SIMULATION OF AN ORDER PICKING SYSTEM IN A MANUFACTURING SUPERMARKET USING COLLABORATIVE ROBOTS

Fábio Coelho, Susana Relvas, Ana P. Barbosa-Póvoa
CEG-IST, Instituto Superior Técnico
Universidade de Lisboa
Av. Rovisco Pais 1
1049-001, Lisboa, Portugal

KEYWORDS

Industry 4.0, Simulation, Manufacturing supermarket, Order picking

ABSTRACT

Manufacturing industries depend on robust internal logistics operations that enable efficient production strategies, as is the case of an assembly line feed by an internal logistics supermarket. Agile decision making in flexible manufacturing elevates the need for planning the overall shop-floor operations and controlling them. This work explores the existing literature regarding the operation of manufacturing supermarkets and proposes a simulation tool that analyses the order picking activity in a logistics supermarket where the usage of robots is explored in order to feed flexible manufacturing assembly lines efficiently leading to economic savings. This is done using Simio – simulation modelling framework based on intelligent objects. The model outputs suggest that the system performance increases with humans. Although, when uncertainty is considered, the collaborative robots are more flexible, which leads to lower variations of performance.

INTRODUCTION

The manufacturing increasing competitiveness imposes the need of efficient production strategies where the support of internal logistics activities has become a requisite in any manufacturing system. Additionally, the use of flexible robotic solutions is nowadays a reality where the interaction human-robot stands up. Thus, the introduction of collaborative robots (cobots or co-robots) is a path being explored, which however needs an efficient design, planning and control of the overall in-house logistics operations. The automobile sector has adopted the supermarket concept to meet the challenges of just-in-time (JIT) part supply of assembly lines, and decentralized logistics areas were created allowing small deliveries of parts that are immediately needed at assembly line (Emde and Boysen 2012). So, the supermarket is one of the key issues for automobile manufacturers and, subsequently, order picking activities too. Also, market pressure enforces companies to allow customers to customize their products, which leads to mixed-model assembly lines, where more than one model is produced at the same line. Therefore, assembly line feeding is an important aspect to increase efficiency and effectiveness of the manufacturer. To do so an efficient management of such systems is required, where order picking activities are a key concern.

Order picking can be divided into parts-to-picker and picker-to-parts systems (de Koster et al. 2007). The former is typically performed with automated guided vehicles (AGV's) that bring the shelves to the picking station, where the human completes the picking. In the latter, the picker goes throughout the product locations to pick them until completing the orders. It is important to note that parts-to-picker is not appropriate when products have a large volume and have to be stored in individual locations. In addition, kitting is a specific case of order picking, where parts are sorted just-in-sequence (JIS) in dedicated bins (JIS-bins) to be delivered in sequence to the assembly line.

In fact, in industry, the order picking activity continues to be performed by humans because up to now the automatic picking systems have been unable to respond to the requisites of speed, flexibility, precision, and safety necessary to both service level and share the workspace with humans. However, following the trend of industry 4.0, the future goes through collaborative robots that physically interact with each other and with humans in a shared workspace.

In the present work, we use Simio - simulation modelling framework based on intelligent objects - to simulate order picking operations in a manufacturing supermarket. In Simio there is no need to write programming code since it is graphical and intuitive (Pegden and Sturrock 2011). Also, it is simple to present the model to decision-makers once the model looks identical to the real world.

Subsequently to the development of the model, several scenarios are studied to determine the most appropriate supermarket configuration that allows a better operational performance.

The main goal of this work is then to offer a simulation tool that analyses the order picking activity in a manufacturing supermarket, allowing one to understand how the system performance responds to the introduction of collaborative robots.

