Enhancing Circular Logistics of Unit Loads by Leveraging Physical Internet Modularization and Consolidation Principles

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Abstract: *Returnable Transportation Items (RTI) such as pallets are crucial for any supply chain, however this remains an understudied area in comparison to other subjects in logistics. As part of a case study, this paper intends to demonstrate the operational benefits that can be achieved by introducing PI concepts of modularization and cargo consolidation into the core process of reparation at an RTI service provider. Different maturity levels of a process were developed based on PI concepts and compared with a baseline to highlight their adaptability to unexpected changes in demand. The results indicate that the implementation of PI concepts could result in significant cost savings and increased supply chain efficiencies.*

Keywords: *Physical Internet, Reverse Logistics, Consolidation, Modularization, Repair, Recycling, Modular Workstations, Simulation, Sustainability, Pallets.*

Conference Topic(s): *PI impacts; PI modelling and simulation.*

Physical Internet Roadmap *(Link): Select the most relevant area for your paper:* ☒ *PI Nodes,* ☐ *PI Networks,* ☐ *System of Logistics Networks,* ☒ *Access and Adoption,* ☐ *Governance.*

1. Introduction

The logistics industry faces new challenges every day as they operate in a dynamic environment and are forced to develop flexible and adaptive responses to customer demand. Customers expect rapid delivery of high-quality products, along with the option of unrestrictive returns, while companies strive to maintain a profitable and sustainable supply chain. In response to these challenges, researchers are exploring the potential of the Physical Internet (PI) framework as it can transform modern logistics and supply chain management.

This paper will focus on two fundamental concepts of PI: modularization and cargo consolidation. The implementation of these concepts typically involves changes in the supply chain and the node network. However, this study aims to explore how the application of modularization and cargo consolidation can reshape the core processes of companies. Specifically, the study will analyze the impact and changes on the dynamics of a repair pallet company, that from now we will refer to as Returnable Transportation Item (RTI) service provider, and how the adoption of such principles makes the company more flexible to attend unexpected changes on the demand.

The paper's structure will be as follows: Section 2 provides background information about the RTI's service provider studied, its operational context, and major challenges. In Section 3, we present the proposed methodology for studying the case and its scope. Section 4 delves into the simulation implementation and how the PI inherent concepts of modularization and cargo consolidation are considered, along with results and insights obtained. Finally, Section 5 summarizes the key insights obtained and evidence-based conclusions will be stated.

2. Industry Context

The Physical Internet (PI) proposes to revolutionize current logistics by incorporating a set of standardized, modular, reusable, and ecofriendly transport containers designed for hyperconnected logistics (Montreuil, 2011; Montreuil et al., 2015); however, in the meantime logistics still heavily rely on the consolidation of bulk cargo that is placed on pallets and totes.

Although pallets and totes as we know are not the ideal transport containers from a PI perspective, we can still study the current dynamics of these items and learn how to improve the operational efficiency of its transportation, reparation, and distribution to obtain valuable insights that we can then apply to the new generation of containers. In this paper, we will analyze specifically the case of pallets.

The flow of pallets is necessarily aligned with the flow of products across the supply chain, for that reason it inherits the complexity of the network which involves multiple tiers and different stakeholders. It is possible to map the relationship between the transportation containers and the supply chain networks, which relevant literature (Gnoni et al., 2015) classified into: Closed Loop Supply Chains (CLSC) or Circular Logistics, and Open Loop Supply Chains (OLSC). In the OLSC, pallets are seen as disposable items, thus the cost of bringing back the items can be saved and provide flexibility to the companies so they can freely decide and change the quality and material.

In the other hand, we have the circular case, under this setting pallets and totes are returnable and can be categorized as Returnable Transportation Items (RTIs). To avoid the additional complexity and costs that will imply that each actor of the supply chain need to move the transportation items to the previous stage or the fact that some of these pallets may be damaged and require a reparation before being returned; the common practice is to include a third-party company that will consolidate the pallets, review the items that require a reparation and perform it, then allocate the optimal number of pallets to each actor (see Figure 1).

