# Analyzing the transition from just-in-time to just-in-sequence: a simulation based approach from the automotive sector

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**Abstract:** In the last years, manufacturing companies have been forced by the market to adapt their production systems to better follow the trends in customer's demand. The trade-off between system responsiveness and inventory management costs is one of the most critical issues to be tackled in order to meet both customers' satisfaction and cost efficiency. To face this challenge, lean production and Just-In-Time (JIT) have been widely applied, especially in the automotive industry, with the aim of reducing drastically the inefficiencies while meeting high quality and time standards. However, today in several sectors companies need to offer increasingly personalized products in order to be competitive. This increase in variety poses even more challenges, for which the JIT model might not be effective anymore. For this reason, in the automotive sector an innovative production model is being studied, taking a further step from JIT: the Just-In-Sequence (JIS) approach aims at achieving short order lead-times and on-time deliveries to customers while keeping low inventories and a fast throughput. The objective of JIS is to deliver not only "the right quality, at the right time, and in the right quantity", but also in "the right sequence". As literature on the topic is still lacking, this work analyzes the transition from a JIT to a JIS production model through a test case from the automotive sector. A discrete-event simulation model has been developed to evaluate the performance of a new JIS process and compare it to the traditional JIT, focusing on the main challenges and critical issues related to the transition and identifying strengths and weaknesses of this approach.

**Keywords**: Just-in-sequence; just-in-time; lean production; discrete event simulation.

## 1. Introduction

In the last years, customers' demand for the automotive industry has become growingly pretentious, asking for increasingly personalized products, with thousands of configurations for each model. Companies are facing the challenge of understanding how to keep a strategic variability (offering several options and a quick response to customers' demand) while maintaining cost-efficient production systems (Suri, 2003). Under these conditions, the traditional strategy of relying on safety stocks to balance the effects of demand uncertainty can generate extremely high operating costs, reducing the company's advantage in today's competitive markets. Next to this, responsiveness in the complex supply networks remains low, and goals such as short order lead-times and on-time deliveries are often missed. In this context, the consolidated Just in Time (JIT) production paradigm has to face its limits: the increasing need of factory space and stock levels, with consequent increase of handling costs (Thun et al., 2007; Wagner and Silveira-Camargos, 2011).

A more sophisticated production method, Just-in-Sequence (JIS), can represent a feasible solution to these problems, facilitating the production of mass-customized goods in a cost-efficient way. While JIT has been defined as a way to deliver the right parts in the right amount at the right time to the assembly line (Ōno, 1988), JIS can be seen as its evolution, requiring the delivery of parts in the right sequence. The most relevant savings potentials of JIS have been recognized in (i) lower inventory and space requirements, (ii) lower quality and logistics costs, as well as (iii) lower handling costs (Thun et al., 2007; Wagner and Silveira-Camargos, 2011). On the other side, what makes JIS more convenient, also makes it more risky than JIT, mainly because of a higher sensitivity to eventual disruptions in the production process, which often can lead to a shutdown of the line (Thun et al., 2007). Nevertheless, some authors acknowledge that JIS production can generate a strong motivation for quality improvement as a response to higher risks (Hüttmeir et al., 2009).

However, switching from JIT to JIS is not so simple, but it requires a preliminary study. Starting from a case study from the automotive sector, the aim of this work is to analyze the transition to JIS, identify the main challenges related and understand how to manage them. A discrete event simulation model has been built with this aim, and the scenario for the implementation of a JIS system has been explored monitoring some KPIs to assess the efficiency in time and space savings.

In the next section, a literature review about the implementation of JIS has been performed, identifying the main gaps. The case study is presented in Section 3 and the methodology explained in Section 4, while results and discussion are presented in Sections 5 and 6.

## 2. Literature review

Although the concept of JIS has been widely discussed in the last decades, and several companies attempted to realize it in their manufacturing sites, research about its implementation is not wide (Wagner and Silveira-Camargos, 2011).

Some of the works analyzed keep a generic focus on the *opportunities and challenges* related to JIS. Wagner and Silveira-Camargos (2011) provide a framework to evaluate the opportunity of switching from JIT to JIS considering the current conditions of a production system. The authors first identify the main differences between JIT and JIS considering module's variety, value and logistic complexity, then they focus on the minimal number of variants and the total cost that can justify the introduction of JIS. The vulnerability of JIS to supply disturbances is analyzed by Heinecke et al. (2013), who show that tightly integrated supplier-buyer relationships might sensitively increase rework, when unreliable processes are present. They explore the mitigation potential of supply chain event management and resequencing, showing how to increase the performance of the system. Resequencing in JIS is also explored by Gujjula and Gunther (2009), through a mixed-integer linear program solved with a local search-based heuristic, which are shown to be able to reduce utility work.

