Improving efficiency of material flows in an automotive assembly plant: A case study

Evanthia Thanou and Aristides Matopoulos

Aston Logistics & Systems Institute, College of Engineering and Physical Sciences, Aston University, Aston Triangle, B4 7ET, UK

Emails: thanoue1@aston.ac.uk; a.matopoulos@aston.ac.uk*

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

*Corresponding author

Improving efficiency of material flows in an automotive assembly plant: A case study

This paper investigates the in-plant logistics processes in automotive manufacturing and specifically, the material flows between the storage facility, the production lines, and the internal returns area. The aim is to improve the efficiency of the plant by looking at the current material flows of the case study company. Qualitative and quantitative data were collected through interviews and personal observations and were analysed. Using discrete event-based simulation, the current material flows were investigated. Our analysis showed that in plant's internal returns area efficiency gains are possible by reducing traffic congestion. A solution with minor changes in the layout was proposed and tested which showed an increase in the capacity of the system and a reduction in delays.

Keywords: automotive; assembly plant; material flows; internal returns area; simulation

1. Introduction

Automotive manufacturers are facing enormous pressures to improve the efficiency of their plants (SMMT, 2020; Holweg et al., 2017; Parkin et al., 2017; Heid et al., 2018), whilst at the same time dealing with a very dynamic market environment, and ever increased product complexity (e.g. more derivatives, increased number of different body styles). Logistics and material flow processes play a critical role in plant's assembly operations and any inefficiency in feeding the lines (e.g. due to disruptions, errors or delays) could have a significant negative impact on the performance of the whole manufacturing system (Li et al., 2020; Boysen et al., 2015; Alnahhal and Noche, 2015). It is estimated that one minute of an unplanned production stoppage can cost from $10,000 to $100,000 to an automotive company (DHL, n.d.; Galligan, 2016) and therefore, minimising the unplanned delays within automotive assembly plants is vital (Immerman, 2018).

In the literature a significant number of studies has investigated material flows in assembly plants, focusing on the storage facility, the mixed-production lines and the material supply systems (Li et al., 2020; Alnahhal and Noche, 2015; Boysen et al., 2015; Jainury et al., 2014; Dörnhöfer et al., 2016). The use of the supermarket concept for example is found to offer great advantages into the assembly plants such as fast and flexible logistics processes (Battini et al., 2013; Emde and Boysen, 2012). Mixed-production lines operations as well as material supply systems that feed the production lines have been also closely reviewed (Jin et al., 2008; Dörmer et al., 2015) with researchers highlighting the positive impact of hybrid supply systems (e.g. increase efficiency by combining different materials supply systems and exploiting their advantages) on system's performance (Caputo and Pelagagge, 2010; Limère et al., 2012).

However, despite the significant number of studies focusing on the flow of materials in automotive assembly plants, there is a number of shortcomings in the literature. One major gap is that previous research has ignored the returns flow in assembly plants. The internal returns area is where empty packages are picked up from the production lines, disposed to another area in the plant and prepared for returns. This is an important process because any delays in picking up the empty boxes can cause production delays, as the production lines will be occupied with empy boxes instead of boxes loaded with new parts required for the continuity of the production. Also, delays in the offloading processes in the returns area can result in the transport vehicles waiting in long queues instead of feeding the lines. Overall, internal returns area can be money and time costly if it operates inefficiently (Boysen et al., 2015).

In light of the gap in the extant literature, this research makes a valuable contribution by focusing on the returns area operations, which has not received attention for its potential to improve the efficiency of the plant. More specifically, we review the material flows of the case study company's assembly plant and propose, after testing, a feasible suggestion for improving efficiency. The assembly plant of the company under investigation (which from now on will be referred as Car Co.) consists of a centralised storage area, known as the marketplace, the production lines and the returns area between which the material flows take place (Figure 1). Using a combination of primary and secondary data we propose and test a simulation model that could be used after adaptations in the returns area of other automotive assembly plants in order to measure and improve the material flow system's performance.

The remainder of the paper is organised as follows. We start in Section 2 with an overview of the related literature followed by the research methodology in Section 3. Next, in Sections 4 and 5 the findings and the discussion are presented respectively, followed by conclusions and recommendations for further work in Section 6.

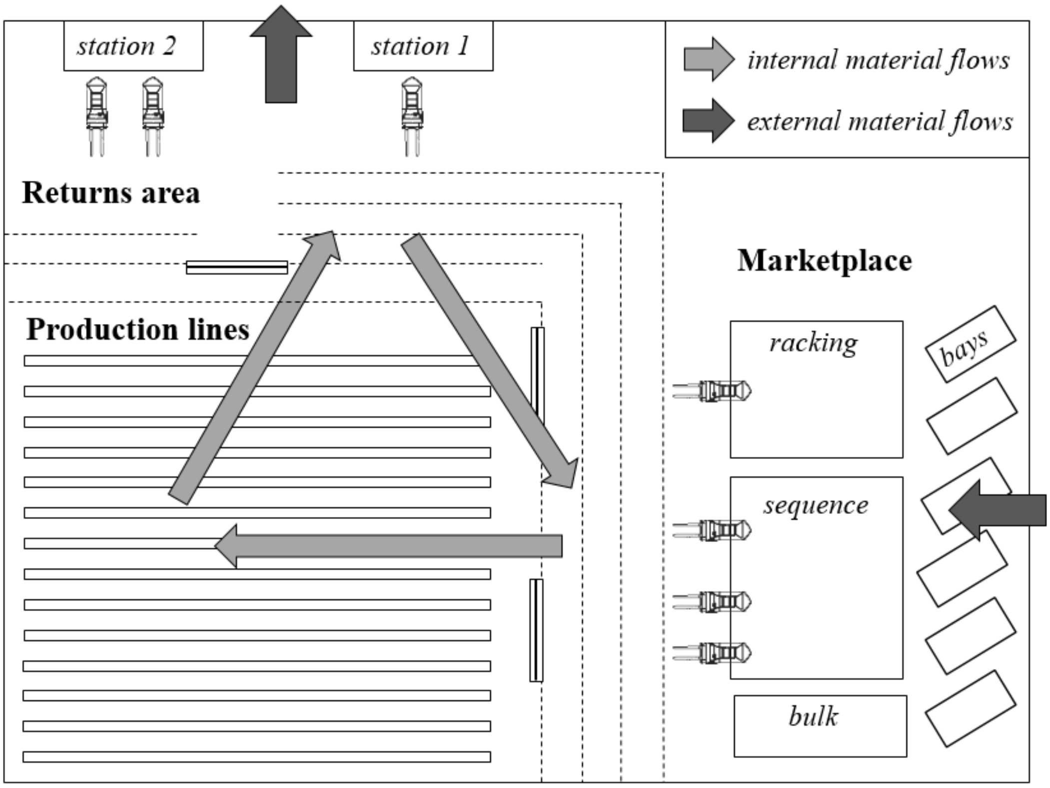

Figure 1. Plant layout of the Car Co.

