Adoption of control policies in a simulative model for the design of AGV systems

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Abstract
Nowadays, industrial applications are showing an increasing interest toward the adoption of automated logistic handling systems, such as systems including Automated Guided Vehicles (AGVs). A logistic handling system represents the physical link between the production system (i.e. parallel production lines) and the shipment system (i.e. fleets of vehicles for goods delivery). The synchronization between these two processes is an important issue, especially for companies producing final goods and giving priority to direct shipments rather than to store products inside the plant. Nevertheless, the variability in the generation of production patterns and shipment arrivals may lead to an unacceptable loss of synchronization. In order to prevent this harmful situation, some control policies can be adopted: it could be necessary to review short-term plans acting on production patterns and/or on shipment priority.

This paper deals with the design and management of a logistic handling system including AGVs by using a simulation model. Normally, the objective of the design phase is the identification of the optimal number of AGVs to include in the system. For this purpose, an effective simulative model has to consider what happens both in the upstream (i.e. production system) and in the downstream (i.e. shipment system) of the logistic system. Nevertheless, the modeling of a real complex system has also to include the control policies that assure the necessary synchronization between the production and shipment processes.

A methodological approach is then proposed and an application to a design problem derived from an actual case study is presented and discussed.

1. INTRODUCTION
Automated Guided Vehicles (AGVs) are usually employed in internal logistic systems being able to execute material handling tasks without human guidance. An efficient integration of AGV system into plant layout leads to significant advantages in terms of overall efficiency.

This paper deals with the design of AGV systems and is especially aimed at those industrial contexts in which direct shipments constitute the main objective to reach. In those systems, a storage area is present in the shop floor to act as a buffer to compensate natural misalignments that can happen between production patterns and shipment plans.

The most popular approaches adopted in literature to support the design of AGV systems are the analytical approach (i.e. [1]) and the simulative one [2, 3, 4].

Few works address the stochastic nature of some input data, such as stochastic relations between production plans and shipment sequences. In [6] a conceptual model is proposed to support the representation of the stochastic relation between production management and shipment occurrence. This conceptual model can be coupled with a simulative model to support the design phase of the AGV system, i.e. to identify the right number of AGVs and the usage of the storage area.

Another important aspect to be able to model are the effects of human actions on the system when some particular situations happen. As an example, when consistent misalignments between production patterns and shipments sequence happen causing a consistent increase of storage area utilization, the planner can reschedule production to avoid the saturation of the storage area and the consequent block of a part of the system.

The innovative contribution of this paper consists in the introduction of a control policy in the framework developed in [6] with the aim to represent actions taken by production planners when consistent misalignments between production and shipments happen. This to improve the capabilities of the framework to better represent the real behavior of the industrial system that is the “world” around the AGV system. In such a way, the best set of input data can be generated and, by means of a simulation model, issues concerning the AGV system design can be better investigated.

The problem under investigation is presented in Section 2., Section 3. describes the proposed methodological approach. In Section 4. a case study is discussed as application of methodological framework application. Finally, in Section 5. concluding remarks are reported.
2. PROBLEM STATEMENT

In this paper a problem concerning the design and the analysis of a logistic system in which AGVs are employed as handling devices is studied. This problem is representative of many actual cases, in particular in companies that operate in the food and beverage packaging and tissue production. In such companies, the production shop floor is formed by a number of parallel production lines, that continuously produce final goods following a specific pattern of production, then these final goods are collected on a pallet that become the loading unit handled in the system.

These lines produce at a constant rate respecting a production pattern that attempts to follow variable customers demand. The final goods must be shipped as soon as a truck that requires that kind of product arrives in the loading area. The trucks arrival is affected by stochastic variability, i.e. due to traffic, weather conditions, and so on. If there is not any truck waiting for specific final products, the need to stock them in the storage area arises. They will then be withdrew as soon as a truck requiring them arrives. The AGV system is adopted to transport the loading units from the production lines to the loading area or to the storage area, and from the storage area to the loading area. The AGVs move on pre-defined paths, forming the network, following specific traffic rules.