One JIS case study in the *electronics* sector is present in literature: Werner et al. (2003) first describe the peculiarities of the assembly process, then analyze the approach of the company considered that realized JIS material supply. They show an overview from the organizational point of view and underline the potential advantages of their system.

However, most of the contributions analyzed focus on *automotive*, the leading sector for lean production practices. Thun et al. (2007) analyze strengths and weaknesses of JIS through an empirical study involving managers from the automotive sector. They identify supplier's selection, employees and information technology as crucial issues in the implementation of JIS, while underlining the expected improvements for inventory and efficiency. Wagner and Silveira-Camargos (2012) provide an overview of current JIS market practices in this sector, exploring the risks entailed in JIS and providing some recommendations for mitigating them. Pawlewski et al. (2012) build a Flexsim simulation model to control the sequence delivery service in a JIS system. The model has been applied to a real company. Hüttmeir et al. (2009) analyze the trade-off between heijunka and JIS by means of a simulation model, as an insight in the bigger trade-off between leanness and agility. They first explore the main principles on which the two practices are founded, pointing out that while heijunka's main purpose is to keep a high average utilization of resources and protect production from demand variability, JIS is meant to follow this variability. Based on a case study, they conclude that the advantages of both the approaches should be exploited in a combined solution. Another case study from the automotive sector is explored by Bautista and Fortuny-Santos (2016), who evaluate the extension of synchronous manufacturing and delivery to suppliers through a conceptual model. They finally highlight some necessary conditions to implement synchronous flow along the supply chain. Dorion et al. (2014) present the case study of JIS strategy implementation in a Brazilian company. On one side, the authors underline the advantages related to inventory reduction and line efficiency, on the other side they discuss some criticalities related to the discipline of the employees in using the JIS tool. Finally, to address the uncertainties related to the stability of order sequences and disturbances in JIS, Meissner (2010) proposes the introduction of specific KPIs to manage risks, testing them in a simulation with different buffer configurations.

## 2.1 From JIT to JIS

Summarizing, JIS is an innovative approach that allows firms to better handle the demand for mass-customization, where JIT might fail. The main advantages that can be realized through JIS are a higher flexibility and responsiveness, a shorter cycle time, lower inventories and space needed, and a consequent higher competitiveness (Hüttmeir et al., 2009; Thun et al., 2007). On the other hand, the risks entailed are quite similar to JIT (sensitivity to delays or quality problems, to malfunctions of the IT-system, to delays or damages due to transportation, etc.), but the negative consequences of these risks are much higher in JIS (Thun et al., 2007). Consequently, the suppliers' reliability has to be very high to avoid interruptions and reworks due to quality problems; employees must be qualified and trained, as they also represent a source of potential failure; the information system must be extremely reliable and efficient to guarantee a smooth information flow (Thun et al., 2007). Table 1 summarizes the main differences between JIT and JIS, derived from the works analyzed.

**Table 1: Main differences between JIT and JIS**

| Feature | JIT | JIS |
|---|---|---|
| Sequence | Defined through leveling production | Defined by downstream process |
| Safety buffers | Needed | Reduced to minimum |
| Sensitivity to shutdowns | Amortized through safety stocks | High |
| Main focus | Leanness | Flexibility and responsiveness |

Despite its potentialities, JIS is not a universal solution: its high sensitivity to risks poses some constraints in its implementation. While the potential advantages and the challenges related to this paradigm are quite clear, little research has been done on how to effectively design a JIS process and how to manage the transition from a JIT to a JIS system. Only one work focused specifically on this issue, but the authors addressed the problem through a general framework that is not applied to a real case study (Wagner and Silveira-Camargos, 2011). In this work, the current knowledge about JIS implementation is applied to a case study from the automotive sector to evaluate the feasibility of a process improvement.

## 3. The case study

According to Wagner and Silveira-Camargos (2011), three main steps have to be performed before implementing a JIS system effectively. First of all, the selection of the adequate *module*: one with minimal variety, high value and increasing logistic complexity would maximize the advantages of JIS. Second, the *cost-efficiency* of JIS compared to JIT has to be evaluated. Finally, the reliability and competences of the *suppliers* must be ensured. In the case study analyzed, the company is interested in exploring the opportunity to switch from a JIT to a JIS production. To do so, they chose an assembly line (L1) to implement a pilot project: the modules have already been selected, while the supplier is another internal line (L5), which gives the company complete control over the whole process and products quality. Thus, the main objective of the company in this phase is the evaluation of the cost-efficiency of the project.