2. Background on in-plant logistics processes

In-plant logistics in the automotive industry have received considerable attention in the literature, mainly because of the complex operations involved and their impact on productivity (Li et al., 2020; Boysen et al., 2015; Jainury et al., 2014; Dörnhöfer et al., 2016; Ellis et al., 2010). The term refers to the parts storage and packaging, as well as to the transportation of the parts to the production lines (material supply systems). It also covers the transport of empty boxes from the production lines to another station into the plant (internal returns) (Boysen et al., 2015).

Centralised or decentralised storage areas are used by automotive companies to storage temporarily the parts and the literature has investigated the typical problems that emerge such as layout design, parts storage assignment, routing and order batching (Boysen et al., 2015; De Koster et al., 2007). The decentralised storage areas in particular (called supermarkets) have received most of the attention as they offer many advantages (e.g. flexibility, reduced delivery time) and appear to be a promising strategy (Emde and Boysen, 2012). Battini et al. (2013) explicitly defined the concept of supermarkets outlining also the problems related to the implementation of the concept. Prior research (Emde and Boysen, 2012; Golz et al., 2011) had also identified problems such as: location planning, vehicle routing, scheduling, and loading of transport.

In the production lines, line balancing, model sequencing, production scheduling and workforce assignment are the four main problems that have received attention (Jin et al., 2008; Thomopoulos, 1967; Dörmer et al., 2015; Battaïa et al., 2015) and various approaches to solve them have been developed like heuristics and programming models.

The material supply systems, also known as the line feeding systems, have received particular attention by several authors in an effort to control and optimise the processes taking place (e.g. Alnahhal and Noche, 2015; Ellis et al., 2010) as well as decide upon the most efficient feeding system. From an information management point of view, there is important research looking at the application and integration of latest technologies (e.g. robotics, modern information technologies such as web services) to support the operations planning and coordination and eventually, increase system's efficiency as well as provide high quality solutions (Kousi et al., 2019; Kousi et al., 2016; Makris and Chryssolouris, 2013). From a system's point of view, four systems have been identified in the literature: line stocking, kitting, sequencing and minomi (Battini et al., 2009; Hanson, 2010).

Line stocking is considered to be the traditional feeding system in which parts are stored in bulk into containers and then containers are delivered at the Border of the Line (BoL) (Caputo and Pelagagge, 2010; Hanson and Brolin, 2013; Hua and Johnson, 2010; Limère et al., 2012; Sali et al., 2016). Kitting is technically more complex system than line stocking and requires preparation processes before the assembly operations. In this system, kits (specific assortment of parts for every end-product) are prepared and are assigned and delivered to a specific workstation. The preparation can be done manually, which requires long time of work or can be done by robots by an automated kitting system as recent studies have shown (Boudella et al., 2018). There are two types of kits: stationary and travelling. A stationary kit is delivered to the station and remains there until it is depleted, while the travelling kit moves with the end product and feed it in several stations (Battini et al., 2009; Bozer and McGinnis, 1992; Caputo and Pelagagge, 2010; Faccio, 2014; Hanson and Brolin, 2013; Hua and Johnson, 2010; Limère et al., 2012). Sequencing is considered as a particular form of stationary kit where the assortment is made of only one type of part (Sali et al., 2015) and similarly to kitting, it requires preparation before the assembly operations. Finally, minomi is a relatively new system, which has not gained much attention by the literature. In this system no containers are used, and the parts are stacked together in racks and hanging from hooks (Liker and Meier, 2016; Hanson, 2010).

Past research has investigated and compared the performance of the material supply systems. It is generally accepted that line stocking is more appropriate when the production volume is high and the variety of parts is low, whilst kitting, sequencing and minomi should be chosen when production volume is low and variety is high (Caputo and Pelagagge, 2010; Sali et al., 2015, Limère et al., 2012). Caputo and Pelagagge (2010) and Limère et al. (2012) concluded that an optimal solution would be to adopt a hybrid system in which some parts will be kitted and sequenced, whilst some others will be stored to the line so that the advantages of the different systems can be exploited. This is in line with Hanson and Brolin (2013), Hua and Jonson (2010) and Sali et al. (2015) who formulated the conditions under which original equipment manufacturers should be applying line stocking, kitting, or sequencing.

On the contrary, the internal returns processes have gained little attention by researchers and mainly from a purely theoretical standpoint. Boysen et al. (2015) described that there are two alternative logistics pathways in terms of the internal returns processes. The first one is when the same transport equipment is used for both the feeding route and the reverse route (leave one filled box and at the same time take one empty). The other way is when these two routes are planned separately. In that case, additional transport equipment is necessary, but time savings could be achieved. All in all, their research showed specific shortcomings in the literature particularly with regards to the internal returns processes.

Internal returns processes are part of the reverse logistics activities, which have been highlighted in the literature for their strategic role and their contribution to a more environmental friendly company (Carter and Ellram, 1998; Tibben-Lembke, 2001;

González-Torre et al., 2010). However, there are certain barriers that make it difficult to manage internal returns. These barriers are mostly organisational problems and the lack of the appropriate information and technological systems (González-Torre et al., 2010).

In Table 1 below, a summary of the literature review is presented. The production lines, the storage area and the material supply systems have received significant attention by researchers, whilst the internal returns processes have been only theoretically described.

