USING DISCRETE SIMULATION TO SUPPORT INTERNAL LOGISTICS PROCESS DESIGN

Tiago M.C. Campos[1], Maria do Sameiro Carvalho[1,2], José António Oliveira[1,2], Pedro Vaz Silva[3], Toni Machado[3]

[1]ALGORITMI Research Center, School of Engineering, University of Minho, Portugal
sameiro@dps.uminho.pt
tiagocampos@dps.uminho.pt
jose.oliveira@algoritmi.uminho.pt

[2]Department of Production and Systems, University of Minho, Guimarães, Portugal

[3]Bosch Car Multimedia Portugal S.A., Braga, Portugal
Pedro_Vaz.Silva@pt.bosch.com
Toni.Machado@pt.bosch.com

ABSTRACT

The objective of this paper is to present the developments of an ongoing project that aims at implementing an internal materials movement system using autonomous vehicles for supporting logistics processes. In particular the project focus on the movement of final products, from assembly lines to the expedition warehouse and the supply of packaging materials (customer packages), from the raw materials warehouse to the assembly lines. This process is currently carried out by two stackers, in a milk-run environment and, in the context of this project, an innovative solution is proposed to improve the performance of the supply and pickup processes, transforming and optimizing an entirely manual process into an automated one. The main challenge was to investigate the impact on the existing internal logistic system of the new solution and, simultaneously, to explore if new management strategies are needed to satisfy both throughput levels and overall supply chain needs. A simulation model was developed using ARENA Simulation Software to get insights concerning the new challenges posed by the solution to be adopted. Results have revealed that the use of simulation allowed the assessment of the impact of the new internal logistics solution and played a critical role to identify the best dispatching rules to schedule transportation orders in such a complex system. This research shows the flexibility of the simulation tool to address several complex management issues simultaneously that arises in the context of innovative solutions aligned with industry 4.0 challenges.

Keywords: internal logistics, autonomous vehicle, industry 4.0, simulation

1 INTRODUCTION

This paper results from an ongoing project designated Smart Autonomous Mobile Units (SAMU) and is one of the projects integrated in the iFactory global project that results from a research & development partnership between Bosch Car Multimedia and the University of Minho, aiming to raise the level of competence and excellence of both entities through the development of innovative projects aligned with industry 4.0 challenges. This project (SAMU) has been developed by a multidisciplinary engineering team composed of researchers from University of Minho and Bosch

Portugal. Its main goal is to develop an internal materials movement system using Autonomous Vehicles (AVs) in a very dynamic environment, aiming to improve overall logistics performance. This technology is within the topic of Industry 4.0, characterized by a strong emphasis on automation in manufacturing systems where autonomous vehicles will interact with humans in a coordinated approach.

The SAMU project takes place at Bosch Braga Plant (BrgP), covering the Raw Materials and Finished Goods (FGs) flows. The focus of this particular research is the FGs flow that is currently assigned to two stackers running in cycles of 20 minutes in a milk-run context. Whenever new products are assembled, they are palletized and must be transferred to the expedition warehouse. Stacker vehicles are used to pick up and transport these FGs to the expedition warehouse's waiting area. Simultaneously, these stackers perform the supply of customer packages (CPs) materials, from raw materials warehouse to assembly lines.

In a first stage, the current internal logistics operations are analyzed and its performance assessed. Then, the design of the new solution it was followed by the development of a simulation model to assess its performance to ensure that the inclusion of the new outbound logistic operations do not compromise the throughput levels or the overall supply chain requirements. Furthermore dispatching rules to schedule materials transport orders need to be explored to ensure an improved operational performance of the overall system.

This paper is structured as follows: Sect. 2 presents the related work; Sect. 3 describes the internal logistics current context; Sect. 4 describes the proposed solution and the discrete simulation modelling approach as well as main results achieved; conclusions are presented in Sect. 5.