Figure 1 shows the current configuration of the production system. L5 and L1 are both in the same plant. L5 produces components for L1 (types A, B, C and D) and for other customers as well (type X). Similarly, L1 uses inputs coming from L5 (types A, B, C and D) and other suppliers (types Y) to produce other components. Specifically, 55% on average of the capacity of L1 is used to produce with components coming from L5. The production is leveled on both lines and regulated through heijunka, with a frozen horizon of two weeks. The company supplied data about the production planning of the two lines, as well as their technical parameters. As reported in Table 2, the two lines have different Overall Equipment Effectiveness (OEE), Number of Parts per Kanban (NPK) and capacities. The weekly schedule is also different, as L5 only works for four days, while L1 operates for six days. The cross-dock area of L5 has a capacity of six carts. The milkrun transporting components from L5 to L1 has a capacity of two carts, transport time of 1 hour and frequency of one run per hour.

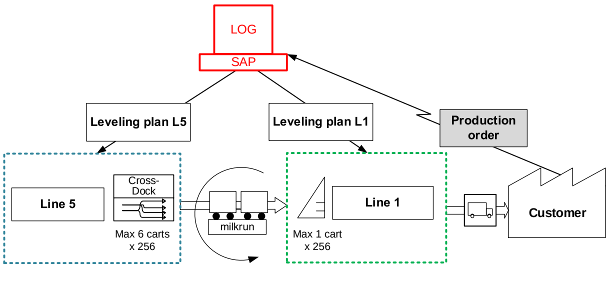

**Figure 1: Current configuration of JIT production system.**

All these characteristics have to be considered for the implementation of the desired configuration: the company's objective is to implement a JIS system where the production sequence is defined starting from the customer's needs. Specifically, the sequence for the upstream line (L5) would be determined by the production schedule of the downstream line (L1); this latter one would be elaborated as a levelled plan starting from customers' orders (Figure 2). It has to be noted that the different NPK on the two lines represents a challenge for the company: implementing a pure JIS production would require the two lines to work with the same NPK, entailing some reorganization of the production line L5 and the its equipment, with all the related costs. Moreover, since Line 5 is not dedicated to production for Line 1, but it also produces for other customers, changing the NPK on Line 5 to adapt it to the necessities of Line 1 would have an impact on other customers as well. For this reasons, in this stage of the analysis the company wants to estimate first the benefits of a partial JIS, where the production sequence of L5 is calculated starting from the demand of L1, but the two lines are working with different NPK. In a further phase of this study, another step towards a perfectly synchronized JIS process could be considered and compared to this first configuration, simulating a scenario with the two lines working with the same NPK.

**Table 2: Technical parameters of the two lines.**

| Parameter | L5 | L1 |
|---|---|---|
| Average OEE | 80% | 90% |
| NPK | 256 pc | 30 pc |
| Capacity | 160 pc/h | 120 pc/h |
| Setup time | 20 m | 5 m |
| Days per week | 4 | 6 |
| Shifts per week | 12 | 18 |

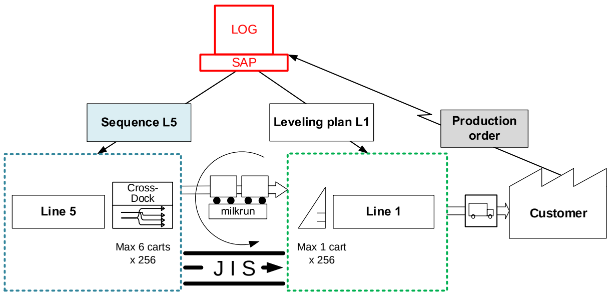

**Figure 2: Desired configuration of JIS production system.**

## 4. Methodology

In order to analyse the implementation of the JIS approach and compare it to the baseline, a discrete event simulation model has been built using the commercial software Anylogic®. The simulation approach allows incorporating in the analysis the uncertainties of the production process, which are usually accounted in the OEE. In this work, the impact of uncertainties related to the fluctuations of customers' demand and of suppliers' inputs are not considered yet.

