Managing Disruptions in Inbound Logistics of the Automotive Sector

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Abstract: Management of the supply chain in the automotive sector is one of the most complex tasks since it involves numerous partners. Managing the inbound flow becomes more vital for large automotive manufacturers with hundreds of suppliers providing components according to just-in-time strategies. This paper presents a decision-support toolkit for monitoring and managing the disruptions in the inbound flow of the automotive sector. When a disruptive event happens, it affects the dock and transportation planning of the manufacturer. To cope with the consequent order displacements, some alternative solutions can be applied, with each alternative incurring additional costs. The paper proposes a managing strategy in which optimization models for the dock plan are utilized to deal with disruptive orders and to minimize the negative impacts on time and cost in the supply network.

Keywords: Inbound logistics, Disruptive events, Automotive sector, Optimization, Dock planning

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1. INTRODUCTION

The new era of manufacturing demands optimized plants and manufacturing chain networks, transforming them into flexible factories that can be quickly "reprogrammed" to provide faster time-to-market in response to global consumer demand. This new model needs transparent production processes that are responsive to changes or unexpected events originating throughout the value chain. Moreover, it requires transparent logistics processes that ensure a just-in-time paradigm guarantees that material flow is optimized just-in-sequence even when disruptive events occur.

This case stems from the need to guarantee business continuity in the ever-changing contemporary manufacturing environment, where production goals are often derailed by late-cycle changes, the use of unqualified and nonstandard parts, unexpected plant floor events, low supplier involvement and the lack of proper decision support tools to handle the above.

This case applies to the automotive sector, and in particular, to one of the largest European car manufacturers (employing more than 200,000 people in 2014), with multiple production sites, including joint-ventures, license production and outsourced production facilities in several countries. Supply chains and production plants need to optimize operations to cope with increasing product variability, uncertainties in the supply chain, shorter lead-times and reduced working capital. Continuous optimization is required and needs adequate technology and methods to perform early validation and to achieve company targets. With a generated turnover that represents 6.3% of EU GDP and ripple effects throughout the economy supporting a vast supply chain and generating an array of business services, the automotive industry is highly competitive, and innovation is its driving force. The automotive industry is the largest private investor in research and development in Europe, investing over €41.5 billion into R&D, with resource-efficiency being one of its major focal points. At the same time, it is based on a complicated multi-stage production process relying on the efficient collaboration among different manufacturing sites and corresponding value chain partners. Considering that each car can have up to 6000 components, the management of suppliers is very important to assure the delivery of the products in due time. In that regard, the system will enable big data extraction from the Internet of Things (IoT), advanced data analytics and complex event processing, also providing automated control through cyber-physical gateways.

In this paper, we describe the work done to design a decision support system for managing the disruptive events in inbound logistics, a topic not elaborated extensively in the literature. The optimization model analyzes some new aspects related to the specific characteristics of the problem.

After a review of the related literature in Section 2, Section 3 explains the problem by classifying the disruptive events and the alternatives to cope with them. In Section 4, a general architecture of the solution approach is explained, followed by the mathematical modelling. Finally, Section 5 discusses the future improvements of the proposed model.

2. STATE OF THE ART

Analyzing the inbound logistics in the automotive sector is an important issue since, on the one hand, it accounts for 10% of the manufacturing costs. On the other hand, this cost is in a trade-off with the on-time delivery of the components to the plant (Miemczyk et al., 2004). The latter is more predominant than the former since most of the inbound flows to automotive manufacturers are delivered by a Just-In-Time (JIT) strategy, and more recently by Just-In-Sequence (JIS) delivery methods which amount to 40% average parts volume of a car (Wagner et al., 2012). Svensson (2002) analyzed the time and functional dependencies among firms and emphasized the role of JIT in automotive manufacturing

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when the time dependency aspect is discussed. It analyzed the role of JIS by focusing on its importance in the elimination of inventory. Thun et al. (2007) showed three approaches for components delivery in a JIS system. In the second approach, where the supplier produces the sequence based on the manufacturer's demand and then transports the products to the manufacturer's site, it was emphasized that the most critical issue is the high cost of production re-scheduling due to disruptions in sequence delivery.