Table 1. Summary of the literature

	Researchers	Research focus	Methods	Findings
Production lines	Zeltzer et al., 2013; Thomopoulos, 1967; Jin et al., 2008; Dörmer et al., 2015; Battaïa et al., 2015	• Line balancing • Model sequencing • Master production scheduling • Workforce assignment	Heuristics & programming models	Decision making models have been developed to address the problems emerge.
Storage area	Battini et al., 2013; Emde & Boysen, 2012; Golz et al., 2012; De Koster et al., 2007	• Supermarket location planning • Vehicle routing • Scheduling of transport vehicles • Loading of transport vehicles	Heuristics & mathematical models	Decision making models and supporting tools have been developed to calculate optimum location, optimum resource allocation etc.
Material supply systems	Battini et al., 2009; Hanson, 2010; Hanson and Brolin, 2013; Hua and Johnson, 2010; Limère et al., 2012; Sali et al., 2016; Caputo and Pelagagge, 2010; Faccio, 2014; Liker and Meier, 2006; Wänström and Medbo, 2008; Boudella et al., 2018; Kousi et al., 2019	• Line stocking • Sequencing • Kitting • Minomi • Planning and coordination • Optimisation	Descriptive cost & mathematical models, simulation, information technologies	• Advantages and disadvantages for each system • Appropriate part characteristics for each system • Hybrid systems can maximise system's performance • Service-based control system
Internal returns	Boysen et al., 2015	Part logistics processes and decision problems	Theoretical description	Research gap in this area

3. Research methodology

3.1 Research approach

Due to the exploratory nature of our research and the prior limited knowledge in this area, a single case study method was employed. This allowed for an in-depth exploration of the material flows into the returns area of the assembly plant, as well as, the collection and analysis of different data sources (i.e. interviews, and observations) (Yin, 2014; Myers and Avison, 2002; Mangan et al., 2004). The single case study approach has been also used in the past in exploratory research works in automotive industry (Dowlatshahi, 2010; White et al., 2015; Che Ani and Chin, 2016).

A mixed-methods choice was also made in this research with regards to the data collection process and both qualitative and quantitative data was collected. The main sources of data were interviews for the qualitative part and CCTV footage for the quantitative part of the research. Interviews were used to provide explanations and personal views as it was important to explore and understand the processes taking place, as well as to identify potential problems and solutions. Also, CCTV footage (video-based research methodology) was used to allow the collection of rich empirical quantitative data because of the ability to rewind the recordings and watch them over in order to collect additional data (Christianson, 2018; Seawright and Sampson, 2007).

As Table 2 presents, the first step was to explore the overall material flows into the plant in order to decide the area of focus. For that reason, five semi-structured interviews were conducted with the planning/operations, logistics and material flows managers in order to map accurately the material flows into the plant. The interview guide included, but was not limited to, topics such as: layout of the plant, flows into the storage area, material supply system, which facilitated a more general discussion with the interviewees and included additional insights about the plant’s logistics processes. The interviews took place in the final assembly plant of the Car Co. and lasted ten hours in total. Based on the outcome of the interviews, the focus area was selected. The second step involved a detailed investigation of the area by conducting observations through CCTV footage that lasted 2 weeks. Next, potential solutions for efficiency improvements were identified and three more interviews (lasting in total an hour and a half) took place with the operations/planning managers in order to assess the “feasibility” of the potential scenarios. In this step, we used structured interviews because the goal was interviewees to provide specific data about the feasibility of potential solutions. So, extra data about the area was collected and a final solution was developed and further explored to test if improvements have been achieved. Car Co. decided to implement this solution since the forecasts suggested that efficiency improvements were possible. The fourth step involved a detailed investigation into the internal returns area (after the implementation of the proposed changes) by conducting observations through CCTV footage that lasted 2 weeks. The aim of this step was to review the area and to test if the expected efficiency improvements had been achieved.

Table 2. Research process

Step	**Goal**	**Method**	**Duration**	**Location**	**Key informants**
1	Explore the current materials flows	5 semi-structured interviews	10 hrs	Car Co. assembly plant & logistics offices	Planning/operations, logistics & material flows managers
2	Investigate in detail the returns area	Observations (24hrs of production)	2 weeks	Car Co. internal returns area	Car Co. CCTV footage

3	Examine potential solutions	3 structured interviews	1.5 hr	Logistics offices	Planning/operations, logistics & material flows managers
4	Review/assess outcome from changes implemented	Observations (24hrs of production)	2 weeks	Car Co. internal returns area	Car Co. CCTV footage

3.2 Data collection

A variety of data was collected in order to help achieving the aim of this research. Initially, five semi-structured interviews with the planning/operations, logistics and material flows managers of the Car Co. were conducted in the assembly plant of the company and lasted 10 hours. The interviews helped deciding the focus area of the analysis and also, provided detailed insights about the layout of the plant, the processes that take place in the marketplace, the production lines and the internal returns area. We collected data about how the marketplace was organised (e.g. where the parts were stored), but also about the mixed production lines (e.g. the processes that take place, how the parts were organised at the BoL and the supply system used to feed the production lines), the internal returns area (e.g. how empty boxes are transferred to this area and then go back to the suppliers) and finally, about any incidents (e.g. type of incident, location, frequency of occurrence, potential causes) and disruptions within the assembly plant

We also investigated in depth the internal returns area. As shown in Figure 2, in the internal returns area, transport vehicles – called tugger trains – loaded with empty plastic boxes follow the first line and wait in the queue in order to be offloaded by forklifts in Station 1 and then exit through door 1. Also, tugger trains loaded with empty metal and sequence boxes follow the other two lines and wait in queues to be offloaded by forklifts in Station 2 and then exit through door 1 again. Forklifts remain solely in the internal returns area for the offloading of tugger trains. Quantitative data about the tugger trains arrivals to the returns area, the tugger trains process time for offloading, the departure rates, the tugger trains characteristics, the capacity of the system and the layout characteristics and plan were collected through CCTV footage of 24hours of production. Any additional movements, by other transport vehicles, performed in the returns area or any disruptions took place, were recorded.