The model simulates the three main processes considered: production on L5, transportation through the milkrun and assembly on L1 (Figure 3). The focus of the simulation is on the components that are produced from L5 and will be assembled in L1, namely product types A, B, C, D. It has to be noted that, while for L5 the simulation includes all the product types scheduled, those that will be sent to L1 (A, B, C, D) and to other customers (X), for L1 only the assembly of the components coming from L5 is considered. The assembly of components Y is not included in the model; therefore, utilization for L1 will refer exclusively to the time in which the machine is working on A, B, C and D product types. Technical data have been provided by the company (as described in the previous section), as well as the production plans of the two lines for the period considered. According to the current production schedule, in the two weeks L1 has to produce 11280 type A, 360 type B, 600 type C and 420 type D products.

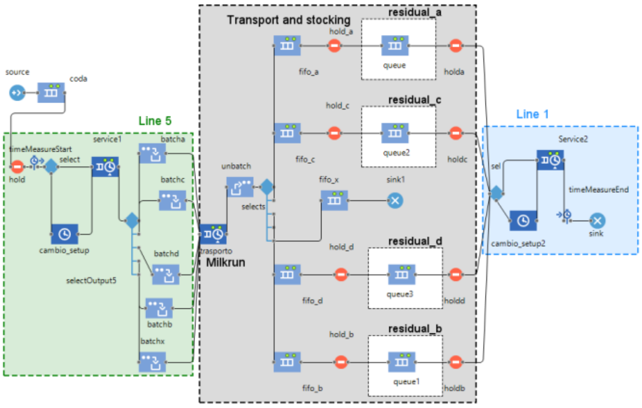

Figure 3. The discrete event simulation model.

The company is particularly interested in estimating the benefits obtained from JIS in terms of reduced buffer size and throughput time. Therefore, in order to evaluate the improvements related to the introduction of JIS production, as well as the entity of the change required, two scenarios have been simulated.

- Scenario 1 is the baseline and represents the JIT system in its current operating conditions, as described in the previous section;
- Scenario 2 represents an "adapted" JIS production system, with different NPK on the two lines.

The following KPIs have been monitored and compared:

- Resource utilization for line 5, line 1 and the milkrun [L5%, L1%, M%];
- Average throughput time (measured considering the boundaries of the system described) and its standard deviation [ATT, ATTsd];
- Maximum and average size of the FIFO buffer for the four product types on L1 [FIFOm_*, FIFOav_*];
- Average value of the residual buffer for the four product types on L1 [RES_*].

## 5. Results

Table 3 summarizes the main results. The resource utilization is quite similar in the two scenarios, as the amount of the four types of products is the same in both cases, and it results in less than 60% for line 5 and less than 40% for line 1. This is consistent with what the company expected: while on Line 5 the production of "x" product types (that will be shipped to different customers) is also considered, on Line 1 only the production of A, B, C, D types is simulated. Therefore, the utilization of Line 1 has to be referred only to the product types considered, meaning that the remaining production capacity can be employed to work on other product types. Similarly, the utilization of the milkrun is only referred to the time allocated to the transportation of the selected products.

Table 3: Simulation results

| | Scenario 1 | Scenario 2 |
|---|---|---|
| **L5%** | 57% | 59% |
| **L1%** | 38% | 37% |
| **M%** | 10% | 10% |
| **ATT [hr]** | 173.53 | 136.79 |
| **ATTsd [hr]** | 35.84 | 20.47 |
| **FIFOm_A [pc]** | 4152 | 3328 |
| **FIFOm_B [pc]** | 3584 | 512 |
| **FIFOm_C [pc]** | 856 | 512 |
| **FIFOm_D [pc]** | 420 | 512 |
| **FIFOav_A [pc]** | 2200.9 | 1305.8 |
| **FIFOav_B [pc]** | 1352.8 | 73.0 |
| **FIFOav_C [pc]** | 237.7 | 41.3 |
| **FIFOav_D [pc]** | 418.4 | 48.2 |
| **RES_A [pc]** | 91.0 | 88.0 |
| **RES_B [pc]** | 32.8 | 1.3 |
| **RES_C [pc]** | 24.9 | 14.0 |
| **RES_D [pc]** | 39.5 | 69.6 |

A significant improvement to the system performance can be noted in the average throughput time, which decreases by 21% in the adapted JIS. The standard deviation decreases by 43% as well, meaning that the production flow is smoother in scenario 2. Evident benefits can also be observed in the FIFO and residual buffers upstream Line 1. The maximum size of the FIFO buffers is reduced by 20% for type A, 86% for type B and 40% for type C. Only for type D it increases by 20%, since in scenario 1 the schedule on L5 did not include the production of D type in the two weeks considered. Similarly, the average size of the residual buffers decreases for three product types (from 3 to 96%), while increases for type D. The average size of the FIFO buffer drastically decreases in the JIS system: a minimum reduction of 41% can be observed for type A, while for the other product types the reduction amounts to 80-90%. The trend during time of the FIFO buffers is shown in Figure 4 and 5 for Scenario 1 and 2 respectively. Overall, the total FIFO average size considering all product types would decrease by 65% (from 4209 to 1468).

