Simulation based Performance Analysis of Production Intralogistics

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Abstract. Production planning and scheduling rely heavily on the efficient operations of production logistics and material handling equipment. Industry 4.0 technologies such as Internet of Things (IoT), Digital Twins, and Artificial Intelligence (AI) can be applied to production logistics in terms of autonomous mobile robots that facilitate to increase the flexibility and productivity of the whole production site. However, before the implementation of an automated production logistics systems, its feasibility must be analysed. This paper describes a simulation-based approach, including the definition of and comparative analysis of Key Performance Indicators (KPIs), to analyse the performance of production intralogistics applied to a selected use case. The presented approach offers a proof of concept on the basis of which decision-makers can implement mobile robots for intralogistics in their own production environments.

1. Introduction

In the scope of production management, the performance of activities such as obtaining raw materials to delivering finished goods to customers, need to be jointly studied and analysed. These activities are highly interconnected, and the analysis of the performance of those activities can help optimize manufacturing and logistics operations. The improvement of production intralogistics – the internal transportation of goods within a given manufacturing facility – has a major impact on the production efficiency of the whole site. As such, the requirement to optimize internal logistics systems in terms of operational performance, throughput and sustainability arises [1]. Although automation contributes a lot to business value creation and has already been to some extent introduced into the intralogistics of manufacturing facilities (e.g. conveyors, fork-lifters and pallet trucks), the aforementioned equipment allows only for a low degree of flexibility, whilst other tasks, such as loading & unloading, and the authorization of goods, are still mainly performed manually [2]. High level automation, such as the introduction of Autonomous Mobile Robots (AMR) into the intralogistics of the facility, offers a more flexible solution that can lead to a more efficient process of transportation.

Whilst intralogistics automation promises many benefits, any change within the production site introduces new challenges. For example, to ensure a smooth transition into the new workflow, a thorough change management course for line operators is recommended to be planned and carried out. Moreover, internal logistics systems are highly complex, with the deployment of AMRs requiring a thorough preliminary study and analysis. Therefore, the method of simulation and 3D visualization can be used to analyse and verify the change. Simulation modelling, paired with the Digital Twin concept and the setup of KPI (Key Performance Indicator) targets, has become a staple framework in operations management today, for the insights gained facilitate better decision-making in terms of financial, time oriented, material and energy savings, as well as the ability to streamline the process activities [3].
2. Literature Review

For the literature review, state-of-the-art articles relevant to the field of this study were analysed. Topics include the automation of production intralogistics through AMRs, the significance of simulation modelling and 3D visualization as decision-making tools, and a brief explanation of relevant Key Performance Indicators. Moreover, similar studies and related approaches are referred to in this section.

2.1. AMR in Intralogistics

Automation and the application of Internet of Things (IoT) have become widely associated with areas such as production, logistics and transportation. From the other side IoT applications in production and logistics should be seamlessly integrated into companies Manufacturing Engineering Systems (MES) [4]. AMRs for factory floor logistics persuade the smart factory concept with disruptive technologies such as Artificial Intelligence (AI), simulation and Digital Twin [5]. The use of AMRs as a type of material handling equipment creates a more ergonomic workspace for the production floor employees. Furthermore, proper deployment of AMRs may lead to an increase of production capacity and flexibility, while reducing transportation defects. Other automated solutions for factory logistics, such as conveyors, forklifts, pallet trucks, and automated guided vehicles, do not offer the same level of flexibility in terms of routing. In contrast, AMRs can be reprogrammed to be used in different applications, reacting to different data inputs. They are smaller in size and more agile than traditional automated guided vehicles; as such, they can access the production area more efficiently [6]. However, the implementation of AMRs for production intralogistics needs to be justified and verified before the physical set-up on the production floor.

2.2. Simulation Modelling and 3D Visualization

Simulation modelling is the creation of a digital model of a real-world system. Various what-if scenarios can be tested on a valid digital representation of a system to analyse, optimize, and predict the performance of processes based on set parameters [7]. After thorough experimentation in this risk-free environment, an optimal system configuration can be found and carried over into the real world. Potential problems and bottlenecks are discovered and reacted upon early in the process, thus leading to the improvement of set KPIs [8]. 3D visualization is an essential tool used to validate the simulation models’ feasibility by taking the geometry of the facility, line or process into account. 2D simulation, in comparison, offers only a low level of visual commissioning. The usage of Industrial Virtual Reality (IVR)-based 3D visualizations, which can be adapted to simulated 3D assembly layouts, product models, and process flows, may prove to be beneficial in such cases [9]. In this study, a production floor was simulated in a 3D simulation software; the assembly steps, including the mechanisms and tools on the factory floor were modelled, and the changes of the location of AMRs were analysed.