2 RELATED WORK

Flexibility is an important feature that must be present in production systems, which are designed under the Industry 4.0 paradigm. Only a flexible production system can respond effectively to the constant changes made by customers to their orders. Hermann, Pentek and Otto [1] present guiding principles for the design of systems that must be aligned with the concept of Industry 4.0. The authors emphasize that the system modularity allows to achieve the needed flexibility to respond to the market. The same authors have made an interesting review of the literature about the design of systems for Industry 4.0 [2], contributing to a clarification of concepts related to Industry 4.0.

Internal Logistics plays a key role in a flexible production system, and itself must be flexible and efficient. Hofmann and Rüsch [3] present a discussion on the current state and future perspectives of the logistics relative to Industry 4.0. The authors highlight three important values for the client; "Availability Value" is their first value that may be achieved making products and services available to the customer through autonomous delivery. Hofmann and Rüsch [3] also emphasize in their work the opportunity of the simulation of the distribution processes due to the increasing digitisation of material flows. Simulation is fundamental in the case of a wide range of products with different production cycles. In these cases, the solution involves the development of a highly dynamic milk-run that is not time-driven, but driven by demand and therefore often it is not used for full capacity. It is possible to verify the characteristics of a dynamic milk run [4] that responds strictly to the demand, transporting material through the factory autonomously.

Intelligent AVs are technologically more evolved than Automated Guided Vehicles (AGV). The intelligent AVs can make decisions regarding the route to be followed and for that reason they are more flexible. This additional flexibility of this equipment justifies their choice to integrate the dynamic milk runs. As suggested Gelareh et al. [5], the methodologies that were used for the study and design AGV networks [6] can be adapted and used for projects with intelligent AVs.

The number of simulation project studies applied to logistics design is enormous, and it is a hard task to choose and highlight the most important publications. However, according to our best knowledge, no study was published related to internal logistics network design in a plant using intelligent AVs. However, we highlight the work of Kavakeb et al. [7] because it is close to our work, where the use of intelligent AVs in a European port is simulated. The authors chose the "Flexsim CT" simulation tool. With this work, the authors dimensioned the fleet of vehicles attending to the cost and performance.

Bruno et al. [8] developed a simulation model for the supply of material to production lines with a milk run, considering the costs and required level of service. The authors used Arena simulation tool. Also Vik et al. [9] used the Arena software to simulate an internal logistic process, while Dias et al. [10] chosen Witness software to model a milk run to supply material to production lines.

Arena simulation tool is considered one of the most popular currently on the market [11, 12] and it is suitable for the study of the design of an internal logistics system, which justified our choice in terms of tool and methodology, because the design and planning of an automated warehouse is a highly complex problem.

3 CURRENT SITUATION

This section describes the current internal logistics processes associated with the final assembly of Finish Goods (FGs) at Bosch BrgP (outbound logistics) and identifies some of the drawbacks of the system.

The outbound logistics consists of two main material flows, carried out by two stackers, in a milk-run context. Every 20 minutes each stacker performs a route supplying Customer Packaging materials from a specific storage location outside the warehouse (ZZ in Figure 1) or Customer Packages (CPs) Waiting Area (in blue, in Figure 1) in the warehouse, to the Customer Packages Pallets area, in the Production area and collecting FGs pallets from FGs pallets locations (close to the Production Lines, orange in Figure 1) and transporting them either to the warehouse in a temporary location (FGs Pallets Waiting Area) or directly to the expedition area. Figure 1 illustrates the layout of the plant where the main relevant areas for this process are identified.

The packed FGs are stored in pallets, at specified areas (orange area, Figure 1) along the corridor next to the production lines (Figure 1). There are 55 different pallet locations (grouped in 8 clusters) and an identical number of CPs pallets locations (yellow area). When a pallet is ready it is checked and receives a green label regarding its content and destination. The driver operator identifies pallets with the green label and transports them to the warehouse, leaving them at a waiting area for later storage on the specified shelves (pink area, Figure 1). Alternatively, the FGs pallet might be required for immediate shipping to the customer. In that case, the stackers move the pallets to other waiting area near the expedition area (dark grey area, Figure 1).