Accordingly, the disruptions in this area cause tremendous costs, not only because of re-scheduling of the supply chain plan but also, more importantly, the necessity for the re-scheduling of the assembly line; this cost may be much higher than the costs of inbound logistics. Bode et al. (2015) defined the supply chain disruption as the combination of an unexpected triggering event that occurs somewhere in the upstream supply chain, the inbound logistics network, or the purchasing environment, and a consequential situation which presents a serious threat to the normal course of business operations for the focal firm.

To overcome the disruptions in the most effective and efficient way, Meyer et al. (2017) proposed a solution framework in four steps: 1. Identifying the disruptive events 2. Analyzing the effect of the event 3. Mitigation actions (i.e. proposing alternatives) and 4. Communicating the corrective actions to the decision-maker. The events that cause disruptions are divided into two main categories: the problems with suppliers (e.g. in terms of quality or failure) and the disruptions in transportation modes (e.g. logistic integration or channel interruption) [Wagner et al. (2012) and El Abdellaoui et al. (2017)]. Meyer et al. (2017) analyzed the delays in transport modes and, as an alternative to cope with such interruptions, proposed the use of faster transport modes (an additional truck). Boysen et al. (2015) used four alternatives when a part is delayed. Among these alternatives, three of them are related to the assembly line; the only solution which is related to the inbound logistics is the use of the express delivery method.

Wagner et al. (2012) stated that process optimization is one of the most effective ways to deal with disruptions. However, it concluded that there is a gap in the literature to quantify the impact of disruptions on the total costs for the company. Boysen et al. (2015) added another aspect of the problem which is related to the arrival of the delayed components to the dock doors of the plant. This problem is divided into the assignment of the trucks to the arrival times at the plant and the assignment of the docks to the trucks. It was mentioned that these aspects were not considered in the literature. However, this problem is partially dealt in the papers which analyze the problem of cross-docking. Boysen et al. (2010) emphasized the focus of both input and output docks in the literature of cross-docking problems. (refer to Yu et al., 2008 for an example). However, for automotive manufacturers, the problems in cross-docking are not the same as those in the arrival docks.

3. THE PROBLEM

3.1 Inbound Logistics

In the analyzed supply chain, the flow of components moves from suppliers through the distribution centers and arrives at the docks of the assembly plants (Figure 1). Then, the arriving components are transferred to the inventory or directly to the assembly line. The correct feeding of the assembly line depends on the timely arrival of the components since a displacement of the parts may incur heavy costs for production re-scheduling. The main events that cause delays can happen at different points in the supply chain (Figure 1):

A. *Supplier*: There might be problems at the suppliers' warehouse due to events such as the quality of the components or the delayed delivery of the orders.
B. *Means of transport*: The means of transport might experience a delay during the trip from suppliers to the assembly plant. In this case, the order is already on the container and is traveling when some problems occur (e.g. traffic or problems at the distribution center).
C. *Dock*: Even though the components arrive on time, there might be some problems at the docks due to issues with handling and unloading equipment, or the dock situation.

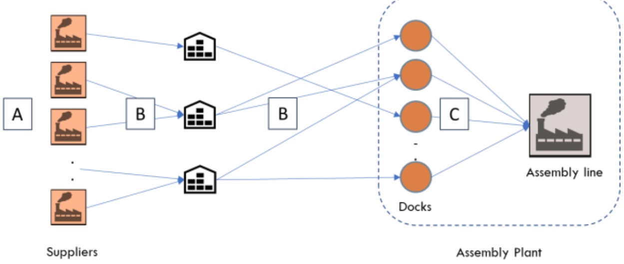

Fig. 1: Flows in the inbound logistics and the corresponding delay events

3.2 Feasible Alternatives

When one of the three delay events occurs, it is possible to apply two strategies to solve the problem, as follows:

1. Transport management. This alternative is considered when the supplier is late or there are problems during transportation (e.g., problems of loading / unloading at distribution centers). In such a case, the module for the optimization will evaluate the use of faster modes, e.g. express delivery, in order to speed up delivery and, if possible, achieve the planned arrival time taking into consideration trade-offs between cost and delivery time.
2. Dock management. This alternative is considered for any kind of disruptive event. The module will optimize the assignment of the arriving orders to the docks taking into consideration different strategies:
    a. Stay in the same dock, changing the time window. This offers the advantage that there is no change in the dock; once it has arrived, the truck waits at the dock until a free-time window arises.
    b. Change dock. This strategy has the advantage of avoiding further delays. If in a dock, different from the planned one, the time window is free when the truck arrives, the truck can be unloaded at the free dock.
    c. Open a reserved dock. In the set of available docks, the company always reserves one free dock during

    the entire time horizon. Based on necessity, this dock can be opened with the related costs of setup.
  d. Increase the number of resources. If the resources available are not sufficient, it is possible to add new resources for the unloading process.