In this first step of the analysis, the selected KPIs show that the advantages related to the implementation of JIS in the case considered would be mainly due to a shorter throughput time and smaller FIFO buffers ahead of Line 1. These would eventually result in a faster manufacturing lead time and smaller stocking areas near the assembly line. However, these results were obtained based on the estimated OEE that the company provided. In order to test the robustness of the results, a sensitivity analysis has been included to verify the influence of a OEE variation on the expected advantages of JIS.

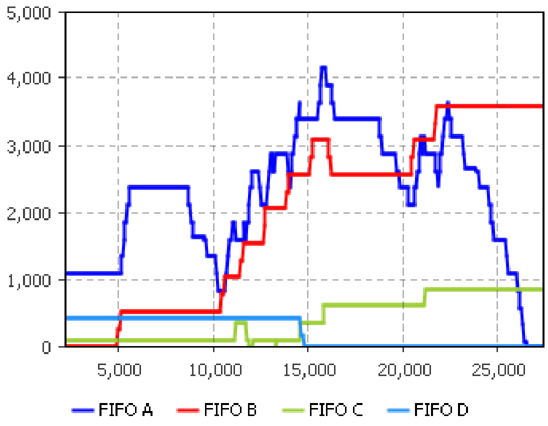

**Figure 4: FIFO buffers size during time (Scenario 1).**

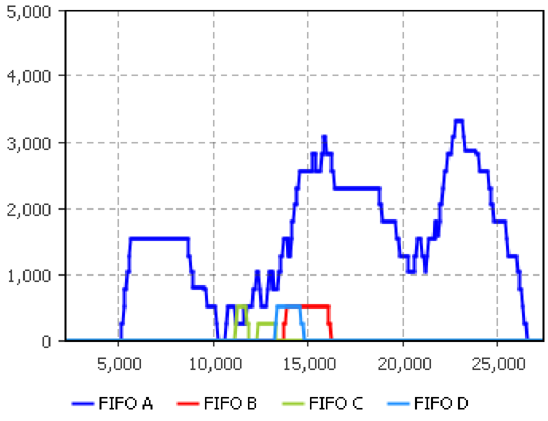

**Figure 5: FIFO buffers size during time (Scenario 2).**

### 5.1 Sensitivity analysis

The sensitivity analysis has been conducted considering two more scenarios with lower values of the average OEE for the two lines in JIT and JIS (named 1.1 and 2.1 respectively), specifically 0.5 for Line 5 and 0.6 for Line 1.

**Table 4: Sensitivity analysis results**

| | **Scenario 1.1** | **Scenario 2.1** |
|---|---|---|
| **#products A [pc]** | 11280 | 10260 |
| **#products B [pc]** | 512 | 360 |
| **#products C [pc]** | 512 | 420 |
| **#products D [pc]** | 420 | 420 |
| **L5%** | 45% | 47% |
| **L1%** | 31% | 28% |
| **M%** | 10% | 10% |
| **ATT [hr]** | 176.87 | 147.66 |
| **ATT st. dev. [hr]** | 35.04 | 24.96 |
| **FIFOm_A [pc]** | 2360 | 2816 |
| **FIFOm_B [pc]** | 3584 | 512 |
| **FIFOm_C [pc]** | 1112 | 256 |
| **FIFOm_D [pc]** | 420 | 256 |
| **FIFOav_A [pc]** | 1338.5 | 606.6 |
| **FIFOav_B [pc]** | 1256.9 | 27.6 |
| **FIFOav_C [pc]** | 228.3 | 24.2 |
| **FIFOav_D [pc]** | 418.4 | 2.2 |
| **RES_A [pc]** | 88.2 | 65.0 |
| **RES_B [pc]** | 36.5 | 1.3 |
| **RES_C [pc]** | 41.1 | 10.2 |
| **RES_D [pc]** | 39.5 | 69.6 |