The next section presents a literature review on manufacturing supermarket, order picking and collaborative robots. Then, a model description and its implementation on Simio are described. Subsequently, we explain the model validation and first results are

Proceedings 32nd European Conference on Modelling and Simulation ©ECMS Lars Nolle, Alexandra Burger, Christoph Tholen, Jens Werner, Jens Wellhausen (Editors)
ISBN: 978-0-9932440-6-3/ ISBN: 978-0-9932440-7-0 (CD)

presented. Finally, conclusions are provided, and some future research directions are presented.

LITERATURE REVIEW

According to some authors the concept of manufacturing supermarket is little explored in the research literature (e.g., Emde and Boysen 2012; Saaidia et al. 2014). Still, the papers dealing with the manufacturing supermarkets usually focus on aspects like the definition of routes and scheduling of tow trains or the size and location of supermarkets (Emde 2017).

Related to supermarket locations, (Alnahhal and Noche 2015) tackle this important problem as well as the use of tow trains. The aim of their work is to minimize both transportation and inventory costs. In the (Golz et al. 2012) work, the routing problem of tow trains related to supermarkets is studied based on the automobile industry. The minimization of the number of trips performed by tow trains from supermarket to the assembly line is performed. In the same way, (Emde and Boysen 2012) solve the routing problem of tow trains in order to minimize the number of tow trains used to feed the assembly line. In addition, (Faccio et al. 2013) present a case study of an automotive industry where they intend to optimize the feeding system of mixed-model assembly lines. They also present a framework for design and relate both the number of tow trains and kanban. Furthermore, (Fathi et al. 2014) and (Emde and Gendreau 2017) studied the scheduling problem of tow trains. The former aims to optimize the number of tow trains trips applied to a real case. The latter wants to minimize in-process inventory and, for that, tackle the problem through exact and heuristic solution methods.

Additionally, (Emde et al. 2012) studied the loading problem of tow trains with the objective of minimizing line stocking while accounting for the capacity of the tow trains. Also, (Sternatz 2015) tackle two interdependent problems in parallel, namely assembly line balancing and parts feeding. He found that the worker takes less time to pick parts from a JIS-bin instead of picking from a bulky load unit. In addition, (Battini et al. 2016) studied the same problem. They test direct and indirect parts feeding and report that the application of a combined approach will possibly reduce line stocking and minimize time losses. (Caputo et al. 2015) assign different feeding policies to orders, namely kitting, line stocking and just-in-time, aiming to minimize delivery costs. Two common types of kitting: zone kitting, and batch kitting are often considered. They differ from each other by the fact that in the first one the JIS-bin moves while being filled. On the other hand, in batch kitting the JIS-bin is fixed until it is filled. (Balakirsky et al. 2013) tackle batch kitting processes and demonstrate a case study of robotic kit building. (Hanson et al. 2015) studied the kitting preparation in a real context and refer that some companies prefer to make one kit at a time, while others choose batch picking. Additionally, (Hanson and Medbo 2016) classify different design aspects that can influence this task time.

To perform the picking operation there exist different kinds of autonomous order picking systems. However, (Kimura et al. 2015) remark that fixed equipment is inadequate for high-mix low-volume warehouses. Also, the majority of common mobile robots explored in the literature have only one arm and, therefore, they cannot make order picking as workers. In (Kimura et al. 2015) work, the authors present a mobile dual-arm robot and an autonomous order picking system suitable for high-mix low-volume warehouses. In the same way, (Lemburg et al. 2011) present a robot with two collaborative arms. On the other hand, in (Nieuwnhuisen et al. 2013) work the mobile robot studied is dual-arm but the two arms are not collaborative.

From the above literature review, it can be seen that supermarket stocking and picking problems are neglected in the literature. Additionally, and according to (Nielsen et al. 2017), there is a lack of research in real-world applications of autonomous mobile robots, which leads to poor employment in the industry.

In this context, we intend to develop a simulation model for a real problem of an automobile manufacturing company in order to study the advantages and disadvantages of the collaborative robots' implementation to perform picking operations in a real context.

PROBLEM DESCRIPTION

The reference company for this study is a Portuguese automobile manufacturer that makes use of supermarket concept for line feeding in order to face the distances between the assembly line and the central warehouse.