Next, we examined potential solutions for efficiency improvements. Alternative scenarios were developed and presented to the managers of Car Co. Three additional structured interviews were conducted with the managers of the company in order to validate and assess the alternative scenarios. The criteria used to assess the proposed scenarios were the feasibility of the proposed actions and/or changes, the time needed to implement them, the potential cost and the perceived overall effort needed to implement them. As a result of the interviews, it was decided to further analyse a particular scenario, which involved minor changes and invested effort, but at the same time could possibly reduce delays in the area.

Finally, we reviewed and assessed the internal returns area after implementing the proposed solution collecting new data through CCTV footage of 24hours of production in the new layout. The new layout included the addition of a new doorway to exit the tugger trains, which were loaded with metals and sequence (Figure 3). Similar to the second step, quantitative data about the tugger trains arrivals rate, process times, departure rates and capacity of the system was collected.

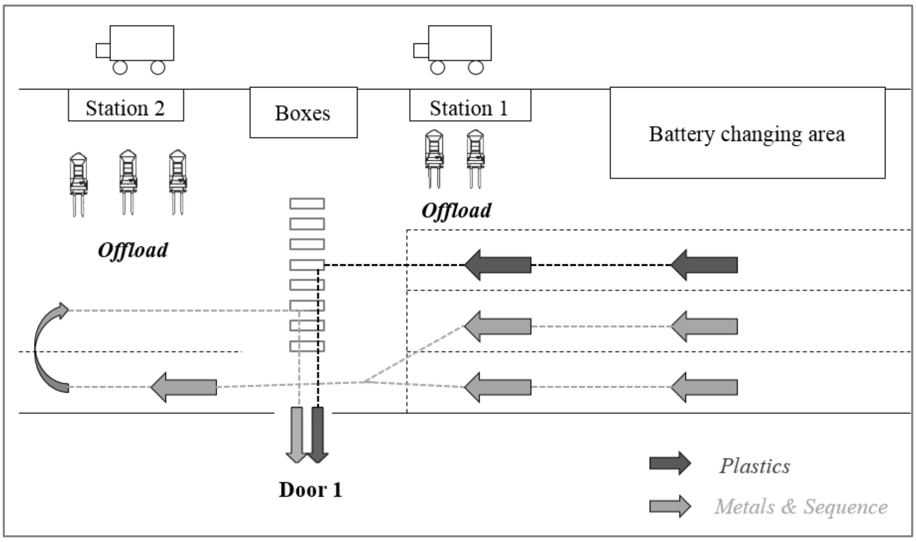

Figure 2. Initial internal returns layout and flows

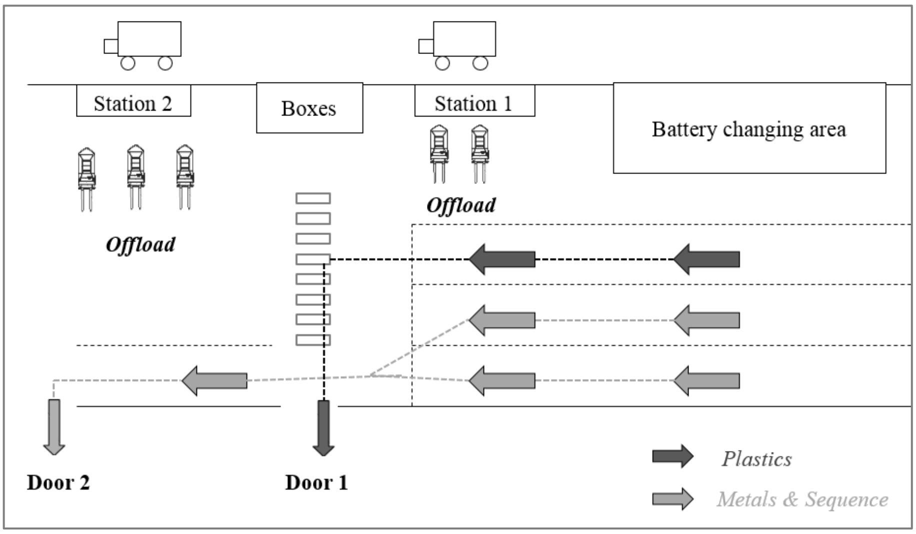

Figure 3. Final internal returns layout and flows

3.3 Data analysis

We analysed the qualitative data collected through semi-structured interviews with the managers of the company. The layout of the assembly plant as well as the processes taking place were explained by managers and maps were developed in order to understand and analyse the material flows. The assembly plant of Car Co. consists of the centralised marketplace, the mixed production lines and the returns area between which the material flows take place and follow a continuous circular route. This continuous circular material flow helps to optimise the flows, the space availability and the resources to the highest possible level. However, due to the route being circular, any inefficiencies or delays that occur either in the marketplace or in the productions lines or the returns area, will affect the performance of the whole material flow system. Analysing maps of the plant in line with managers’ experience and views, the internal returns area was identified as an area where efficient gains are possible –long queues and delays had been reported.

Next step was the simulation analysis of the internal returns area and the representation of the actual system. The Arena 14.5 (Rockwell Software) with the SIMAN (Simulation Modelling and Analysis) programming language was used. A simulation model was built which represented the processes that take place in the real environment of the internal returns area. Figure 4 presents this model, which consists of various modules (i.e. the basic building blocks for Arena model), representing the flowchart and data objects that define the processes that take place (e.g. entities creation module, process module, decision module, transport module). Under each module, a box has been added to indicate the exact parameters used and a detailed explanation of these parameters as well as the logic of the model follows.