There are no pre-defined routes, but the transport of the FGs and CPs pallets are triggered by visual inspection and, in the case of the CPs, also by requests issued by a min-max strategy: when the quantity of CPs reaches a pre-defined minimum value, the replacement is triggered to the maximum allowed quantity.

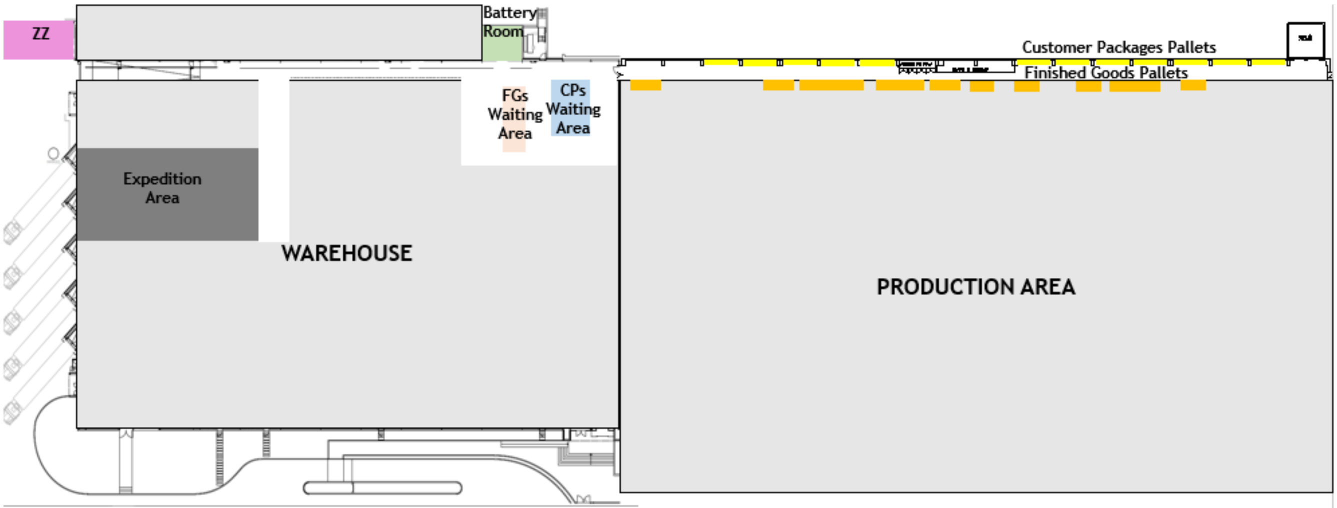

Figure 1: Layout of the study area

During the pickup task of the FGs, the stacker vehicles should load and transport two pallets at the same time. On average, 133 pallets of FGs and 161 pallets of CPs are moved per day (this average takes into account only 5.5 days per week since throughput rates at weekends are much lower). There are three shifts per day of eight hours each, seven days per week. On average, the pickup operation takes 95.5 seconds and the drop-off task, 80 seconds per pallet.

The FGs pickup process is dynamic, and is based on visual recognition (by the operator) of pallets ready to be picked up. This leads to different travelled distances carried by stacker vehicles (when are empty) until they find a pallet ready to pick up. However, they have to complete the cycle in about 20 minutes. It is expected that in one cycle, one stacker picks up to two FGs pallets and supply several CPs with a travel speed of approximately 8 km/h.

Some of the main issues of current solution are associated with the lack of dispatching strategies to deal with different requests to pick-up and deliver pallets. All the procedure is mainly based on visual inspection and operators experience actions which leads to excessive travelled distances. Additionally, the dynamic context of the assembly lines leads to a non-balanced operation and a non-efficient milk-run system.