In order to build a simulation model, it is needed to understand how the real operation is performed. The materials handling begins with the arrival of the products to the factory. Typically, the factory is supplied through the external warehouse or JIT-suppliers, but the materials can also be delivered through external supply. Subsequently, the materials are distributed by tow trains or AGV to both point-of-fit and supermarket locations. Through this system, only the parts needed for a small number of production cycles are available on the line, releasing space at the assembly site and reducing the occurrence of errors.

These supermarkets have a fixed layout, like the one represented in Figure 1, and each supermarket has one dedicated picker.

In the order picking operation under study, when a sequential order arrives (i.e., when an empty dedicated JIS-bin arrives at the supermarket) the assigned picker starts the operation by visiting different supermarket locations to pick the products in order to fulfil a specific kit. After that, the picker leaves the finished kit in a specific place to be later transported in sequence to the assembly line. It is important to note that the picker can perform only one order at a time.

Therefore, the problem developed in this work has to do with order picking in a manufacturing supermarket approached by a simulation model. The objective is that the current operations exclusively developed by humans can also be developed by robots since this is the intention of the company in order to become more flexible and better face future challenges.

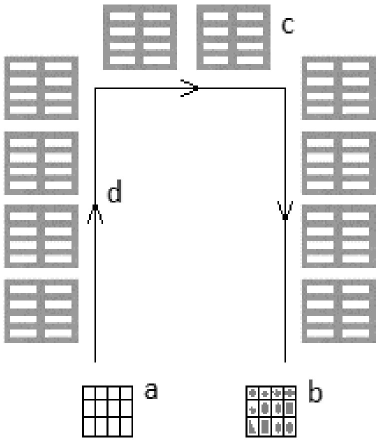


Figure 1: Scheme of Order Picking Operation (a – Empty JIS-bin; b – Fulfilled Kit; c – Different Product Locations; d – Oriented Path)

MODEL DESCRIPTION AND SIMIO IMPLEMENTATION

Based on the real operation described in the previous section a simulation model is developed, which is described below. Such model is then generalized to describe the order picking system of a manufacturing supermarket using collaborative robots.

The supermarket is modelled using an agent-based approach. It consists of humans, cobots, products, storage locations and empty JIS-bins to collect the products.

When an order (i.e., empty JIS-bins dedicated to a given kit type) arrives at the supermarket, one available picker (human or cobot) is assigned to it. Then, it goes through different storage locations in order to fulfil the order (complete the kit) with the requested products. Since the kit is finished, it goes to the final location waiting for transport to the assembly line. At this point, the picker is released and can start the next order.

The purpose of this work is to simulate the order picking operations performed in a manufacturing supermarket in order to calculate the number of kits fulfilled per minute.

In order to build the model in Simio, we use some standard software objects, such as source, worker, vehicle, server, and sink (for readers unfamiliar with Simio, please see Pegden and Sturrock 2013). Therefore, the order picking operation has been modelled as follows:

- Empty JIS-bin – entities sequentially generated by a "source" object that are processed in the supermarket. The empty JIS-bin waits for an available picker that transports it throughout the supermarket locations and completes it according to the kit type;
- Picker – there are two different types available (human, modelled as "worker"; or cobot, modelled as "vehicle") and its function is to fulfil the orders according to each kit type;
- Product locations – modelled as "combiner" object (without processing time), that represents the storage locations of the different products in the supermarket;
- Products - entities generated by a "source" object that are waiting for picking in the storage locations;
- Kit – an entity that represents a fulfil order ready to feed the assembly line.

In order to understand the way the model works some pictures about the properties of some entities and the correspondent symbols are presented. Figure 2 shows the representation of human picker and cobot in Simio. The main properties of these two entities are depicted in Figure 3 and Figure 4.