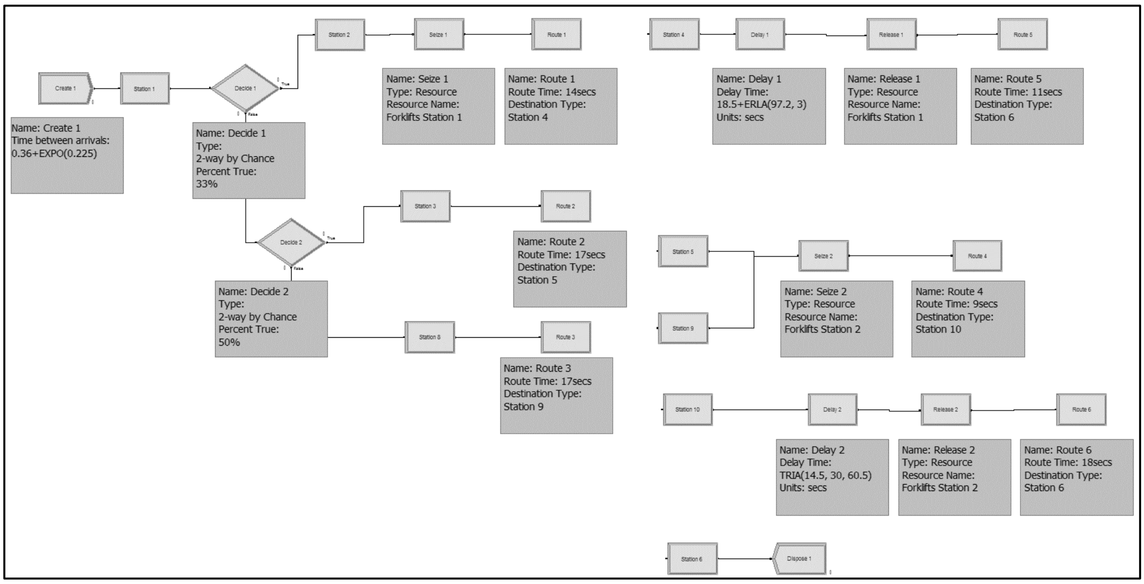

Figure 4. Simulation model representing the internal returns area processes

In order to build this model, we first analysed the quantitative data collected through the CCTV footage in the internal returns, using the SPSS software and the Arena Input Analyser (standard component of the Arena environment). The aim was to statistically analyse the data and determine whether they follow a particular distribution, which would then be inserted onto the simulation model. Tugger trains are considered to be the entities of the system which arrive in the returns area following an exponential (EXPO) distribution with a mean value of 0.58minutes, meaning that the tugger trains arrivals occur continuously and are independently at a constant average rate (poisson processes). The expression 0.36 + EXPO (0.225) gives the SIMAN code needed within Arena to generate the values from the exponential distribution and was automatically coded and generated from the Arena Input Analyser. Then, the model distinguishes the tugger trains based on the material that they carry. One third (33%) of the tugger trains is loaded with plastics, whilst the rest 67% is loaded with sequence and metals. Tugger trains with plastics will take the 1st line whilst the others will take the 2nd and the 3rd line (as previously showed in Figure 2). Regarding the tugger trains loaded with metals and sequence, the model sends 50% of them in the 2nd line and 50% in the 3rd line. Also, the time needed in order tugger trains to take the lines is at around 17 seconds. Forklifts are considered to be the resources of the system. Their capacity is two in station 1 and three in station 2. The offloading process time in station 1 follows an erlang (ERLA) distribution which is a probability distribution and the main parameter is its shape which is equal to 3. The expression 18.5 + ERLA (9.72, 3) gives the SIMAN code needed within Arena to generate the values from the erlang distribution and was again automatically coded and generated from the Arena Input Analyser. The offloading process time in station 2 follows a triangular (TRIA) distribution in which the minimum process is 14.5 seconds, the average is 30 seconds and the maximum is 60.5 and the SIMAN coded expression was TRIA (14.5, 30, 60.5). After the offloading process, tugger trains exit from the door. Tugger trains from station 1 need on average 11 seconds to exit, whilst tugger trains from station 2 need on average 18 seconds to exit. The simulation model run for 24 hours and 100 times and after that, a report with outcomes about system's behaviour was generated. The representation of the internal returns environment was useful for validation purposes and for providing a clearer picture of the system and the improvements needed.

3.4 Verification and validation

As far as the model verification is concerned, two techniques have been applied in order to ensure that there were no errors in the coding; tests runs and animation inspection (Greasley, 2004; Kelton et al., 2010; Sargent, 2011; Kleijnen, 1995). In the first technique, test runs were implemented, and the results were checked under specific scenarios. It was shown that the number of tugger trains offloaded in 24 hours, in the current scenario (arrivals distribution: 0.36+EXPO (0.225)), was 2,561 while in the extreme scenario of high demand levels (arrivals distribution: 0.45+EXPO (0.225)) it was 2,972 and in the extreme scenario of low demand levels (arrivals distribution: 0.25+EXPO (0.225)) it was 2,131. Also, the queues length and the utilisation factors of the resources had been increased and decreased accordingly. Therefore, the model behaves reasonable and the output measures were the ones expected.

In the second technique, animation inspection has been applied. The model's operational behaviour has been displayed graphically as the model moves through time in order to check for suspect behaviour. The simulation model executed at a very slow speed in order to check all the entities flows. The outcome from this analysis was that the flows were correct.

Regarding the model validation, the model needed testing against conceptual and operation validity. For the conceptual validity it was important to assure that the model is a simplification of the real world and the functions take place during the model execution are the ones that take place in the real system (Greasley, 2004; Kelton et al., 2010; Sargent, 2011; Kleijnen, 1995). Therefore, after the development of the simulation model and the verification process, the model was presented to the planning/operations, logistics and material flow managers of Car Co. in order to receive feedback on whether the model and its behaviour was reasonable (i.e. face validity). In that way the model was tested and approved for its conceptual validity.

For the operational validity, a comparison between observable results and simulation results was carried out (Greasley, 2004; Kelton et al., 2010; Sargent, 2011). Specifically, the results from the CCTV footage analysis (in the initial layout) were compared with the results from the simulation analysis (in the initial layout). It was found that the deviation between the results was less than 2% and that was presented to the managers of the company (who are the decision-makers) in order to accept or reject the model (Tsioptsias et al., 2016). They accepted the deviation and the simulation model and they concluded that the model behaves in a reasonable manner.

4. Findings

After the simulation of the current environment in the internal returns area, we examined potential solutions for efficiency improvements and found that traffic congestion in the area around door 1 was causing major delays, long queues and waiting times. Based on that, alternative scenarios were developed and presented to the managers of the company. These scenarios suggested changes like the addition of a new line by expanding the area, the increase in the number of resources and the addition of a new doorway. But limited space availability, physical obstacles and extra costs, made it difficult to implement changes like layout expansion and increase in the number of resources. So it was decided that the most practical and feasible scenario was the addition of a new doorway and minor changes in the route of the tugger trains. A new (based on the initial) simulation model, was developed to represent this scenario and make forecasts about the performance of the new system. The outcomes showed that efficiency improvements were possible and the company decided to implement the proposed changes.