2.3. KPIs for Production Intralogistics

Performance indicators or KPIs aim to deliver information needed for the performance analysis of manufacturing operations. Intralogistics come under the discipline of operations management, and as a result, KPIs related to manufacturing operations are appropriate to production intralogistics as well, as defined in the ISO 22400 family of standards. The standard classifies KPIs based on their purpose of use, such as performance that can be measured in terms of cost, time, quality, flexibility and sustainability. Likewise, they are applicable to different types of operations, such as production, material handling, quality assurance, maintenance, and so on. [10]. Performance indicators not only showcase what has happened; they also indicate what will happen, as reactive steps will be taken by decision-makers to combat any weaknesses represented in the KPIs [11].

In this study, KPIs like utilization, throughput, and cost of AMRs, as well as transportation defects were chosen. The paper proposes a 3D simulation-based approach to analyse the performance of the production intralogistics process, though the suggested approach can be implemented to other processes as well. Several other research papers addressed the topics of intralogistics automation and the deployment of mobile robots for transportation on the factory floor [5], [12], [13]. The value of this study lies in the simplicity of the synchronized analysis approach, compared to the more difficult to construct and adopt procedures described in the aforementioned papers.
3. Simulation-based Approach for Analysis

The continuous 4-step approach (see figure 1) was adopted through the comprehensive literature review. The case study technique was used as a research method, and a use-case is introduced to validate the relevancy of the proposed approach.

3.1. Model Creation

Creation of the model, a fundamental step in simulation-based analysis, facilitates to capture and describe the problem properly. A model is created by mapping the real environment to the virtual one through a specified computer-based application. A model should grasp and reveal the dynamics of a process such as the occurring of events, changes in activity timing, and resources’ state. Model parametrization also includes the selection of components (entities, source and sink, resources, etc.) relevant to the specific problem statement and system.

3.2. Performance Parameters

The acquisition of data related to the target process or system is crucial for the setup of the desired KPIs in this second step. Process parameter data, such as system specifications, input variables, and process performance metrics, are needed for the analysis. The aforementioned indicators numerically describe the behaviour of the resources, as well as activities’ performance. Despite a wide selection of performance metrics being presented in various literature, KPIs must be selected depending on the underlying strategies of the company, for only then can the simulation model be built in response to the specific problem statement of the organization. For the intralogistics performance analysis and the objective of the test case, we incorporated throughput, utilization, cost and defects of the transportation activity as KPIs for the simulation analysis. Further details can be found in table 1.

| KPI          | Formula                                                                 | Description                                                                 |
|--------------|-------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| Throughput   | \[Throughput(R) = \frac{Average\ Inventory(I)}{Average\ Flow\ Time(T)}\] | Shows the number of products transferred by an AMR from one station to another per unit time |
| Utilization  | \[Utilization = \frac{Task\ Performing\ Time}{Total\ Working\ Time} \times 100\] | The percentage time that an AMR performs tasks out of the total working time or a shift duration |
| Cost         | \[Cost = Initial\ Investment + Operating\ Cost\]                        | Shows the monetary impact of AMR in monetary terms                           |
| Defects      | \[Defects = \frac{Number\ of\ irregularities}{Number\ of\ transportations} \times 100\] | Expressed by irregularities in the transportation process (wrong number of goods, wrong type of goods, wrong destination) |

3.3. Visualization

The exact-scale digital model of the production floor in 3D verifies the work of the real system, ensuring that the created model behaves as intended. 3D simulation assists users to visualize staff, equipment, building facility, and other items and processes in the virtual environment. The verification can be performed by providing real input data to the model and comparing the results with historical data.
Visualization also represents processing data in the form of a dashboard which helps to determine between strategic alternatives.