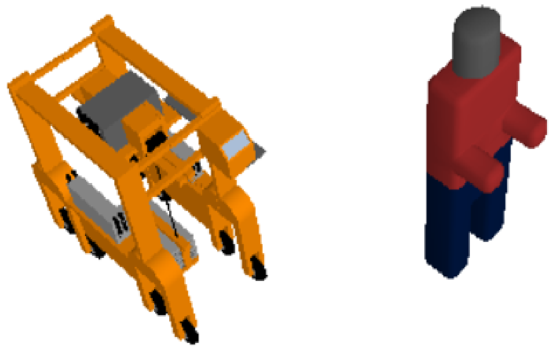
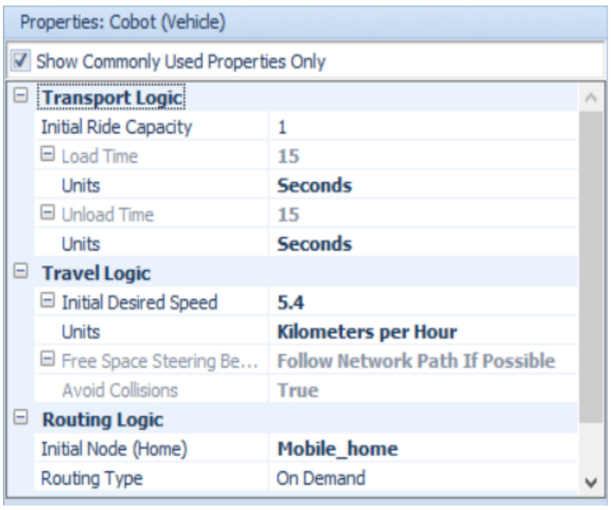


Figure 2: Symbols of the Cobot and Human Picker

Regarding the picking routes, the picker knows exactly which locations he must visit, taking into account the type of kit (order) he receives. In addition, each storage location owns an indication about the quantities of that specific product needed for each type of kit.



Properties: Cobot (Vehicle)

☑ Show Commonly Used Properties Only

Transport Logic	
Initial Ride Capacity	1
Load Time	15
Units	**Seconds**
Unload Time	15
Units	**Seconds**
Travel Logic	
Initial Desired Speed	**5.4**
Units	**Kilometers per Hour**
Free Space Steering Be...	**Follow Network Path If Possible**
Avoid Collisions	**True**
Routing Logic	
Initial Node (Home)	**Mobile_home**
Routing Type	On Demand

Figure 3: Properties of the Cobot

Some parameters are adjustable, like speed and load/unload times for both cobot and human picker depending on whether the analysis is deterministic or not.

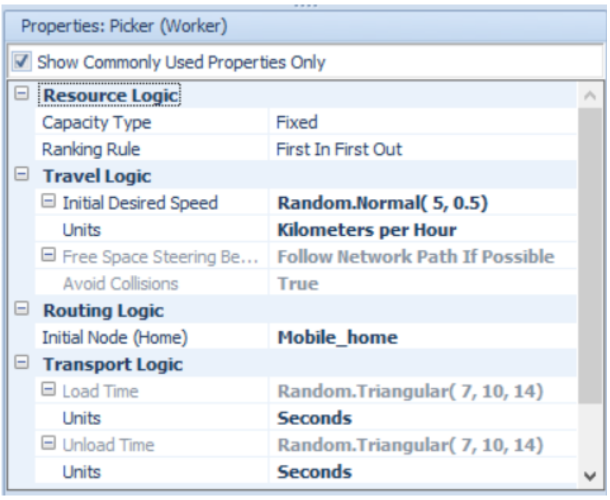


Figure 4: Properties of the Human Picker

MODEL VALIDATION AND PRELIMINARY RESULTS

As mentioned the layout and mode of operation considered in the model developed are representative of the referred automobile company reality.

On the other hand, the operational data introduced in the model has been changed due to confidentiality reasons. However, they are representative and illustrative of the day-to-day operations of the company. For this reason, it enables the execution of the model in order to test different scenarios and analyse both how the model works, and the results obtained.