Table 3 below summarises the main findings of the analysis in the internal returns area. The queues length and the throughputs are reported in the initial layout before the new doorway, in the forecasts for a new doorway and in the final layout after the addition of a new doorway. Forecasts had shown that a new doorway would reduce queues length and would increase throughput by 1.6%. Indeed, queues length was reduced as projected, but the throughput was increased by 31%, much more than the projected number. A possible explanation is that the data collection in the new layout took place months after the data collection in the old layout and the company had already made plans for an increased capacity into the plant as customers' demand was rising.

In more detail, Figure 5 below illustrates the improvements achieved in the number of tugger trains offloaded per hour in the internal returns area by comparing the total throughput per hour before and after the new doorway based on the data from the observations. Despite the fact that the total throughput increased, the traffic congestion and the queues length was reduced. Also, the total throughput per door was reduced as the exits became two and this reduction is significant for two reasons: firstly, it reduced the traffic congestion around the initial door and secondly adequate space for an increased demand in the area was created.

Table 3. Summary of the findings

		Before the new doorway	**Forecasts with a new doorway**	**After the new doorway**
		Observations	*Simulation*	*Observations*
Queues length	Average no. of tugger trains waiting in the queue for Station 1	2	1	1
	Average no. of tugger trains waiting in the queue for station 2	6	5	5
Throughput	Total throughput in 24 hours	2561	2601	3373
	Average throughput Exit through Door 1	106 tugger trains/hour	36 tugger trains/hour	47 tugger trains/hour
	Average throughput Exit through Door 2	-	73 tugger trains/hour	94 tugger trains/hour

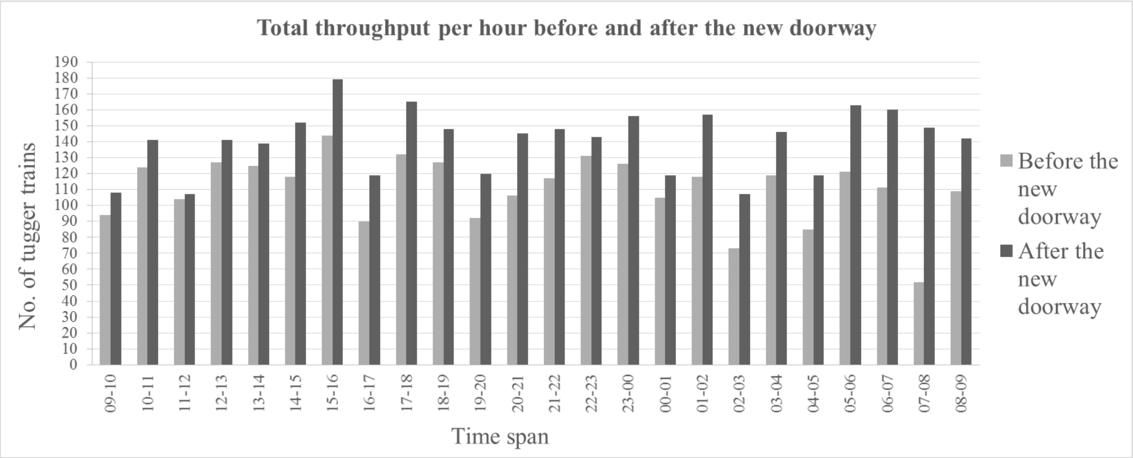

Figure 5. Comparison diagram before and after the changes

5. Discussion

Car Co. operates a functional centralised marketplace and uses a hybrid material supply system in order to feed the production lines. A combination of line stocking, sequencing as well as minomi systems help increasing the efficiency of the plant and this is in line with previous research on the benefits of hybrid systems (Caputo and Pelagagge, 2010; Limère et al., 2012). Each of these supply methods has a distinct area in the marketplace from which the parts are supplied and transported to the BoL. This centralised marketplace helps the company to save space and also to avoid the complexities of the supermarkets as the planning and logistics managers deal with the traditional decision problems of the centralised storage areas (e.g. layout of racks, storage location of parts), (Boysen et al., 2015).

A continuous circular material flow is kept in the plant of the Car Co. which is performed by tugger trains and begin from the marketplace to the production lines, then to the internal returns area and finally, back again to the marketplace. This circular route optimises the flows, the space availability and the resources. However, it also means that any inefficiencies or delays occur, either in the marketplace or the production lines or the returns area, they will affect the performance of the overall material flow system. After the analysis of Car Co. layout and material flow system as well as the interviews with the company's managers, it was revealed that the internal returns area is an area where there are opportunities for improvements and more effort is needed in order to increase efficiency. This is in line with findings from the literature (Boysen et al., 2015; Carter and Ellram, 1998) that also highlighted the need to investigate more in this area.

The investigation into this area revealed traffic congestion causing major delays, long queues and waiting times. Interestingly this is a factor that has not received much attention in the literature. Most research works that investigated automotive assembly plants, focused on the mixed production lines, the materials flow systems, the transport logistics strategies and the use of robotics while little attention has received the traffic congestion factor into the plants (Li et al., 2020; Boysen et al., 2015; Michalos et al., 2010).

6. Conclusion and future research

This research investigates the material flow processes into the automotive assembly plant of the case study company. The current environment of the case study company was analysed, using the discrete event-based simulation technique and the causes of inefficiencies were identified. Further analysis of the data led to the development of a new solution to reduce the congestion and to improve efficiency. A new simulation model was developed which showed that by reducing the traffic congestion, major improvements could be achieved in terms of capacity and efficiency. The case study company implemented the proposed solution which was shown to lead to efficiency improvements and to increased system capacity.