The results obtained are summarized in table 4 and confirm the better performance of JIS for what concerns throughput time and space utilization. Indeed, the average throughput time is 17% lower than the JIT scenario, while the average FIFO size for the four product types are from 55% to 99% lower (Figures 6 and 7). Overall, the results for the KPIs considered are not considerably different from before. Nevertheless, it has to be pointed out that this apparent improvement in scenario 2.1 is highly influenced by the lower number of pieces produced from the system in the two weeks considered. Looking specifically at the amount of pieces produced for each product type, it is evident that scenario 2.1 was more affected than scenario 1.1 by the loss of productivity due to the lower OEE values. The total amount of pieces produced is 10% lower (11460 in JIS versus 12724 in JIT). Moreover, the JIT system was able to satisfy the demand for three product types (A, B and D), while the JIS only for two of them (B and D). This is a side-effect of the reduced FIFO buffers, that in the JIT scenario work as safety stock for L1 when the supplier (L5) is down. These results are consistent with the expected outcome, since JIS is known to be more agile than JIT, but at the same time much more exposed to the risks related to uncertainties and fluctuations.

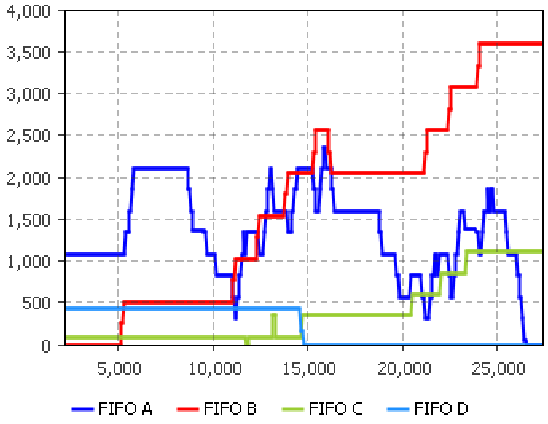

**Figure 6: FIFO buffers size during time (Scenario 1.1).**

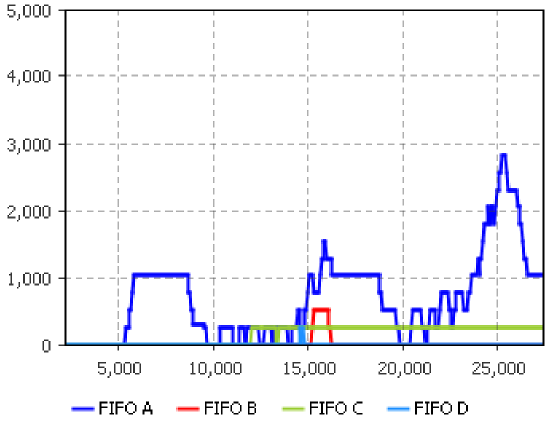

**Figure 7: FIFO buffers size during time (Scenario 2.1).**

## 6. Discussion and conclusion

This study aimed at framing the main challenges and opportunities of turning a JIT in a JIS production system. After a literature review, which revealed a huge gap in the research related to this topic, a test case from the automotive sector has been analyzed through a discrete event simulation model. The test case described can be a typical example of transition from a JIT to a JIS production process. On one side, the discrete event simulation model helped to estimate the extent of the expected benefits that a JIS process entails compared to the JIT approach currently implemented by the company. The reductions in throughput time and inventory size that represent the main strenghts of the JIS approach were verified in the scenarios simulated and estimated for the specific test case. With the current equipment and conditions, the company could reach an average of 21% shorter throughput time and 65% smaller inventory. This could be possible without any change to the current NPK on Line 5, simply scheduling the production on this line "in sequence" with the demand of Line 1. On the other side, the analysis confirmed the expected limitations related to the JIS approach: when considering lower OEE on both lines, the JIT approach turned out to be safer than JIS, as this last one was less able to satisfy the customer's demand in the time scheduled, producing 10% less pieces than JIT. Although the lower inventory level and throughput time were confirmed, this approach cannot be satisfying for the company when the reliability of the system decreases. This results can be useful to the company as they quantify the benefits and risks related to the transition to JIS on the assembly line considered, thus serving as a starting point for decision making.

It has to be noted that the quantitative results cannot be generalized to other processes; nevertheless, the case can be useful to other practitioners to derive some trends, and at the same time it proposes a "partial" JIS approach, where the system is converted to JIS without performing any major change to the equipment used. When feasible, this solution can be a possible compromise for starting a conversion to JIS without huge investments, at the same time keeping higher safety buffers than pure JIS (due to the different NPK between supplier and customer).

Further reaserch will be focused on estimating the consequences of switching to a pure JIS model in the test case considered.

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