Therefore, Bosch BrgP faces a set of challenges regarding the current processes used to move FGs materials such as:

- Lack of automation;
- Difficulty to determine with accuracy the location of the transport vehicles inside the plant as they move around it;
- Incapacity to track the materials in a minimum latency time;
- Dependency regarding human operators;
- Lack of efficiency of existing internal logistics processes.

The solution to be explored is based on the use of AVs providing Bosch with an almost independent system, capable of optimizing the main material flows. Note that the lack of automation in the materials movement process arises other issues, such as possibility of errors in the deliveries, supply irregularities and even the risk of accidents. Also, there are operation costs associated with the internal material's movement processes.

4 PROPOSED SOLUTION

This project aims to give an innovative solution providing increase in flexibility, process autonomy, productivity and efficiency to the existing system. Implementing this solution will optimize the outbound flows of materials. Once this solution is implemented, it is expected to be possible to monitor the vehicles inside the plant, configure each vehicle to go through a specific route and detect obstacles (static or dynamic objects and humans). Bosch aims to achieve the technology frontline in the context of Industry 4.0 guidelines, and this could be one of the most innovative projects regarding the internal materials movement process.

The iSAMU system is the main Information System that contains the functional modules needed to accomplish the above mentioned objectives. The Logistics Planner (LP) module is responsible for the logistics planning such as vehicle tasks building/scheduling and task management. LP system should compile a list of all the material requests either to collect Finished Goods (FGs) pallets or to refill Customer Packages (CPs). This list then should be organized according to some rules (First In First Out (FIFO), Earliest Due Date (EDD), priorities). After that, and considering the capacity of the vehicle, the route with sources/destinations and tasks (pickup or drop-off) is calculated and assigned to a specific vehicle.

4.1 Simulation model

The design of the new solution was, in a first stage, supported by a discrete simulation model developed in ARENA, to assess the different operational scenarios (Figure 2).

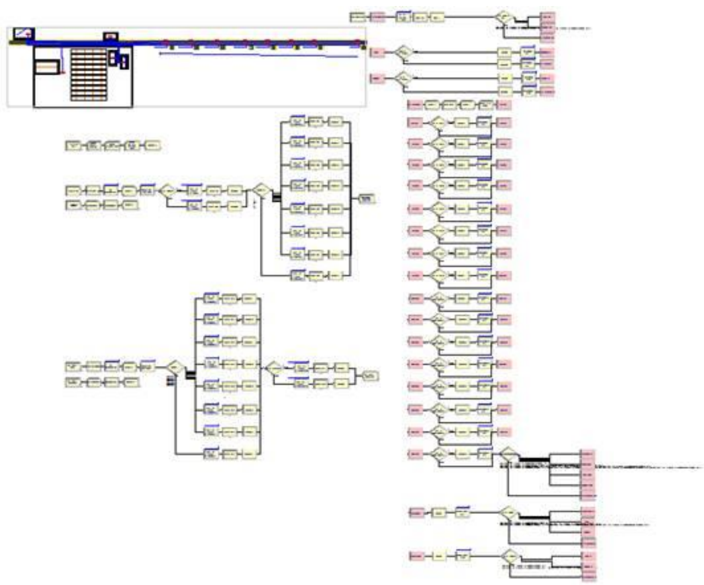

Figure 2: ARENA simulation model of the outbound logistics process

The main objectives of the model are to assess whether an AV with specific characteristics (capacity of 2 pallets and average speed of 7.7 km/h) is able to handle all the outbound logistics operation (replacing the two stackers), in the existing dynamic assembly conditions and, at the same time, explore different dispatching strategies to process materials movement requests to control the autonomous vehicle operation.

A list of material requests either to collect FGs pallets or to refill CPs must be generated. Historical data from existing operation was collected from January to June 2016 to produce movement requests (an average of 3200 requests of FGs pallets and 3875 requests of CPs, per month). Each movement request has several attributes: origin, destination, task and due date). A total of 8 clusters of FGs positions (clusters have a total of 55 positions) and 10 CPs positions, including both CPs Waiting Area and ZZ buffer (pallets already requested but waiting AV pick up task). It was assumed that there is no limit for CPs pallets on the production area since the replenishment is based on a min-max strategy.