Whilst the simulation method has been previously applied in the literature to optimise material flows in automotive assembly plants (e.g. Kousi et al., 2019), it has not been used to study the internal returns area and its impact on the overall efficiency of the plant. Therefore, a distinctive contribution of this research is the application of discrete event-based simulation to investigate the flows into the internal returns area for which prior knowledge in the literature is scant. In addition, the use of CCTV footage contributes to the literature on video-based research methodologies by demonstrating the ability to precisely collect various metrics such as frequency (e.g. tugger trains departure rate) and duration (tugger trains process time for offloading). This research also further support and extend the works of Li et al. (2020) and Kousi et al. (2019) by empirically demonstrating how the simulation technique can be used as a decision-making support system in automotive assembly plants and have a direct impact on system’s performance. Regarding the practical impact, our research shows that even minor layout changes can have a notable impact on the efficiency of the plant. Moreover, our simulation model can be used with adaptations (e.g. changes in the number of resources) in the returns area of the automotive assembly plants and improve their efficiency.

One of the limitations of this research is related to the data collected in order to build the simulation models. Specifically, the quantitative data in the internal returns area collected from one day (24 hours of production), so it lacked the ability to study change and development phases. Also, the human factor (e.g. tugger trains drivers' behaviour) was not investigated in the current work but, future research should take that into consideration and especially, look at how the workflow might be affected. Finally, further work should be conducted that will integrate the in-plant logistics processes (i.e. flows between the storage area, the production lines, and the returns area).

References

Alnahhal, M. and B. Noche. 2015. "Dynamic material flow control in mixed model assembly lines." *Computers & Industrial Engineering* 85: 110-119.

Battaïa, O., X. Delorme, A. Dolgui, J. Hagemann, A. Horlemann, S. Kovalev, and S. Malyutin. 2015. "Workforce minimization for a mixed-model assembly line in the automotive industry." *International Journal of Production Economics* 170: 489-500.

Battini, D., M. Faccio, A. Persona, and F. Sgarbossa. 2009. "Design of the optimal feeding policy in an assembly system." *International Journal of Production Economics* 121: 233–254.

Battini, D., N. Boysen, and S. Emde. 2013. "Just-in-Time supermarkets for part supply in the automobile industry." *Journal of Management Control* 24: 209–217.

Boudella, M., E. Sahin, and Y. Dallery. 2018. "Kitting optimisation in Just-in-Time mixed-model assembly lines: assigning parts to pickers in a hybrid robot operator kitting system." *International Journal of Production Research* 56 (16): 5475-5494.

Boysen, N., S. Emde, M. Hoeck, and M. Kauderer. 2015. "Part logistics in the automotive industry: Decision problems, literature review and research agenda." *European Journal of Operational Research* 242: 107-120.

Bozer, Y., and L. McGinnis. 1992. "Kitting versus line stocking: A conceptual framework and a descriptive model." *International Journal of Production Economics* 28: 1-19.

Caputo, A., and P. Pelagagge. 2010. "A methodology for selecting assembly systems feeding policy." *Industrial Management & Data Systems* 111 (1): 84-112.

Carter, C., and L. Ellram. 1998. "Reverse logistics: A review of the literature and framework for future investigation." *Journal of Business Logistics* 19 (1): 85-102.

Che Ani, M. N., and J.F. Chin. 2016. "Self-reinforcing mechanisms for cellularisation: a longitudinal case study." *International Journal of Production Research* 54 (3): 696-711.

Christianson, M.K. 2018. "Mapping the Terrain: The Use of Video-Based Research in Top-Tier Organizational Journals." *Organizational Research Methods* 21 (2): 261-287.

Chuah, K., and J. Yingling. 2005. "Routing for a Just-in-Time Supply Pickup and Delivery System." *Transportation Science* 39 (3): 328-339.

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: 481-501.

DHL. n.d. "Bringing supply chain agility to automakers." DHL Resilience 360. Accessed 02 May 2018. https://resilience360.com/sectors/automotive/

Dinsdale, E., and D. Bennett. 2015. "Benefits; drawbacks and boundaries to deliver JIT." *Benchmarking: An International Journal* 22 (6): 1081-1095.

Dörmer, J., H. Günther, and R. Gujjula. 2015. "Master production scheduling and sequencing at mixed-model assembly lines in the automotive industry." *Flexible Services and Manufacturing Journal* 27 (1): 1-29.

Dörnhöfer, M., F. Schröder, and W. Günthner. 2016. "Logistics performance measurement system for the automotive industry." *Logistics Research* 9 (1): 1-26.

Dowlatshahi, S. 2010. "A cost-benefit analysis for the design and implementation of reverse logistics systems: case studies approach*." International Journal of Production Research* 48 (5): 1361-1380.

Du, T., F. Wang, and P. Lu. 2007. "A real-time vehicle-dispatching system for consolidating milk runs." *Transportation Research Part E: Logistics and Transportation Review* 43 (5): 565-577.

Ellis, K., R. Meller, J. Wilck, P. Parikh, and F. Marchand. 2010. "Effective material flow at an assembly facility." *International Journal of Production Research,* 48 (23): 7195-7217.

Emde, S., and N. Boysen. 2012. "Optimally locating in-house logistics areas to facilitate JIT-supply of mixed-model assembly lines." *International Journal of Production Economics* 135: 393-402.

Faccio, M. 2014. "The impact of production mix variations and models varieties on the parts-feeding policy selection in a JIT assembly system." *The International Journal of Advanced Manufacturing Technology* 72 (1-4): 543-560.

Galligan, D. 2016. "What 1 minute of unplanned downtime costs major industries?" Business Insider. Accessed 02 May 2018. http://uk.businessinsider.com/what-1-minute-of-unplanned-downtime-costs-major-industries-2016-9?r=US&IR=T

Golz, J., R. Gujjula, H. Günther, S. Rinderer, and M. Ziegler. 2012. "Part feeding at high-variant mixed-model assembly lines." *Flexible Services and Manufacturing Journal* 24 (2): 119-141.

González-Torre, P., M. Álvarez, J. Sarkis, and B. Adenso-Díaz. 2010. "Barriers to the Implementation of Environmentally Oriented Reverse Logistics: Evidence from the Automotive Industry Sector." *British Journal of Management*, 21 (4): 889-904.

Greasley, A. 2004. *Simulation modelling for business*. 1st ed. Aldershot; Burlington, Vt.: Ashgate

Hanson, R. 2010. "Effects of using minomi in in-plant materials supply." *Journal of Manufacturing Technology Management* 22 (1): 90-106.