Thus, such a kind of logistic systems usually includes these three main areas:

- the end of line area (EOLA), where loading units wait in a number of queue to be transported;
- the loading area (LA), which is composed by a number of loading bays where products of an order are collected on the ground waiting to be loaded on the truck by manually guided forklift vehicles for shipment;
- the storage area (SA), where loading units are temporary stored waiting to be required for shipping.

The storage area is necessary to store the loading units when the direct shipping is not possible due to a misalignment between production and shipments.

The scope of this paper is then to analyze a logistic system with this configuration in order to design the fleet of AGVs and in particular to find a trade-off between the number of AGVs and the performances of the system.

3. METHODOLOGICAL APPROACH

The main issue in addressing the aforementioned problem is to be able to represent the variability in production patterns and in shipment arrivals, while keeping balanced the average flow that comes through the system. This assures that in a mid-long term perspective all the production is shipped stating that the average production is leveled with the average demand. Obviously, in a short term perspective, temporary misalignments can happen due to variabilities produced by production scheduling optimization and by truck arrivals uncertainty.

In order to support the design of such logistic systems with a simulative approach, a model able to reproduce the mechanism at the base of the production planning generation and its correlation with customers demand is necessary.

Figure 1 represents the block diagram of the model proposed in [6] for the generation of production patterns and shipment arrival. Customer demands is generated by means of a probabilistic distribution function representative of the market behaviour. Two flows are created based on the stochastic generation of customer demand. One flow will be treated as a queue of production orders that undergo scheduling policies to optimize line utilization and reduce setup needs. The other flow represents a queue of truck arrivals, to which stochastic variability is added to represent delays as they can happen in the real world.

The first flow consists in a generator of production batches to be assigned to production lines. Production patterns are generated by the production scheduler block so as to reproduce the typical behaviour of mid term and short term production planning activities of a real company. Hence, production batches are launched with the objective to reduce changeovers on the lines.

The addition of a control policy that acts on the scheduling strategy once a high level of some type of products is already

![Figure 1. Conceptual model of the production pattern generator.](image-url)
present in the storage area can be useful to model the real behaviour of production planners in such kind of production systems. The case study reported in Section 4. reports a possible way to implement such a kind of control policy.

4. CASE STUDY

The case study deals with a logistic system served by AGVs, partitioned in three main areas as explained in Section 2. A simulation model built in the Flexsim™ environment was developed with the following characteristics:

- five sources that generate loading units with respect to assigned production orders; every source is connected to a queue in the EOLA where products wait to be transported towards the LA or the SA;
- seven racks in the LA where the truck load is collected on the ground;
- a rack in the SA to stock loading units awaiting for trucks arrival;
- the path composed by network nodes, connected each other to form paths, and governed by specific traffic rules to avoid collisions;
- the dwell point where AGVs park and waits for a new mission;
- one dispatcher to assign available AGVs to specific missions;
- the fleet of transporters (i.e. AGVs).

The aim is to find a trade-off between the number of AGVs deployed in the lay-out and the following Key Performance Indicators (KPIs):

- Mean EOL queue size (Mean EOL): the average number of loading units in the EOLA;
- Maximum EOL queue size (Max EOL): the maximum number of loading units in the EOLA;
- Mean SA occupation (Mean SA): the average number of items stored in the SA;
- Maximum SA occupation (Max SA): the maximum number of items stored in the SA;
- Mean Service Time (Mean ST): the mean time necessary to perform the truck load arrangement, that is, the mean time between the arrival and the departure of a truck;
- Number of shipments (# Shipments): the number of the shipments executed;
- Mean Percentage of AGVs Idle (Mean Idle): the mean percentage of AGVs non utilization;
- Maximum Percentage of AGVs Idle (Max Idle): the maximum percentage of AGVs non utilization.

Different scenarios have been tested by varying the number of the available AGVs and the truck loading time, i.e. the time necessary for the manually guided forklifts to transfer the pallets arranged in the LA on the trucks.

If a control policy is not adopted to reduce the effects of misalignments between production and shipments, a remarkable increase of loading units transportation from the EOLA to the SA is emphasized, and the effects are shown in Figure 2. Hence, to the scheduling strategy adopted in [6] the following control policy has been added to delay the production of an incumbent order if a certain amount of loading units of the same kind of such order is already present in the storage area.