3.4. Variation Test
In this step, the simulation model can be allowed to test several tactical variations and scenarios that capture uncertainty. Sensitivity Analysis and Parameter Variation experiments are commonly used to reveal the effect of randomness and parameter change to the simulation model’s behaviour.

4. Case Study
The proposed simulation-based approach was applied to the intralogistics process of a chemical manufacturer which produces detergents and hand sanitizer. The manually operated transportation of goods is a key operation in the production facility. Due to the high demand of products and, thus, the subsequent increase of production capacity and flexibility, the company decided to analyse and improve the intralogistics process with the intention to automate the production floor logistics by implementing AMRs. This solution is expected to reduce the transportation time and ultimately increase the process productivity, as well as cut down on workers' fatigue. The studied production facility consists of four production lines that fill empty bottles (in containers) of different sizes with liquid, label and cap them. The intralogistics related activities, planned to be executed on four different stations with the help of an AMR, are as follows:
1. Loading of products (empty bottles) in warehouse and transportation to production line
2. Unloading of empty bottles at the start of production line
3. Loading of filled bottles at the end of production line and transportation to finished goods area
4. Unloading of filled bottles in Finished Goods (FG) area and moving back to the Warehouse (WH)

![Figure 2. Simulation model of a single production line with AMR.](image)

The 3D simulation models of the use case were created and analysed in Visual Components 4.2, a 3D manufacturing simulation software. The physical setup of the production lines and routes mapping of the AMR were constructed on the basis of full-scale production layout. Figure 2 gives a concise view and a single production line simulation model, where the intralogistics activities were marked and executed as defined above with the corresponding numbers. Figure 3 is a holistic view of the production facility and illustrates the transportation of goods using the AMR following the route WH → Production → FG → WH. The movement of the AMR was mapped and analysed during the simulation, with the green-coloured marking showing the movement of the AMR in the production area, the red-coloured one to and from the FG area, and the yellow-coloured route – to WH and from WH.
The results of the simulation analysis can be observed in figure 4. The graph, showing the time spent and distance covered by the AMR, helps to perceive the idleness and busyness of the robot. One AMR was used to feed and serve four production lines. For the 8-hour simulation run, performance metrics such as throughput and utilization were determined. By introducing variations in the simulation model (like the number of AMRs needed for the current production capacity), the effect of an AMR implementation to the transportation cost and defects was observed. The impact of the change, i.e. the automation of the production intralogistics operation, was monitored through previously defined KPIs; the results are shown in table 2. The deployment of an AMR shows a positive impact on every KPI.
Table 2. KPI observations of current real-world and simulated scenarios.

| KPIs | Current Scenario (Manual Labor) | Automated Scenario (AMR - Simulated) | Remarks |
|------|--------------------------------|-------------------------------------|---------|
| Throughput | 11 pallets per shift (8 hours) | 11 pallets per shift (8 hours) | Same throughput, but AMR more flexible than manual process (+ve) |
| Utilization | Fully loaded | Half-loaded | Use of AMR → extra capacity to feed/serve more than four lines (+ve) |
| Cost | Manual transportation costs | Enables effective (human & robot) resource allocation | Use of AMR → less logistics employees → reduced transportation costs (+ve) |
| Defects | Irregularities due to disorganized corridors | Irregularities did not exist thanks to designated routes for AMR | Use of AMR → neat and clean routes → less irregularities (+ve) |

5. Conclusion
The proposed simulation-based approach is intended to help analyse the feasibility of automation of intralogistics processes and the implementation of AMRs in production logistics. Due to the possibility of achieving a high level of accuracy in the representation of a real production facility in 3D modelling and simulation software, the authors of this study recommend using the aforementioned Industry 4.0 tools as part of the decision-making workflow when automating intralogistics processes. The case study ensured the effective use of 3D simulation and visualization which helped to reduce the installation time of AMRs and analyse the production capacity to figure out the number of AMRs needed to fulfil the current capacity requirement. Moreover, with the defined KPI analysis, it is technically feasible to use AMRs for intralogistics, and it may enhance the proactive decision making as well. Mobile robots are flexible tools which can be applied in different use cases as needed and can be introduced to a production facility stage-wise, first testing a solution with just one AMR, and then gradually increasing their number per required capacity. The simulation-based approach can be replicated in other companies in the future, especially those that are dealing with similar business processes and production environments.

6. References
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