4. SOLUTION METHODOLOGY

4.1 General Architecture

To manage the disruptive events which occur in the inbound logistics process, different levels of analysis are required. In figure 2, a general architecture is presented to integrate the data which comes from four important different tools to minimize the impact of the disruptions on the entire supply chain. The tools are Complex Event Processing (CEP), database (DB), a simulation module, and an optimization module which is formed by two sub-modules: one for the transportation and dock management, the other for the production re-scheduling.

1. The CEP module, based on data collected from trucks, docks and suppliers, allows the detection of the delay events; the output of this module is an alert for each type of delay.
2. DB allows a firm to manage all the data derived from the enterprise information system (including ERP, SCM WMS) and collects all the information needed for the simulation and optimization.
3. The simulation module allows a firm to measure the impact of delays identified by CEP on the production plant KPIs. Simulation results are not applied to the optimization module, but comparing the KPIs with the company targets for those KPIs, it is possible to understand if it is necessary to activate the optimization module to mitigate the impact of the delays.
4. The optimization module allows a firm to take the following decisions:
    a. Transport and docks management based on input data such as unloading cost, transport cost, and dock assignment. The results are a new transportation plan and dock assignment.
    b. Re-scheduling production management based on input data such as re-scheduling cost, inventory costs, production planning, etc. The output is a new production plan.

    The two sub-modules for the optimization are linked to each other. In fact, the transport and dock management require the cost of the production re-scheduling while the second sub-module requires new transport and dock plans. Once the optimization module has calculated a solution to reduce the impact of delay, these results can be used as inputs for a new simulation to measure the impact of the new solutions on the KPIs.

This architecture allows a firm to manage the disruptive events with real-time integration of the data from different sources. This strategy represents a novel use of digital platforms.

In relation to the two sub-modules for the optimization, different use cases (UC) have been defined within the company to describe how the modules address the related use cases. These cases are useful to explain how the digital platform can communicate and interact with the user to support the decision process in the context of production re-scheduling and inbound logistics.

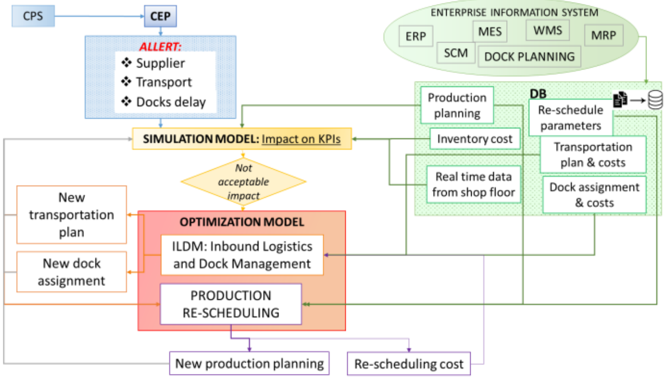

Fig. 2. General architecture

- UC_1: *Provide alternatives for optimal production scheduling*. The optimization module provides a holistic production scheduling tool that, given the input (events, horizon, shop-floor configuration), handles all the corresponding running flows and produces a feasible schedule that addresses the selected events based on user-specified optimization criteria.
- UC_2: *Provide alternatives for delays in delivery*. In this use case, the optimization module produces feasible alternatives to handle delays in the delivery of components, in order to provide a new transportation and dock management plan, minimizing the impact of the delay on the production schedule. The strategies employed include the alternatives presented in section 3.2.
- UC_3: *Provide a combination of production schedule, transportation plan and plan for activities at docking stations*. This use case enables a firm to select alternatives to handle delays in the delivery of components by providing alternatives in the transportation plan or the activities at the dock stations. Subsequently, this strategy allows a firm to obtain an optimal schedule given the changes proposed in the delivery of components by the various alternatives, as well as other events that the user may choose to handle.
- UC_4 *Evaluate the transportation plan and activities at docking stations*. For this use case, optimization offers an evaluation of the set of feasible alternatives in the transportation plan or the activities at the dock stations to handle delays in the delivery of components. This evaluation includes the following impact estimation metrics:
    - New transportation and dock plan
    - Total cost of the implemented solutions
    - Number of solved delays
    - Number of delays not solved (treated by production re-scheduling)

In the following sub-sections, we focus on the optimization module and, in particular, we propose a model to address the management of the dock's assignment when some disruptive events occur.