Assuming one AV with capacity to move two pallets simultaneously, the route with sources/destinations and tasks (pickup or drop-off) is calculated and assigned to the autonomous vehicle. During the vehicle trip, if a path is blocked or another order occurs with higher priority (only when stacker does not have any load), the route has to be updated. Battery charging planning will be scheduled by opportunity and must also be considered whenever there are not pending tasks to perform. We defined Cycle Time as the time interval between two operations performed by the AVs and includes the time that vehicle spends in CPs dropping-off, FGs picking up and battery charging.

Different scenarios were evaluated:

- Scenario 1 – stacker can move 1 or 2 pallets per movement without due date (FIFO)
  - S1.1 – empty trips allowed – a trip starts when there is at least one request
  - S1.2 – empty trips not allowed – a trip can only start when there is at least one request for CPs and one request from FGs
- Scenario 2 – stacker can move 1 or 2 pallets per movement with due date (EDD)
  - S2.1 – trips triggered by 4 requests (2 FGs **and** 2 CPs pallets) or due date approximation
  - S2.2 – trips triggered by 2 requests (2 FGs **or** 2 CPs pallets) or due date approximation

4.2 Simulation results

Table 1 shows results from the simulation model: average values of different Key Performance Indicators (KPIs) measured.

Table 1: Results of simulations for different scenarios

KPIs	S1.1	S1.2	S2.1	S2.2
Total Number of Cycles (6 months)	32 543	13 134	12 116	15 748
Number of cycles per day	192	78	72	93
Average cycle time (min)	7.50	18.58	20.15	15.50
Average trip time (min)	1.6	2.4	6.2	7.9
Service Level CPs (%)	100%	100%	97.6%	100%
Service Level FGs (%)	100%	100%	95.8%	99.4%
Vehicle Battery Charging Time (min) – Average time interval between cycles	5.9	16.2	13.9	7.6
Vehicle Capacity Utilization (%)	29.9%	74.0%	80.3%	61.8%
Vehicle Standby Time (%)	78.8%	87.2%	69.1%	48.9%
Average CPs request waiting simultaneously	0.06	3.03	2.98	0.62
Maximum CPs waiting simultaneously	11	38	40	24
Average FGs request waiting simultaneously	0.06	4.34	1.35	0.63
Maximum FGs waiting simultaneously	46	132	57	46

The simulation results show that in all scenarios, only one AV is able to deliver high levels of service level (100% whenever due dates are not considered and between 95% and 100% when due dates apply) while vehicle utilization ranges from around 30% in S1.1 and 80% in S2.1. S1.1 shows a large number of short cycles and low vehicle utilization rates while S1.2 by not allowing empty trips improves utilization level, and decreasing by 60% the number of cycles performed (therefore reducing distance travelled by the vehicle).

Considering that there are only 10 spaces to store CPs pallets (awaiting transference to the production area) and 55 positions for FGs ready pallets, scenarios S1.1 and S1.2 show that, although, on average, these limits are not violated, maximum number of pallets waiting to be moved reach values greater than maximum acceptable (11 and 38 pallets of CPs on S1.1 and S1.2 respectively and 132 FGs pallets on S1.2).

Scenario 2 aims to increase process efficiency by allowing cycles to start whenever a minimum number of requests exist or a due date is close. The number of cycles per day ranges from 72 in S2.1 to 93 in S2.2 (significantly lower than S1.1) and utilization rates above 62%. As expected, average trip time increases: from 1.6 and 2.4 (S1) to 6.2 and 7.9 in S2.

Scenario 2 shows also some concerns concerning pallets buffers capacity: while average values fit constrains, maximum values are again above buffers capacity (although not so severely as S1.2 for FGs pallets. Further analysis allowed to realize that the number of observations (S2.2) where this value is higher than 10 pallets was 0.9% of the total observations. The counting of observations is shown in Figure 3.