The new production scheduling strategy, containing the control policy, is explained in the following steps:

- each time a line ends a production batch, consider the first four production orders in the input production queue;
- if none of the selected order has exceeded a maximum waiting time do the following:
  - compare the types of the selected orders with the type of the product just processed on the line;
  - check the amount of the considered type of product already present in the storage area;
  - if such an amount does not exceed a specified maximum level, allocate to the line the production order. Otherwise allocate the first order of in the input queue that does not exceed the maximum level in the storage area;
In the other cases, allocate the first order on the input production queue.

else, allocate to the line the first order that exceeds the maximum waiting time.

Hence, it is privileged the assignment to EOLs of orders that satisfy shipping requests of kind of products not available in high quantity in the SA.

Input data for the simulation model are the same as the ones reported in [6]. Different scenarios were tested by varying the following factors:

- the number of the available AGVs: 10, 11 and 12;
- the truck loading time, i.e. the time necessary for the manually guided forklifts to transfer the pallets arranged in the LA on the trucks: 8, 7.5, 7, 6.5 and 6 minutes.

The number of AGVs represents the variable that has to be optimized. The second parameter, i.e. truck loading time, depends on the number and the typology of the manually guided forklifts employed to load the pallets from the LA on the trucks. This variable is controlled by the managers of the company and not from the AGV system supplier. Hence, its effects on the AGV fleet dimensioning must be correctly estimated.

The simulation campaign is constituted by eight runs of model for each different combination of the aforementioned factors, i.e. the number of AGVs and the truck loading time (TLT). Table 1 represents the average value of the KPIs obtained.

The ANOVA [7] methodology was used to analyze the effects of variations in the analyzed factor over the KPIs. Table 2 reports statistical results. A p-Value < 0.05 means that the variance of the parameters or their interaction is significant.

In particular, for the Mean EOL both the variance of the two parameters and their interaction are significant; for Max EOL only the number of AGVs is significant; for Mean SA, Max SA, Mean ST and #Shipments only the truck loading time is influent. For what concerns AGV idle time, the mean values is influenced by the two main factor individually, while the max value is also influenced by the interaction between the two factors.

The most significant ANOVA plots are reported in Figure 3. Mean EOL is mainly influenced by the number of AGVs, showing an increase by passing from 10 to 11 AGVs. However, it can be observed that the variation of Mean EOL is not so relevant. Mean SA and Max SA depend on the TLT, because if the cargo is transferred on the truck more quickly, the occupation of the storage area is lower. This is explained by the fact that if the loading bays are emptied in a smaller time they are able to receive a new shipping order soon, hence the number of missions to the storage area is reduced. Mean Idle and Max Idle of the AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs. This results is necessary to understand if an increase of the number of AGVs fleet is influenced mainly by the number of AGVs.

We can conclude that the system is adequately satisfied by the use of 10 AGVs, since they are sufficient to serve the

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Table 1. Simulation result for each scenario (Average Value).
The adoption of the new control policy allowed to have more suitable results since huge misalignments are prevented, as it is also in the real industrial practice. In [6] a set of experiments were executed adopting a fleet of 9 AGVs, and the results showed that instability phenomena provoked a continuous utilisation of the storage area, making this fleet unable to satisfy requested shipments. The same set of experiments were also executed by adopting the new model including the control policy to prevent huge misalignments. Nevertheless, the fleet of 9 AGVs did not result sufficient to satisfy shipment requests. We can than conclude that a fleet of 9 AGVs is definitely inadequate to manage the production flow.

Table 2. Statistical results for the KPIs.

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5. CONCLUSIONS

In this paper a framework to support AGV logistic system design by means of simulation approach is presented. The conceptual model developed is designed to represent the stochastic interaction between production patterns and shipment arrivals in companies that aim at manage their production/shipment floor in a cross-docking manner. In this situation, a storage area is introduced in the system to act as a buffer to compensate short term misalignments between production and shipments. A control policy was also introduced in the model to represent typical intervention of production planners each time huge misalignments are noticed. A model, derived from an actual case study, was developed and a simulation campaign was deployed to assess the suitability of the proposed methodology. The adoption of control policies constitutes a step ahead in obtaining model more and more able to better represent the real behaviour of the environment in which the AGV system operates.

REFERENCES


Figure 3. Some ANOVA results (loading time is measured in minutes).