Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 180 (2021) 1034–1041

Procedia Computer Science

www.elsevier.com/locate/procedia

International Conference on Industry 4.0 and Smart Manufacturing

Economic evaluation of automated guided vehicles usage in a food company

Letizia Tebaldi[a], Giulio Di Maria[a], Andrea Volpi[a], Roberto Montanari[a], Eleonora Bottani[a]*

[a]*Department of Engineering and Architecture, University of Parma, Parco Area delle Scienze 181/A, 43124, Parma, Italy*

Abstract

Nowadays, companies are more and more attracted and interested by the possibility of automating processes which can be easily carried out by devices or machines instead of employees, allowing saving in costs, higher productivity and flexibility. Among the most spread ways of automating processes, more precisely in this specific case the flow of materials, the Automated Guided Vehicles (AGVs) stand out. But the main question that everyone asks is the following: is it convenient or not? In this paper, the answer is provided for a company operating in the food context, which intends to automate the transport of raw ingredients from the kitchens where they are produced and prepared to the filling lines; to this end, an economic feasibility study is carried out, taking into account three different levels of automation for three different lines. Results from all the three scenarios demonstrate the convenience in terms of achievable revenues, saved hours and manpower, and will support the management in their operational decisions.

Keywords: AGVs; industry 4.0; economic analysis; food industry.

1. Introduction

Automated Guided Vehicles (AGVs) are mobile devices typically used in industrial applications as automated tools for transporting materials from pickup places to drop off places (i.e. material handling tasks), specifically in facilities such as distribution centers, manufacturing plants, terminals and warehouses [1]. They are connected to a central navigation system which sends the instructions to the vehicles, gets their position information through different on-board sensors and guides them in completing the corresponding transportation tasks along pre-established paths [2].

10.1016/j.procs.2021.01.352

They started to become popular with the advent of the Fourth Industrial Revolution, which brings with it among the main keywords the concept of *automation*, supported by the fact that around half of the time spent by workers on industrial activities may be easily substituted by automatic devices [3]. Indeed, AGVs allow to fully automate the material flows between several departments, avoiding in this way manual activities carried out by operators. Moreover, they provide high throughput at reduced costs, continuous handling operations (24 hours a day, seven days a week) and consistent container handling operations [4].

AGVs' global market was worth USD 3.89 billion in 2018, and it is estimated to reach USD 10.00 billion by 2024, as the Automated Guided Vehicle (AGV) Market Report states [5]. In support of this, note that industrial applications are not the only possible implementations of this technology: AGVs can also be involved for transporting baggage in airports, for assistance to disabled persons, for delivering food, water and medicine, for bomb and mine mapping, for retrieval and disposal of nuclear products as well as for plant inspections and many other activities [6], making them extremely flexible and versatile. Moreover, looking beyond the mere benefits achievable in terms of performance, it was also demonstrated that AGVs may have an impact on sustainability by significantly reducing energy consumption and harmful emissions within industrial plants [7].

Literature existing on these devices is extremely varied; for instance, it ranges from the topic of battery management (e.g. [8] or [9]) to the path design issue (e.g. [10] or [11]), or to real case studies of implementation in industrial contexts (e.g. [12] or [13]). More in general, for completeness, we recall literature reviews by [14], [15] and [16] respectively on AGVs scheduling optimization, control algorithms and techniques and implementation in flexible manufacturing systems.

In the light of this brief introduction, the aim of this paper is to present a study carried out in a company based in the North of Italy operating in the food context, which deals with a feasibility study on the possibility of introducing AGVs or LGVs (namely Laser Guided Vehicles, a subgroup of the main class of AGVs whose path planning is done by the use of laser technology [1]) shuttles for automating the manual transport of raw materials trays between the kitchens and the filling area of the production lines, currently made by operators. Clearly, the selected automated systems should endure suitability of application in the food industry in which they will operate. Moreover, AGVs/LGVs will work in the presence of operators and will therefore need to comply with safety requirements. Finally, it is self-evident that the selected material handling system will have to guarantee the flow of raw materials necessary for the productivity of the lines.