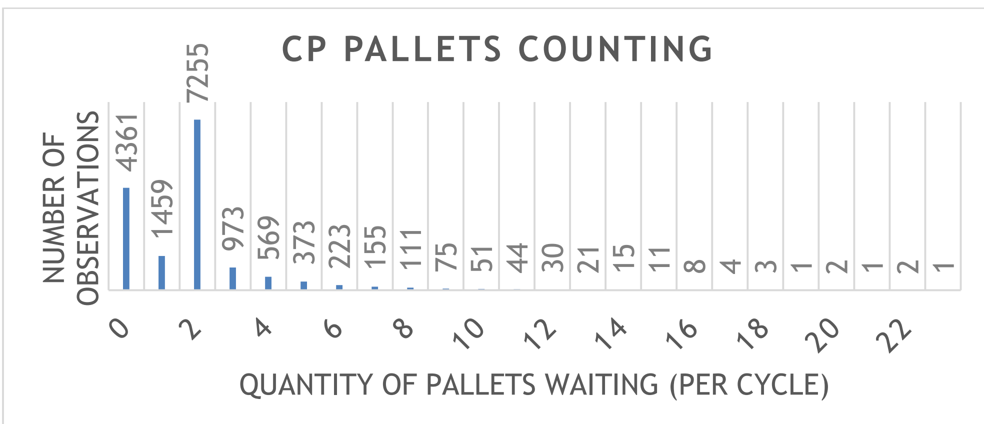

Figure 3: CPs pallets simultaneously in the waiting areas

This type of events results from the very dynamic and complex production environment, where balanced operations are difficult to achieve and, consequently, to manage. This means that the existence of buffers of FGs and CPs materials are inevitable to implement a flexible operation but creates additional complexity to the design of the operation. The right level of buffers to achieve flexibility without compromising operations performance is critical for the design of the future operation.

Additional studies need to explore further possible scenarios, but results achieved so far show that S2.2 has the best trade-off between vehicle utilization and service level and buffer capacity constraints. Sensitivity analysis to some simulation characteristics, such as vehicle speed, is also needed to take into account the dynamics of production environment. In fact, AV interacting with dynamic objects and humans must have a very prudent behavior to ensure the safety and the success of the overall system.

5 CONCLUSION

In this paper a new paradigm resulting from the fourth industrial revolution is explored: to redesign an internal logistics operation that takes into account the challenges that arise with advanced Information and Communication Systems, new intelligent autonomous vehicles and a highly flexible and dynamic industrial environment. A simulation based tool developed in ARENA Software was applied in a real context and it was critical to assess the impact of the explored operational alternatives as well as to identify different dispatching strategies to process materials movement requests to control the autonomous vehicle operation.

In particular, in this paper we address the design problem of the outbound logistics system at Bosch BrgP, using simulation technique, in the context of a research & development partnership between the industrial company and the University of Minho. The project aimed at identifying operational issues in the outbound logistic flows as a result of the adoption of an AV to perform Finished Goods (FGs) and Customer Packages (CPs) pallets movements.

Besides a literature review of related work the project involved the development of a simulation model of the outbound logistic. Four main scenarios have been implemented to incorporate different dispatching rules concerning requests management. Preliminary results allowed to identify the need of ensuring a good vehicle utilization without compromising service level (due dates) as suggested by scenario 2.2. An additional issue identified concerns the capacity of the buffers of FGs and CPs pallets. Existing buffers capacity might have to be re-dimensioned to cope with trade-off between the number of vehicles and its utilization and some peak periods where existing capacity can be insufficient.

The use of discrete simulation allows us to evaluate complex systems and to test different operating strategies prior to implementation. Furthermore, simulation models allowed a better understanding of the systems characteristics and requirements.