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4.2 Dock Management Model

The model implements the second alternative proposed in section 3.2. The following assumptions have been defined:

1. Each arriving truck is associated to one order.
2. Each time window is equal to one hour.
3. The unloading process for all the orders is fixed to one hour (15 minutes of preparation and 45 minutes of unloading).
4. To unload each truck, one resource is required.
5. Two types of docks are available:
   a. Standard docks, where the orders are normally unloaded.
   b. Reserved docks, where usually no order is assigned to them. These docks are reserved so that they are opened in case of necessity.

The model manages the incoming disruptive events and minimizes the total cost to update the dock assignment in order to find a new optimal solution for the dock management.

The most important aim is to respect the “actual production time” which indicates the time when the incoming order is required on the assembly line. Based on this time, it is possible to calculate when, at maximum, the order must be ready at the dock (due time) (Figure 3). Due time is the difference between the “actual production time” and the time needed to transport the order from the warehouse which is close to the docks to the assembly line. It is possible to manage the transfer of the components from the warehouse to the assembly line in different ways: the standard method (used to define the “due time”) and two faster strategies which feature more expedient transport and more costs and which are used to compensate for the delay when the delayed orders arrive after the “due time”. Therefore, the two strategies define two moments (acceptable due time_S1 and _S2): these are calculated as the difference between the “actual production time” and the respective transfer time by applying each transfer equipment. If the delayed orders arrive after these two moments, the only solution to accommodate the delay is production re-scheduling. Consequently, it is possible to define the buffer time as the time between the “due time” and the specific time window when the production re-scheduling is required. If the order arrives after the buffer time, it is considered to be within the re-scheduling time.

When a disruption occurs, the order will arrive after the planned arrival time, a period known as the estimated arrival time. After the arrival of an order to the dock, it takes a specific amount of time to be unloaded and transferred to the warehouse (unloading duration). After unloading, the order is ready to be transferred to the assembly line (readiness time). If the estimated readiness time is before the due time, there is no additional cost. But if it is later than the due time, it would have the cost related to the buffer time or re-scheduling cost according to the delay amount (Figure 3).

Based on this information, we list the set and parameters used in the model. The sets are defined as follows:

i : orders ($i = 1..I$)

k : docks ($k = 1..K$)

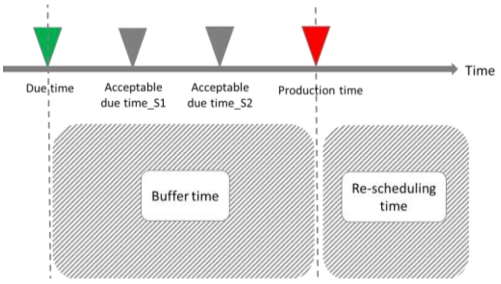

Fig. 3: Calculation of the buffer and re-scheduling time

t : time window, the unit of time which the planning is based on ($t = 1..T$)

s : strategies for the transferring of the orders to the assembly line ($s = 1,2$)

Based on the dock assignment and the amount of delay, which respectively come from DB and CEP, it is possible to define the following parameters:

$PDA_{i,k,t}$: Planned dock assignment for order i assigned to dock k at time t

$DDA_{i,k,t}$: Dock assignment after the disruptive events; it shows the impact of the events A and B on the dock plan; it is possible to see some overlaps between orders since some orders could arrive at the same dock in the same time window

AD_i : Assigned dock for order i. It is calculated from $PDA_{i,k,t}$

AT_i : Arrival time of order i; it considers the amount of the delay per each order. If a specific order is affected by a disruptive event, it is calculated from $DDA_{i,k,t}$

$DP_{k,t}$: Dock problem for dock k at time t

NAR_t : Number of available resources at each time t

$BT_{i,s,t}$: Buffer time for time t of each order i with each of the transferring strategies (S1, S2). It is one when, in the arrival of an order, it is required to use one of the strategies to speed up the transferring.