The novelty and the contribution of this study are twofold; indeed, there are no evidence in literature of similar applications within the food industry, and moreover, the same reasoning applies to economic feasibility analysis linked to an implementation of this kind. The only interesting study it is worth mentioning according to the opinion of the authors, is by [17], who integrate the Radio Frequency Identification (RFID) technology in the AGV system of a food warehouse. Nonetheless, another interesting contribution comes directly from one of the main American colossus, the renown Walmart; indeed, they wanted to make their instore fulfillment of online grocery orders faster and more efficient, and built a simulation model to assess the benefits achievable from the implementation of a specific model of AGVs, Alphabot®, and due to the brilliant expected results, they launched a proof-of-concept pilot of Alphabot® in one of their supercenters, in March 2019 [18].

The remainder of the paper is as follows: section 2 describes the context of study, which targets the food industry; section 3 introduces the methodological approach followed for the evaluation of the AGV introduction in that context; section 4 presents three different scenarios, in which three different levels of automations are introduced, together with the corresponding economic outcomes; the last section (5) concludes and indicates future steps.

2. The context

The context in which this project was carried out is a food company based in the North of Italy (anonymous for privacy reasons) producing frozen pizzas, providing the large-scale retail trade and reaching 55 countries worldwide. The specific role of AGVs/LGVs should be that of transporting the raw ingredients for filling pizzas from the kitchens where these ingredients are prepared, to the production lines where pizzas are filled, according to the kind of pizza in production. Raw materials are transported in standard trays one at a time, through a trolley manually pulled towards the different lines. Specifically, the steps of this operation are the following: once left the kitchen, the operator goes to the scale point to weigh the ingredients (and notes the weight), and then he is heading to the filling lines, where he leaves the full tray and gets back the empty one, which will be returned to the kitchens to be refilled, again. It is clear that among the main disadvantages the possibility of transporting only one tray at a time stands out, which implicates a less efficient system; moreover, at least one operator must be present and dedicated to this operation, thus generating high labor costs since for determined productions two or three workers are simultaneously required. The automation of this process aims at solving these questions.

3. Methodology

3.1. Scenarios

The plant under examination consists of three different lines, all taken into account in the analysis: 1, 2A and 2B. 2A and 2B originates at the final process stage from the same main line (clearly, line 2). The assessment of the economic feasibility is made on three different scenarios, which consider three different degrees of automation:

- *Scenario 1*: only transports to line 1 are assumed to be automated;
- *Scenario 2*: transports to lines 2A and 2B are automated;
- *Scenario 3*: all three lines are automated.

Figure 1 below shows the area under investigation with the main legs, to be clearer.

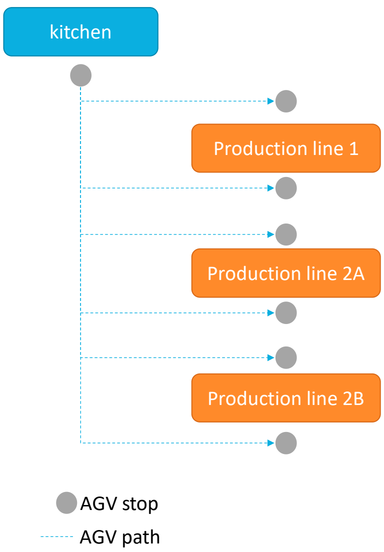

Fig. 1. Lay-out of the plant area under examination.

Kitchens are located at the top left of the plant; the grey point close to the kitchens represents the start of the paths to reach the three production lines. These paths are currently covered by employees but are expected to be (partially or fully) automated with the introduction of AGVs in the plant. The end of the paths is highlighted by the grey points close to the production lines and represents the point where workers load or unload the raw materials. Workers (and consequently AGVs in the case of automation of the line) should come back to the kitchen after having carried out their loading/unloading task.

3.2. Steps of the analysis

The starting point for carrying out the present research was to try to understand the current (AS IS) situation of the plant under evaluation and make a detailed analysis of the transport of raw materials from the kitchens to the production lines. To this end, direct observations were made to the production area to determine the routes taken by the raw materials, from their preparation in the kitchens to their arrival at the production lines. During the observations, the time taken by each employee to transport the raw materials, weigh them, unload them, take the empty trays and bring them back to the kitchens was measured and recorded.