Hanson, R., and A. Brolin. 2013. "A comparison of kitting and continuous supply in in-plant materials supply." *International Journal of Production Research* 51 (4): 979-992.

Heid, B., C. Huth, S. Kempf, and G. Wu. 2018. "Ready for inspection: the automotive aftermarket in 2030" McKinsey&Company. Accessed 17 August 2018. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/ready-for-inspection-the-automotive-aftermarket-in-2030

Holweg, M., Davies, P. and Wood, M. 2017. "Growing the automotive supply chain: Local vehicle content analysis." Automotive Council UK. Accessed 28 Jun. 2017. http://www.automotivecouncil.co.uk/wp-content/uploads/sites/13/2017/06/Automotive-Council-UK-local-sourcing-content-research-2017-Final-1.pdf

Hua, S., and D. Johnson. 2010. "Research issues on factors influencing the choice of kitting versus line stocking." *International Journal of Production Research* 48 (3): 779-800.

Immerman, G. 2018. "The real cost of downtime in manufacturing." Accessed 21 Jan. 2021. https://www.machinemetrics.com/blog/the-real-cost-of-downtime-in-manufacturing

Jainury, S., R. Ramli, M. Ab Rahman, and A. Omar. 2014. "Integrated Set Parts Supply system in a mixed-model assembly line." *Computers & Industrial Engineering* 75: 266-273.

Jin, M., Y. Luo, and S. Eksioglu. 2008. "Integration of production sequencing and outbound logistics in the automotive industry." *International Journal of Production Economics* 113 (2): 766-774.

Kelton, W., R. Sadowski, and N. Swets. 2010. *Simulation with Arena*. 5th ed. Dubuque: McGraw-Hill.

Kleijnen, J. 1995. "Verification and validation of simulation models." *European Journal of Operational Research* 82: 145-162.

Kousi, N., S. Koukas, G. Michalos, and S. Makris. 2019. "Scheduling of smart intra – factory material supply operations using mobile robots." *International Journal of Production Research*, 57 (3): 801-814.

Kousi, N., S. Koukas, G. Michalos, S. Makris, and G. Chryssolouris. 2016. "Service Oriented Architecture for Dynamic Scheduling of Mobile Robots for Material Supply." *Procedia CIRP*, 55: 18-22.

Li, G., S. Yang, Z. Xu, J. Wang, Z. Ren, and G. Li. 2020. "Resource allocation methodology based on object-oriented discrete event simulation: A production logistics system case study." *CIRP Journal of Manufacturing Science and Technology* 31: 394-405.

Liker, J., and D. Meier. 2006. *The Toyota Way Fieldbook*, 313-321. New York: McGraw-Hill.

Limère, V., H. Landeghem, M. Goetschalckx, E. Aghezzaf, and L. McGinnis. 2012. "Optimising part feeding in the automotive assembly industry: deciding between kitting and line stocking." *International Journal of Production Research* 50 (15): 4046-4060.

Makris, S. and G. Chryssolouris. 2013. "Web-services-based supply-chain-control logic: an automotive case study." *International Journal of Production Research*, 51 (7): 2077-2091.

Mangan, J., C. Lalwani, and B. Gardner. 2004. "Combining quantitative and qualitative methodologies in logistics research." *International Journal of Physical Distribution & Logistics Management* 34 (7): 565-578.

Michalos, G., S. Makris, N. Papakostas, D. Mourtzis, and G. Chryssolouris. 2010. "Automotive assembly technologies review: challenges and outlook for a flexible and adaptive approach". *CIRP Journal of Manufacturing Science and Technology* 2: 81-91.

Myers, M., and D. Avison. 2002. *Qualitative research in information systems*, 79-99. London: SAGE.

Parkin, R., R. Wilk, E. Hirsh, and A. Singh. 2017. "2017 Automotive Trends." Strategy&. Accessed 02 May 2018. https://www.strategyand.pwc.com/trend/2017-automotive-industry-trends

Rogers, D., and R. Tibben-Lembke. 2001. "An Examination of Reverse Logistics Practices." *Journal of Business Logistics* 22 (2): 129-148.

Sali, M., and E. Sahin. 2016. "Line feeding optimization for Just in Time assembly lines: An application to the automotive industry." *International Journal of Production Economics* 174: 54-67.

Sali, M., E. Sahin, and A. Patchong. 2015. "An empirical assessment of the performances of three line feeding modes used in the automotive sector: line stocking vs. kitting vs. sequencing." *International Journal of Production Research* 53 (5): 1439-1459.

Sargent, R.G. 2011. "Verification and validation of simulation models". *In Proceedings of the 2011 Winter Simulation Conference*, edited by S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, 183-198. New Jersey: Institute of Electrical and Electronic Engineers Inc.

Seawright, K.K., and S.E. Sampson. 2007. "A video method for empirically studying wait-perception bias." *Journal of Operations Management* 25: 1055–1066.

SMMT. 2020. "Motor Industry Facts 2020". Accessed 23 Oct. 2020. https://www.smmt.co.uk/reports/smmt-motor-industry-facts-2020/

Thomopoulos, N. 1967. "Line Balancing-Sequencing for Mixed-Model Assembly." *Management Science* 14 (2): 59-75.

Tsioptsias, N., A.A. Tako, and S. Robinson. 2016. "Model validation and testing in simulation: a literature review. " *Presented at the 5th Student Conference on Operational Research (SCOR 2016)*, Nottingham University, 8-10th April.

Wänström, C., and L. Medbo. 2008. "The impact of materials feeding design on assembly process performance." *Journal of Manufacturing Technology Management* 20 (1): 30-51.

White, G., X. Wang, and D. Li. 2015. "Inter-organisational green packaging design: a case study of influencing factors and constraints in the automotive supply chain." *International Journal of Production Research* 53 (21): 6551-6566.

Yin, R. 2014. *Case study research*. 5th ed. Los Angeles: Sage Publications.

Zeltzer, L., V. Limère, H. Van Landeghem, E. Aghezzaf, and J. Stahre. 2013. "Measuring complexity in mixed-model assembly workstations." *International Journal of Production Research* 51 (15): 4630-4643.