$RT_{i,t}$: Re-scheduling time at time t for each order i

DSC_k : Dock setup cost for each dock k; this cost occurs when the order i is unloaded in a new dock (standard or reserved) which is different from the planned one.

ARC : Cost of the additional resources required to guarantee the unloading process at each time window t

WC : Waiting cost; it depends on how many time windows one order has to wait between its arrival time and the assigned time window in the new dock assignment because of the lack of free docks.

BC_s : Buffer cost for strategy s; the cost of transferring the orders from the warehouse to the assembly line for each buffer strategy.

RC_i : Re-scheduling cost for order i; The main cost is due to the production re-scheduling and therefore, losses in job-per hour (JPH).

The decision variable is defined as:

$NDA_{i,k,t}$: New dock assignment for order i to dock k at time t

The objective function minimizes the total cost:

$$Min \sum_{i,k\neq AD_i,t} (NDA_{i,k,t} \times DCS_k) + \qquad 1.1$$

$$\sum_{i,k,t} NDA_{i,k,t} \times \left[\sum_{s} \left(BC_s \times BT_{i,s,t+1}\right) + \left(RC_i \times RT_{i,t+1}\right)\right] + \qquad 1.2$$

$$\sum_{t} ARC \times \max\left\{\sum_{i,k} (NDA_{i,k,t}) - NAR_t \ , 0\right\} + \qquad 1.3$$

$$\sum_{i} (WC \times \sum_{t,k} \left[\left(t \times NDA_{i,k,t}\right) - AT_i\right]) \qquad 1.4$$

(1.1) shows the calculation of the setup cost. This cost is considered just when the assigned dock in the new dock assignment is different from the assigned dock in the planned dock assignment. (1.2) calculates the buffer and re-scheduling costs. (1.3) calculates the additional resource cost when the number of available resources is not enough for the incoming orders in the new dock assignment. When the number of orders is less than the number of available resources in each time window, no additional resource cost should be considered, and therefore, this line should be zero. (1.4) calculates the waiting cost when, in the new dock assignment, the order is assigned to a later time than its arrival time.

The constraints are as follows:

$$\sum_{i} NDA_{i,k,t} \leq 1 \times \left(1 - DP_{k,t}\right) \quad \forall k,t \qquad (2)$$

$$\sum_{k,t} NDA_{i,k,t} = 1 \quad \forall i \qquad (3)$$

$$\sum_{i,k,t\leq (AT_i - 1)} NDA_{i,k,t} = 0 \qquad (4)$$

Constraint (2) ensures that, in the new dock assignment, there should be maximum one order assigned to a specific dock in a specific time; but in case of dock problems, no order can be assigned. Constraint (3) ensures that one order cannot be assigned to more than one dock and one time window. The last constraint (4) ensures that each order cannot be assigned to an earlier time than its arrival time at the dock.

To avoid the cases for which the model cannot find a solution, a condition has been developed which has to be checked before running the optimization. In the constraints (2), (3), and (4), the total number of orders assigned to a specific time window, considering the delay per each order, has to be less than or equal to the number of time windows available from that specific window to the end of the time horizon (T). It is also necessary to consider the problems at the docks which make them unavailable:

$$\sum\nolimits_{i,k,t_1 \leq t \leq T} DDA_{i,k,t} \leq k \times \left(T - t_1 + 1\right) - \sum\nolimits_{k,t_1 \leq t \leq T} DP_{k,t} \quad \forall t_1 \in t$$

If this condition is verified per each time window, the model can provide a solution; otherwise, the model sends the list of orders to be solved in the next time horizon.

4.3 Preliminary results

In Table 1, the most important input data is summarized (from A to D): these data create an overview of the problem to deal with the proposed model and derives from the processing of the parameters listed in section 4.2. The input data are as follows:

A. Number of arriving orders: Number of the total orders dealt with the model (represented by i)
B. Disruptive orders: Number of orders which have a delay caused by one of the three events listed in section 3.1. “b1” are the orders affected by event A, B and/or C, and “b2” are the orders affected only by event C (it derives from the comparison between $PDA_{i,k,t}$ and $DDA_{i,k,t}$)
C. Number of time windows with more than one orders: indicates when there are overlaps between orders that have to be solved (it derives from $DDA_{i,k,t}$)
D. Initial delay: the total amount of delay of the disruptive orders (it derives from the comparison between $PDA_{i,k,t}$ and $DDA_{i,k,t}$)