Direct observations also led to the consideration that workers could not be completely removed from the production lines, since at least an employee in each line is required to take the trays arriving by shuttle buses, unload them and load the empty trays on the shuttles to send them back to the kitchens. Nonetheless, time measurements and direct observations were useful to estimate how the production environment could change when introducing the automatic shuttles. Indeed, starting from the layout of the area involved in the transport of raw materials, the length of all possible routes was first calculated; by dividing that distance by the average speed of each worker, it was easy to estimate the time required to cover the possible routes between the kitchens and the production lines. Using the same distances and applying the average speed of an automated shuttle, it was finally possible to compare the usage of the automated material handling system with the manual process.

The results of this preliminary evaluation showed that a worker took much less time than a shuttle to complete a complete cycle (from/to the kitchens); in fact, a worker takes about 5 minutes and 30 seconds for completing a tour, while a shuttle took more than 8 minutes. However, while a worker can handle only one tray per cycle, a shuttle could carry up to six trays. Overall, it was estimated that an employee could transport about 165 kg of raw materials per hour, while a shuttle could reach 600 kg; this makes it clear that the introduction of automatic shuttles could lead to important savings in terms of time and personnel.

3.3. Constraints and assumptions

The following parameters were analyzed at decision-making level, together with the management of the company:

- *Space Constraints*: paths to follow, loading/unloading stations position, battery charging areas position, obstacles management during journeys;
- *Vehicle Characteristics*: type of navigation (magnetic stripe or laser), payload and speed, number of trays transportable, on board load cell for weighing products, wet resistance, interaction with operators and obstacles, time and mode of recharge;
- *Food Safety*: possibility of avoiding contaminations and make sure that the ingredients do not defrost;
- *Required Operator Tasks*: what to do once the vehicle reaches the line and when let it return to the kitchens;
- *Fleet Size*: number of lines to automate and number of vehicles for each line;
- *Costs*: purchasing and maintenance costs.

With regard to the food safety, the management reached the conclusion that mixed loads (i.e. trays of different raw materials) are not feasible, and that each line should be served by exactly one shuttle at a time (which, however, can hold up to six trays, meaning that a higher level of efficiency is achievable).

3.4. Data source

The main data source for setting up the scenario analysis was the 2020 production budget of the single products (i.e. the different kinds of pizza) manufactured by the company under examination. The full list of those products and relating flows is too long to be fully reported in the paper; indeed, the plant manufactures 286 product variants overall. Nonetheless, to provide the reader with an idea of the input data, the Appendix shows an extract of the flows for a selection of products, together with the indication of the total amount of production and trays.

Starting from these data, the following further elements were computed:

1. Amount of raw materials involved for the whole year [kg/year]. This was obtained by multiplying the planned number of products by the amount of necessary raw material on the basis of the product recipe;
2. Number of trays [trays/year] to be transported from the kitchens to the lines. This parameter was obtained by dividing the raw materials quantities for the capacity of each single tray. Results of this computation can be seen in Appendix as well, for the selection of products considered;
3. Number of employees required in the current scenario. This was derived on the basis of the daily scheduled production during a work shift;

3.5. Economic evaluation

On the basis of the parameters listed above, a cost/saving balance and an investment evaluation were varied out. To be more precise, automating the lines through the usage of AGVs would involve the following savings, investments and costs and:

- *Saving in manpower*. It is reasonable to assume that only one operator is still necessary (for supervision) in case the lines are automated using the AGVs. Consequently, all operators except one are saved. This can be easily translated in a corresponding number of working hours saved and therefore in an economic saving. For computational purposes, it was assumed an hourly labor cost equal to 23.50 € [19], in line with Italian values;
- *Purchase of AGVs*. Depending on the degree of automation introduced in each scenario, a given number of AGVs need to be purchased by the company. For evaluating the relating expense, the company had two meetings with an AGVs and a LGVs producers; however, at the time of writing the choice on the specific model of vehicle to be purchased had not (yet) been made. Some quotations were nonetheless available to determine the investment required for purchasing the AGVs;
- *Operating cost of AGVs*. Using the AGVs involves expenses for electricity (battery charging) and maintenance of the vehicles. Once again, from the meeting with the AGVs and a LGVs producers, the company was able to derive an estimate of the cost for having the vehicles working in the plant.