The different scenarios under analyses are the following:

- Scenario 1 represents the current system configuration with one human picker;
- Scenario 1.1 represents the current system configuration but replacing the human by the cobot;
- Scenario 1.2 represents the current system configuration but human and cobot share the same workspace;
- Scenario 1.3 represents the current system configuration, but now with two human pickers;
- Scenario 1.4 represents the current system configuration, but replacing the human by two cobots;
- Scenarios 2, 2.1, 2.2, 2.3 and 2.4 consider uncertainty in terms of speed and load/unload times of human picker, and uncertainty related to expected orders in scenarios 1, 1.1, 1.2, 1.3 and 1.4, respectively.

For scenarios dealing with uncertainty, we consider for the cobot speed a fixed value of 5.4 kilometres per hour and for the human picker a random value that follows a normal distribution with a mean of 5 and standard deviation of 0.5 kilometres per hour. In the same way, load/unload times (that represents order picking operation) for human picker has a random value that follows a triangular distribution (with a lower limit of 7 seconds, an upper limit of 14 seconds and a mode of 10 seconds), while the cobot has a fixed value of 15 seconds. Regarding the arrival of orders, it follows a random exponential distribution (with a mean of 1 minute) to simulate the uncertainty across different work days. It is important to note that the choice of distributions was made based on i) application to real cases demonstrated in the existing literature (e.g., Liong and Loo 2009), and ii) distribution that best fits the real data observed. Additionally, the user can change the number of both humans and cobots in the model to see how the system responds in terms of service level.

The simulation duration was 24 hours to meet the uninterrupted work of the company under study (24 hours a day). The model was run terminating since the company wants to know how many kits are completed at the end of a 24 hours cycle. The break times are excluded from the model as work always continues exactly as it left off before the break. Regarding experiments, 100 replications were performed with an average computational time of 3,1 minutes each. It is important to note that this number of replications is acceptable since we are interested in estimating the mean of the number of kits per minute. However, if we want to estimate a maximum value the number of replications would have to be higher.

Table 1 shows the comparison of the average number of kits per minute and the distance travelled by the pickers for the six scenarios under analysis.

Table 1: Scenarios' preliminary results

Scenarios	Number of kits per minute	Total number of kits	Number of pickers	
			Human	Cobot
Without uncertainty				
1	0,40	576	1	-
1.1	0,31	446	-	1
1.2	0,70	1008	1	1
1.3	0,81	1166	2	-
1.4	0,63	907	-	2
With uncertainty				
2	0,30	432	1	-
2.1	0,30	432	-	1
2.2	0,66	950	1	1
2.3	0,67	964	2	-
2.4	0,62	893	-	2

The results show that comparing human versus cobot, the former achieves a better performance, especially in deterministic scenarios. This can be explained by the fact that cobot has higher load/unload times than the human picker. However, if we look more closely at the results, we can see that when uncertainty is considered this conclusion is not so obvious. On the one hand the human picker obtains a better performance compared to the robot, but on the other hand presents a greater variation of performance than the robot when the uncertainty is considered.

For example, scenarios 2, 2.2 and 2.3 – where uncertainty in terms of speed and load/unload times of human picker, and uncertainty related to expected orders are considered – reaches a slightly lower performance compared with scenario 1, 1.2 and 1.3, respectively. Again, this can be explained by the fact that all the referred scenarios involve human picker, which is more affected by uncertainty, unlike the cobot. In contrast, scenarios 2.1 and 2.4 present almost the same performance of deterministic scenarios 1.1 and 1.4, respectively.

DISCUSSION AND FUTURE RESEARCH

This paper presents a simulation modelling tool to analyse the order picking activity in a manufacturing supermarket, as well as to analyse how the system performance answers due to the implementation of collaborative robots.