From the row E to L, the solution of $NDA_{i,k,t}$ has been aggregated in appropriate KPIs to support the company in understanding the results and comparing different scenarios. In particular:

E. Total waiting time: the sum of time that some orders have to wait once they arrive at the docks
F. Final delay: the sum of D and E
G. Total cost of solution: the cost to implement the new dock assignment provided by the model (derives from (1))
H. Number of orders solved in buffer time (S1 or S2): the total number of orders which are unloaded in a time window inside the buffer time implementing strategy 1 or 2
I. Number of orders solved with re-scheduling: the total amount of orders which are unloaded after the re-scheduling time and for which production re-scheduling is required
J. Number of orders assigned to the reserved dock: the total number of orders which are unloaded at the reserved dock
K. Time windows with extra resources: the number of time windows when an extra resource is required to unload the orders assigned to a specific time window
L. Number of extra resources: the total number of extra resources required to unload the arriving orders

To test the model, we assume that the company uses the model to manage the disruptive events which affect the orders in one day. There are three standard docks and one reserved dock. In addition, the company works on two eight-hours shifts, so the model manages 16 time windows per each dock. Cases 1, 2 and 3 are differentiated by the number of arriving orders: Case 1 is the worst because it has the maximum number of arriving orders (48, 3 standard docks per 16 time windows): the results show that (Figure 4) if the

Table 1. Comparison of the results

Input	*case 1*	*case 2*	*case 3*	*case 4*
A	48	32	36	36
B	21	19	23	21
b1	20	19	23	19
b2	1	0	0	2
C	13	10	10	10
D	33	33	33	61
KPIs	*case 1*	*case 2*	*case 3*	*case 4*
E	21	2	3	10
F	54	35	36	71
G	3689	2482	2148	4238
H	17	13	23	12
I	5	5	1	8
J	8	2	2	3
K	4	-	-	1
L	4	-	-	2

company has to deal with the maximum number of orders, it becomes necessary to implement all the strategies listed in section 3.2 to manage the disruptive events and in particular the waiting cost, the re-scheduling cost and the cost for extra docks and resources are higher than the costs in the other two cases. In cases 2 and 3, for example, no extra resources are required and the waiting cost is very low.

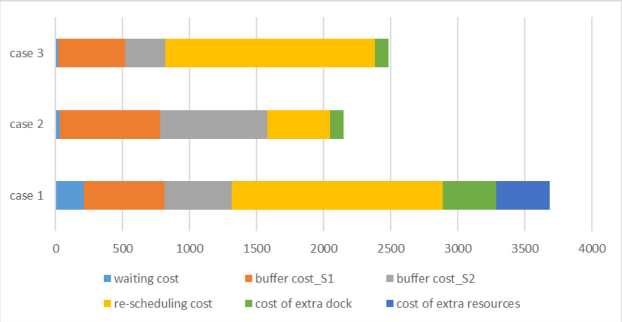

Fig. 4: Results comparison

Comparing cases 3 and 4, the model manages the same number of arriving orders but the total delay in case 4 is almost doubled compared to case 3. This higher amount of delay causes the use of the re-scheduling strategy for most of the disruptive orders: in case 3 the percentage of orders solved with the re-scheduling is 4% whereas in case 4 it is 38%.

5. CONCLUSION

Every day manufacturing flow interruptions caused by problems in the supply chain management of the analyzed company affect the overall productivity due to micro-stops and macro-stops, accounting for 2-4% of Overall Equipment Effectiveness (OEE). Moreover, changes in production schedule as an impact the plant resources (manpower, consumption, material scheduling) constitute 4% of operating costs. The main objectives for the company are to reduce manufacturing downtimes due to the external events which immobilize capital throughout the supply chain.

For this reason, an optimization model is developed to manage the disruptive events that occur during the inbound logistics, and to optimize the alternatives defined according to the company disciplines. The model works with a simplified problem; future research aims at increasing the dimension of the problem and measuring the impact on the most important KPIs of the company. The model, in fact, is expected to influence the following dimensions: job-per-hour (JPH), OEE, stock-out, and the capability to respond properly to disruptive events. Furthermore, in the proposed model in this paper, the dock management does not have strategies for reducing the delay caused by disruptive events. The model could be further refined by considering the transport management strategies to reduce this amount.

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