For the sake of completeness, some of the characteristics of the AGV models the company was evaluating are listed below. Both kinds of vehicles are able to transport up to six trays, which was a requirement of the company. Because of privacy reasons, the commercial names of the AGVs and their manufacturers are omitted.

- The first model consists of a forklift AGV guided by large magnetic stripes. This is a very small device made of stainless steel; it does not reach particularly high speed. On the other hand, the charging time is very small (6-7 minutes per hour); small charging stations would need to be located near the loading and unloading stations;
- the second model is a magnetic guided AGV whose charging time is at least 15 minutes. The maximum size of the shuttle is 100 cm in width and the average speed is 0.5 m/s. This AGV cannot work in a wet environment; nonetheless, some adjustments can be made to improve its compatibility with wet surfaces.

The investment evaluation was made assuming an interest rate of 2%, which is in line with European indications.

4. Scenario analysis

In this section, the three different scenarios considered in this study are depicted, together with an evaluation of the results and key benefits achievable. Specifically, for each of them, the path the AGVs should travel is provided, together with the economic impact, which is evaluated in terms of the annual cost/benefit balance, net present value (NPV) of the investment and payback period.

4.1. Scenario 1

In the first scenario, only the path between kitchens and line 1 (see Figure 1) was chosen to be automated; being shortest and having just two arrival stations, four AGVs would be required in this case (two operating and two spare), resulting in a quite limited initial investment. At the same time, this investment would ensure the possibility of preliminarily evaluating the performance of the automated system in a limited area and, in case of positive results, purchasing additional AGVs in the future for automating the remaining lines.

As far as the economic assessment, Table 1 shows costs and saving which this solution would involve and the corresponding investment evaluation.

Table 1. Economic assessment related to Scenario 1 (interest rate: 2%).

	Year 0	Year 1	Year 2	Year 3
Annual costs [€]	248,000	15,000	15,000	15,000

Annual savings [€]		128,270	128,270	128,270
Cost/benefit balance [€]	-248,000	113,270	113,270	113,270
NPV [€]	78,657.46			

Purchasing the AGVs leads to an initial (i.e. year 0) investment of 248,000 €, including the purchase, installation, accessories and workers' training. For two vehicles in usage, the annual operating cost (electricity and maintenance) is estimated to be about 15,000 €. Nonetheless, the automated solution would allow a yearly saving equal to 128,270 €, resulting from the reduced cost of manpower. The cost/benefit balance, obtained by subtracting costs from the annual saving, is therefore positive across years 1 to 2. Applying an interest rate of 2%, the NPV of the investment is after three years is approximately 78,600 €; the payback period is approximately equal to 2 years and 2 months, confirming the absolute advantage of the investment.

4.2. Scenario 2

Scenario 2 contemplates the automation of transports to both lines 2A and 2B (see Figure 1). Clearly, being two lines, overall four stop stations are involved; it follows that four AGVs are required, plus the usual two spare.

Table 2, instead, reports the annual costs, savings and revenues which can be achieved thanks to this choice. In this case, the initial investment is higher than in scenario 1, because of the increased number of AGVs required; similarly, the annual cost for AGVs functioning and maintenance is higher as well, proportionally to the number of AGVs working in the system. The savings from the usage of automation reach 150,518 €, leading to a positive cost/benefit balance (approx. 120,000 €/year). Applying an interest rate of 2%, it is easy to derive that the NPV of the investment is 25,500 € after three years. The convenience in economic terms is therefore tangible, with a payback period equal to two years and seven months.

Table 2. Economic assessment related to Scenario 2 (interest rate: 2%).