According to simulation results, the performance increases when the human picker is considered. Although, when uncertainty is considered, the collaborative robots are more flexible, which leads to lower variations of performance in these cases. This result can be generalized to several types of uncertainty.

Given that this is an ongoing work, there are future improvements that will be introduced in the model, such as inventory control, routes of tow trains. In future work, we also intend to improve model's layout and analyse how this influences the operation performance. Through all this, the model can be tested all together and validate it with real data.

The developed tool aims to support the automobile company in the design and planning of the aforementioned supermarkets allowing the testing of several scenarios of order picking operation accounting for the presence of uncertainty.

Finally, the model can be generalized to other companies that use the manufacturing supermarket concept.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support from Portugal 2020 framework, under the project POCI-01-0145-FEDER-016418 financed by EU/FEDER through the programme COMPETE2020.

REFERENCES

Alnahhal, M., B. Noche. 2015. "A Genetic Algorithm for Supermarket Location Problem", *Assembly Automation*, 35:1, 122-127.

Balakirsky, S., Z. Kootbally, T. Kramer, A. Pietromartire, C. Schlenoff and S. Gupta. 2013. "Knowledge driven robotics for kitting applications". *Robotics and Autonomous Systems*, 61:11, 1205–1214.

Battini, D., M. Calzavara, A. Otto and F. Sgarbossa. 2016. "The Integrated Assembly Line Balancing and Parts Feeding Problem with Ergonomics Considerations". *IFAC-PapersOnLine*, 49:12, 191-196.

Caputo, A. C., P. M. Pelagagge and P. Salini. 2015. "A Decision Model for Selecting Parts Feeding Policies in Assembly Lines". *Industrial Management and Data Systems*, 115:6, 974-1003.

de Koster, R., T. Le-Duc and K. J. Roodbergen. 2007. "Design and Control of Warehouse Order Picking: A Literature Review". *European Journal of Operational Research*, 182:2, 481-501.

Emde, S., M. Fliedner and N. Boysen. 2012. "Optimally Loading Tow Trains for Just-in-Time Supply of Mixed-Model Assembly Lines". *IIE Transactions*, 44:2, 121-135.

Emde, S. and N. Boysen. 2012. "Optimally Routing and Scheduling Tow Trains for JIT-Supply of Mixed-Model Assembly Lines". *European Journal of Operational Research* 217, 287-299.

Emde, S. 2017. "Scheduling the Replenishment of Just-in-Time Supermarkets in Assembly Plants". *OR Spectrum*, 39, 321-345.

Emde, S. and M. Gendreau. 2017. "Scheduling In-House Transport Vehicles to Feed Parts to Automotive Assembly Lines". *European Journal of Operational Research*, 260, 255–267.

Faccio, M., M. Gamberi, A. Persona, A. Regattieri and F. Sgarbossa. 2013. "Design and Simulation of Assembly Line Feeding Systems in the Automotive Sector Using Supermarket, Kanbans and Tow Trains: A General Framework". *Journal of Management Control*, 24:2, 187–208.

Fathi, M., M. J. Alvarez, F. H. Mehraban and V. Rodríguez. 2014. "A Multiobjective Optimization Algorithm to Solve the Part Feeding Problem in Mixed-Model Assembly Lines". *Mathematical Problems in Engineering*, 2014:1, 1-12.

Golz, J., R. Gujjula, H-O. Gunther, S. Rinderer and M. Ziegler. 2012. "Part Feeding at High-Variant Mixed-Model Assembly Lines". *Flexible Services and Manufacturing Journal*, 24:2, 119-141.

Hanson, R., L. Medbo and M.I. Johansson. 2015. "Order Batching and Time Efficiency in Kit Preparation". *Assembly Automation*, 35:1, 143-148.

Hanson, R. and L. Medbo. 2016. "Aspects Influencing Man-Hour Efficiency of Kit Preparation for Mixed-Model Assembly". In *Proceedings of the 6th CIRP Conference on Assembly Technologies and Systems*, 44, 353-358.

