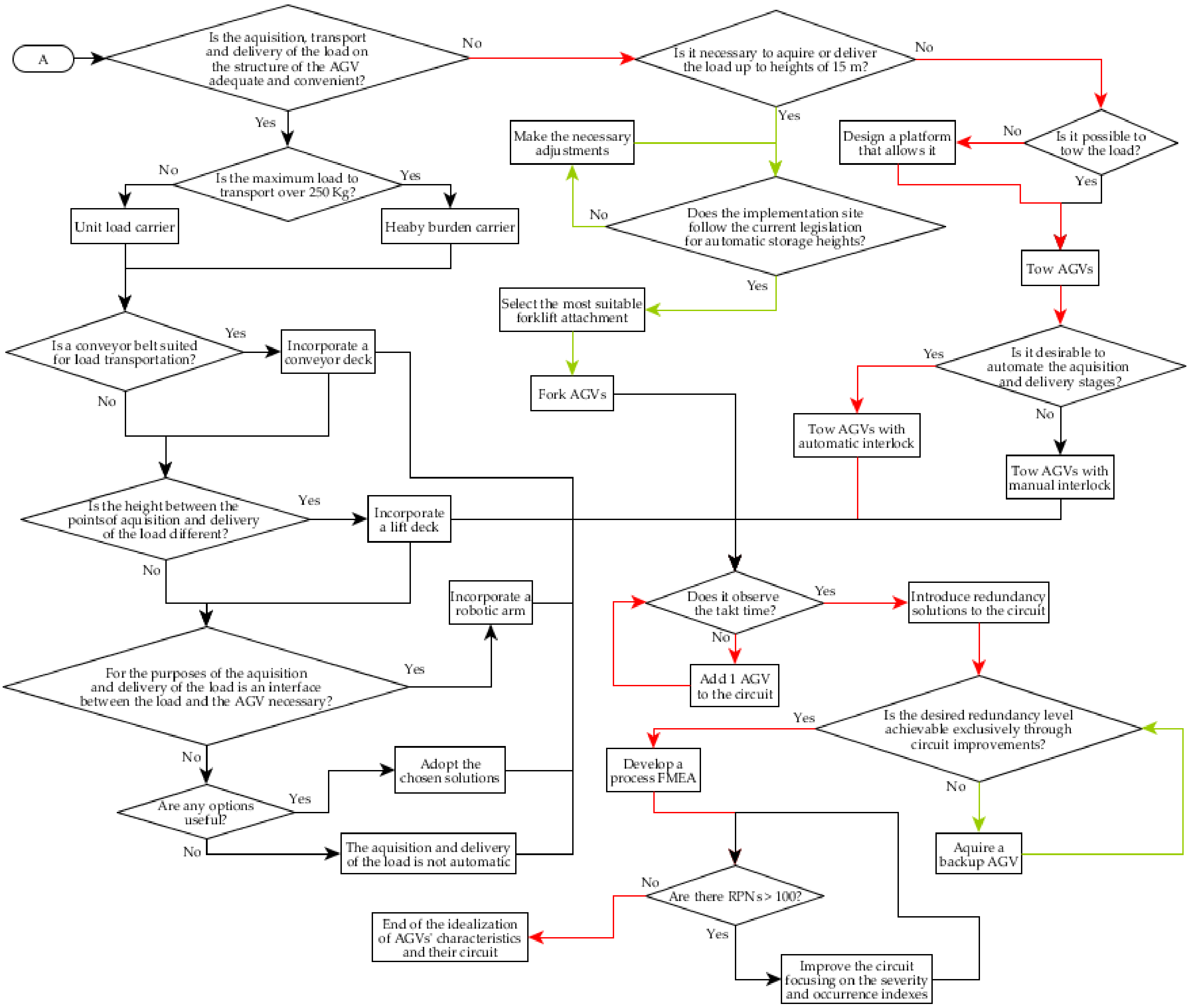

Fig. 16. AGV types, takt time, process redundancy and FMEA, [17]

8. CONCLUSIONS

From the company's point of view, whether or not the tow AGVs were the best suited for this case they constitute a satisfactory replacement to the previous part transportation method while generating significant savings. Specifically, after the breakeven point this technology will allow a monthly saving of 5430€.

From an academic perspective, based on Fig.14 and Figure 16 it is concluded that the forklift AGVs would embody a more appropriate contender technologically and financially (long term).

This implementation allowed the development of a methodological proposal for AGV implementations in a non-definitive attempt of generalizing the correct approach in this engineering area, for which, none was previously found.

9. ACKNOWLEDGEMENT

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