	Year 0	Year 1	Year 2	Year 3
Annual costs [€]	337,000	30,000	30,000	30,000
Annual savings [€]		150,518	150,518	150,518
Cost/benefit balance [€]	-337,000	135,518	135,518	135,518
NPV [€]	53,818.09			

4.3. Scenario 3

The last scenario under investigation considers the complete automation of the three lines of the production area linked to the kitchens. For this configuration eight vehicles should be purchased overall (as already stated for the two previous scenarios two spare shuttles are included in the investment), with all the paths previously proposed in Figure 1 being covered by the AGVs. In Table 3 results from the economic assessment are provided.

Table 3. Economic assessment related to Scenario 3 (interest rate: 2%).

		Year 1	Year 2	Year 2
Annual costs [€]	411,000	45,000	45,000	45,000
Annual savings [€]		278,932	278,932	278,932
Annual revenues [€]	-411,000	233,932	233,932	233,932
NPV [€]	290,796			

The payback period of this scenario is particularly interesting, as it corresponds to approximately one year and eight months. Despite the initial investment, which is course higher compared to the previous configurations because of the more vehicles to be purchased, this scenario allows to save around 279,000 € per year, which could justify the investment itself. Results of the investment evaluation also show that this is the best solution for the company, in terms of future revenues, with a NPV of approx. 290,000 €.

5. Conclusions

The aim of this paper was to demonstrate the effective feasibility of implementing AGVs (or LGVs) for automating the transport flow of raw material from kitchens to the production lines of a company operating in the food context, and its benefits soon achievable in economic terms. To this end, three different scenarios were evaluated, having three different levels of automation and a different number of vehicles involved. Clearly, the greater the number of vehicles, the higher investment is initially required, but the sooner profits arise; on the other end, staring from automating just one line (i.e. Scenario 1) would guarantee a slow entrance of the technology, which would probably lead to an easiest approval by the top management and understanding by the operators. Starting from Scenario 1, it would also be possible to assess along the way the trend so as to be ready and prepared for further automation.

From a practical point of view, it is expected that the company's management will soon decide the scenario to be implemented for AGV introduction. Moreover, the company is also evaluating a second feasibility study, targeting the transportation of mozzarella instead of raw materials for filling pizzas. This study is motivated by the fact that, unlike other raw ingredients which vary according to the kind of pizza, mozzarella (together with tomato sauce) is ever-present in all the types of products, and according to that, the volumes involved are relevant. The way mozzarella is transported is similar to the AS IS scenario for raw materials, but trays are of bigger size and heavier. It follows that, in the light of results achieved thanks to the three investigated scenarios, also the case of mozzarella could benefit from automation introduction. Further results could be obtained from the usage of simulation to reproduce the system under examination in the AS IS scenario and in the case AGVs are used to automate the process. Such an analysis is left for future studies.

As a closing consideration, many processes of the food industry are still not automated; as this paper grounds on a case study, it is likely that the results proposed could be of interest for different companies in the food industry when pondering the introduction of automation for their internal processes. More specifically, the economic outcomes here obtained are valid only for this specific company, since data can change in different contexts; nonetheless, the same procedure can be considered as starting point for carrying out similar economic evaluations in other companies.

Appendix

Table A-1. Example of input data for scenario analysis: expected flow of products in line 1 in 2020 (extract).

Product ID	kg / hour	trays / hour	kg / year
P060008	891.75	47	15,375
P107006	891.75	47	8,561
P004105	674.25	43	3,875
P167003	609	33	2,310
P158002	587.25	32	2,025
P161002	587.25	31	675
P090014	543.75	31	39,375
P002016	508.95	31	79,140
P001204	565.5	30	0
P139009	587.25	30	2,025
P130007	587.25	30	2,700
P090013	587.25	30	24,300
P158003	587.25	30	1,350
P161003	369.75	30	340
P089004	587.25	30	4,725
P079012	565.5	30	13,650
P103004	548.1	29	25,830

P027033	552.45	29	6,350
…	…	…	…
TOTAL AMOUNT	**82,251.54**	**4597**	**1,889,126.99**

References

[1] Gul, F., Nazli Alhady, S.S., and Rahiman, W. (2020). "A review of controller approach for autonomous guided vehicle systems". Indonesian Journal of Electrical Engineering and Computer Science, 20 (1): 552-562.