Kimura, N., K. Ito, T. Fuji, K. Fujimoto, K. Esaki, F. Beniyama and T. Moriya. 2015. "Mobile Dual-Arm Robot for Automated Order Picking System in Warehouse Containing Various Kinds of Products". In *Proceedings of the 2015 IEEE/SICE International Symposium on System Integration*, 332-338.

Lemburg, J., J. de G. Fernández, M. Eich, D. Mronga, P. Kampmann, A. Vogt, A. Aggarwal, Y. Shi, and F. Kirchner. 2011. "AILA - Design of an Autonomous Mobile Dual-Arm Robot". In *Proceedings of the 2011 IEEE International Conference on Robotics and Automation*, 5147-5153.

Liong, C-Y and C. S. E. Loo. 2009. "A Simulation Study of Warehouse Loading and Unloading Systems Using Arena". *Journal of Quality Measurement and Analysis*, 5:2, 45-56.

Nielsen, I., Q-V. Dang, G. Bocewicz and Z. Banaszak. 2017. "A Methodology for Implementation of Mobile Robot in Adaptive Manufacturing Environments". *Journal of Intelligent Manufacturing*, 28:5, 1171–1188.

Nieuwnhuisen, M., D. Droeschel, D. Holz, J. Stückler, A. Berner, J. Li, R. Klein and S. Behnke. 2013. "Mobile Bin Picking with an Anthropomorphic Service Robot". In *Proceedings of the 2013 IEEE International Conference on Robotics and Automation*, 2327-2334.

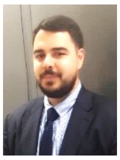
Pegden, C. D., and D. T. Sturrock. 2011. "Introduction to Simio". In *Proceedings of the 2011 Winter Simulation Conference*, 21-31.

Pegden, C. D. and D. T. Sturrock. 2013. “Rapid Modeling Solutions: Introduction to Simulation and Simio”. Pittsburgh: Simio LLC.

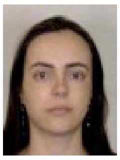
Saaidia, M., S. Durieux and C. Caux. 2014. “A Survey on Supermarket concept for Just-in-Time Part Supply of Mixed Model Assembly Lines”. In *Proceedings of the 10th International Conference of Modeling and Simulation*.

Sternatz, J. 2015. “The Joint Line Balancing and Material Supply Problem”. *International Journal of Production Economics* 159, 304-318.

AUTHOR BIOGRAPHIES



FÁBIO COELHO is a PhD student at the Engineering and Management Department of Instituto Superior Técnico (IST), University of Lisbon. He holds a MSc degree from IST. His research focus is on simulation, operations research, logistics and decision support systems. His work develops in close collaboration with industry. His e-mail address is: `fabiocoelho@tecnico.ulisboa.pt`.



SUSANA RELVAS is an Associate Professor at the Department of Engineering and Management of Instituto Superior Técnico (IST), University of Lisbon. She holds a PhD in Industrial Engineering and Management from IST. Her research focus is on Logistics, Supply Chain Management and Operations Management, by applying state of the art solution methods to real life problems. Through a systems approach, she collaborates with peers and companies in national and international research projects. She is the author of several papers in top impact factor journals and supervises several PhD and MSc candidates. Her e-mail address is: `susana.relvas@tecnico.ulisboa.pt`.

ANA P. BARBOSA-PÓVOA is a Full Professor in Operations and Logistics, at the Engineering and Management Department of Instituto Superior Técnico (IST), and she holds a PhD from the Imperial College of Science Technology and Medicine. Her research focuses on developing a comprehensive understanding of a variety of problems in supply chains and operations management, supported by novel engineering systems models and techniques. Her work develops in close collaboration with leading companies from a variety of different industries in the decision support and optimization of their operations. She has published widely in international journals and has participated in a large number of conferences where she has presented several plenary lectures. Her e-mail address is: `apovoa@tecnico.ulisboa.pt`.