This project can bring new insights in using simulation as a flexible tool to address several issues in a complex outbound logistics system and proving support in analysing different scenarios both in terms of designing and management policies. Results also supports that all the operations within the warehouse are interrelated. Thus, the impact of a change in an operating policy should be verified. Furthermore, the simulation solution developed in the context of this research project will allow decision makers to rapidly reconfigure logistic system settings to face constant changes associated with existing complex industrial contexts, such as sudden changes in production levels to satisfy customer’s needs, in a more tactical decision making environment.

Future work includes more simulation experiments to test the sensitivity of the solution to some parameters as well as new dispatching strategies. Finally, a return on the investment analysis should be performed. These analyses should include the number of AVs that can be assigned to these activities and the operation performance.

Acknowledgements

This work has been financially supported by the Portugal Incentive System for Research and Technological Development in scope of the projects in co-promotion nº 002814/2015 (iFACTORY 2015-2018).

6 REFERENCES

[1] **Hermann, M., Pentek, T., & Otto, B. 2016.** Design principles for industrie 4.0 scenarios, In System Sciences (HICSS), Proceeding of the 49th Hawaii International Conference on System Sciences, Kauai, Hawaii, United States of America, January 05-08, pp. 3928-3937.

[2] **Hermann, M., Pentek, T., & Otto, B. 2015.** Design Principles for Industrie 4.0 Scenarios: A Literature Review. Working Paper, No. 01 / 2015.

[3] **Hofmann, E., & Rüsch, M. 2017**. Industry 4.0 and the current status as well as future prospects on logistics, *Computers in Industry*, 89, pp 23-34.

[4] **Bremer Institut für Produktion und Logistik GmbH [BIBA]. 2016**. The Industry 4.0-Competence and Transfer Centre at BIBA, (2016). Retrieved May 10, 2017, from http://www.biba.uni-bremen.de/industrie4.html?&L=1.

[5] **Gelareh, S., Merzouki, R., McGinley, K., & Murray, R. 2013.** Scheduling of intelligent and autonomous vehicles under pairing/unpairing collaboration strategy in container terminals, *Transportation Research Part C: Emerging Technologies*, 33, pp 1-21.

[6] **Bechtsis, D., Tsolakis, N., Vlachos, D., & Iakovou, E. 2017**. Sustainable supply chain management in the digitalisation era: The impact of Automated Guided Vehicles, *Journal of Cleaner Production*, 142, pp 3970-3984.

[7] **Kavakeb, S., Nguyen, T. T., McGinley, K., Yang, Z., Jenkinson, I., & Murray, R. 2015**. Green vehicle technology to enhance the performance of a European port: a simulation model with a cost-benefit approach, *Transportation Research Part C: Emerging Technologies*, 60, pp 169-188.

[8] **Costa, B., Dias, L. S., Oliveira, J. A., & Pereira, G. 2008**. Simulation as a tool for planning a material delivery system to manufacturing lines, Proceeding of the Engineering Management Conference, Estoril, Portugal, June 28-30, pp 1-5.

[9] **Vik, P., Dias, L., Oliveira, J., & Pereira, G. 2008.** Using 3D simulation in an internal logistic process, Proceedings of 15th European Concurrent Engineering Conference, Porto, Portugal, April 9-11, pp 116-120.

[10] **Dias, L., Vik, P., Oliveira, J. A., & Pereira, G. 2012.** Simulation in the design of an internal logistic system-Milk run delivering with Kanban control. Proceedings of 10th International Industrial Simulation Conference, Brno, Czech Republic, June 4-6, pp 159-166.

[11] **Pereira, G., Dias, L., Vik, P., & Oliveira, J. A. 2011.** Discrete simulation tools ranking: a commercial software packages comparison based on popularity, Proceedings of 9th Industrial Simulation Conference, Venice, Italy, June 6-8, pp 5-10.

[12] **Dias, L. M., Vieira, A. A., Pereira, G. A., & Oliveira, J. A. 2016.** Discrete simulation software ranking—A top list of the worldwide most popular and used tools, Proceedings of the 2016 Winter Simulation Conference, Arlington, Virginia, United States of America, December 11-14, pp 1060-1071.