[2] Yang, Q., Lian, Y., and Xie, W. (2020). "Hierarchical planning for multiple AGVs in warehouse based on global vision". Simulation Modelling Practice and Theory, 104: 102124.

[3] Bughin, J., Manyika, J., and Woetzel, J. (2017). "Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation". McKinsey Global Institute, pp. 1-160.

[4] D'Souza, F., Costa, J., and Pires, J.N. (2020). "Development of a solution for adding a collaborative robot to an industrial AGV". Industrial Robot: The International Journal of Robotics Research and Applications, 47 (5): 723-735.

[5] Market Reports World (2019). "Automated Guided Vehicle (AGV) Market – Growth, Trends, and Forecast (2019-2024).

[6] Das, S.K., and Pasan, M.K. (2016). "Design and Methodology of Automated Guided Vehicle – A review". IOSR-JMCE Journal of Mechanical and Civil Engineering, 03: 29-35.

[7] Bechtsis, D., Tsolakis, N., Vlachos, D., and Iakovou, E. (2017). "Sustainable supply chain management in the digitalization era: The impact of Automated Guided Vehicles". Journal of Cleaner Production, 142: 3970-3984.

[8] Frivaldsky, M., Sedo, J., Pipska, M., and Danko, M. (2020). "Design of measuring and evaluation unit for multi-cell traction battery system of industrial AGV". Electrical Engineering, 102 (3): 1579-1591.

[9] Kabir, Q.S., and Suzuki, Y. (2019). "Comparative analysis of different routing heuristics for the battery management of automated guided vehicles". International Journal of Production Research, 57 (2): 624-641.

[10] Gu, G., Hong, Z., and Luo, D. (2019). "A data-driven intelligent algorithm for dynamic design of automated-guided vehicle systems". Proceedings of 2019 IEEE 3rd Advanced Information Management, Communicates, Electronic and Automation Control Conference, IMCEC 2019, 8983941: 1106-1111.

[11] Rubaszewski, J., Yalaoui, A., and Amodeo, L. (2016). "Solving unidirectional flow path design problems using metaheuristics". Operation Research/Computer Science Interfaces Series, 60: 25-56.

[12] Correia, N., Teixeira, L., and Ramos, A.L. (2020). "Implementing an AGV system to transport finished goods to the warehouse". Advances in Science, Technology and Engineering Systems, 5 (2): 241-247.

[13] Soundattikar, S.A., Naik, V.R., and Adake, C.V. (2020). "Design and development of intelligent handling system for components in small and medium scale industries". Materials Today: Proceedings, 27: 87-95.

[14] Fu, J., Zhang, H., Zhang, J., and Jiang, L. (2020). "Review on AGV Scheduling Optimization". Journal of System Simulation, 32 (9): 1664-1675.

[15] De Ryck, M., Versteyhe, M., and Debrouwere, F. (2020). "Automated guided vehicle systems, state-of-the-art control algorithms and techniques", Journal of Manufacturing Systems, 54: 152-173.

[16] Ali, M., and Khan, W.U. (2010). "Implementation issues of AGVs in flexible manufacturing systems: A review". Global Journal of Flexible Systems Management, 11 (1-2): 55-62.

[17] Xue, R., Zeng, S., and Zheng, S. (2015). "Design of food storage guided vehicle system based on RFID Technology". Advance Journal of Food Science and Technology, 9 (4): 278-282.

[18] Anylogic. "Walmart's Alphabot: Designing Material Handling System with Simulation". Available at: https://www.anylogic.com/walmart-s-alphabot-designing-material-handling-system-with-simulation/ [Accessed 30 October 2020].

[19] Istat (2018). "Lavoro e retribuzioni nelle grandi imprese". Available at: https://www.istat.it/it/files/2018/05/Nota-informativa-GI_base-2015.pdf [Accessed June 2020].