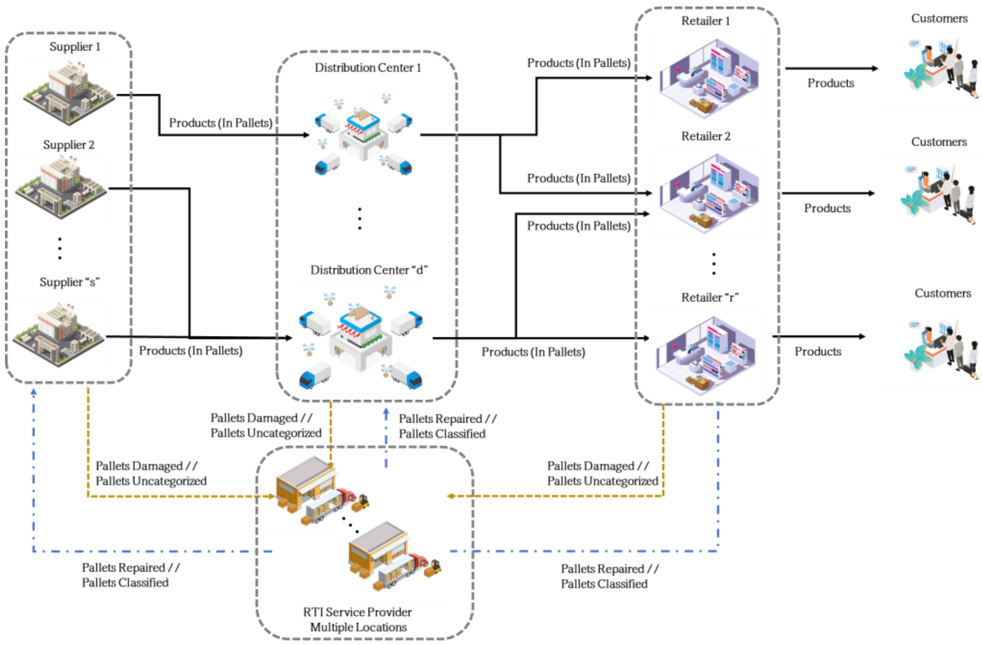

Figure 1. Flow of resources in Circular Supply Chains with outsourced Reparation Facilities.

2.1 RTI's Workflow inside Reparation Facilities

The commencement of the company's operational workflow is conditioned upon the arrival of pallets, which typically ensues through 35 ft trucks. The unloading process of a truck can either be manually done by removing the pallets one by one and placing them in a buffer zone, or by unloading pallets in groups of ten using forklifts. Once the pallets are stacked in the buffer zone, workers move them to the workstations, where they undergo inspection to identify the type and level of damage. Pallets are classified into three categories: Class A (high quality pallets), B (medium quality pallets), or C (low quality pallets). If the pallet is a Class C, it is taken to the recycling buffer, otherwise, the pallet goes through preparation where broken boards and debris are removed. After preparation, the pallet is repaired and sent to the buffer of final products. If a request for pallets is received during this process, they are loaded onto a truck and dispatched to the clients. Figure 2 summarizes the process:

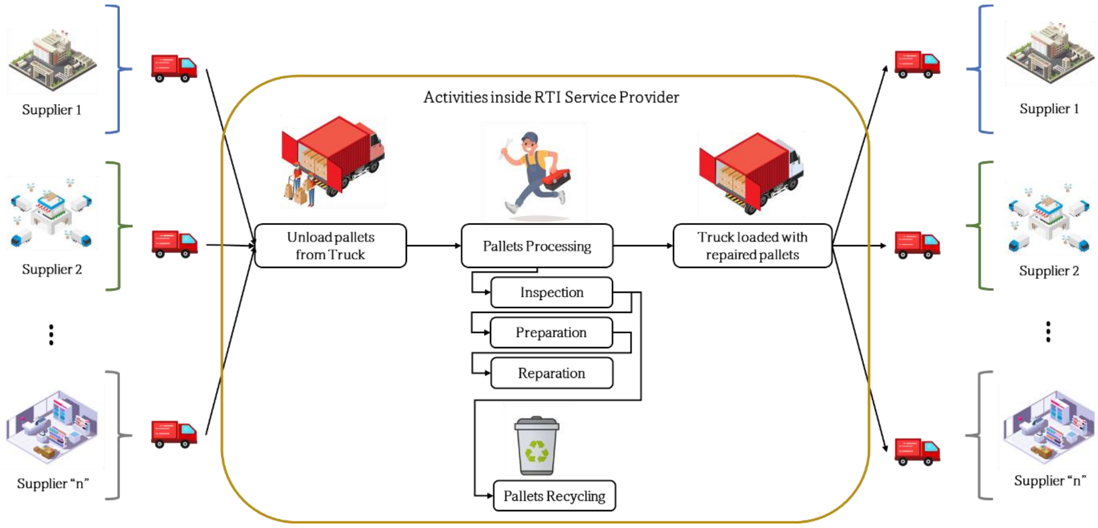

Figure 2. Operational workflow within Reparation RTI Facilities.

2.2 Challenges faced by RTIs Service Providers in Circular Logistics

When a third-party company is engaged to handle the reparation, transportation, and allocation of RTI's, it automatically inherits the complexity of the entire supply chain as it necessitates the optimal allocation of these RTI's among each actor involved. This represents a multitude of significant challenges, including:

2.2.1 Demand Fluctuation of RTIs

The number of RTI's demanded to a service provider is constituted by the number of pallets and totes that are requested from each player of the supply chain: Suppliers, Distribution Centers (DCs) and Retailers. As expected, this amount is not fixed and varies according to the seasonality of some products, special occasions, and holidays, or by shortcomings in the production. Additionally, it must be considered that RTI service provider's ability to satisfy the demand imposes a capacity constraint.

Notice as well that in some cases is not desired to process all the pallets received in a short period of time; for example, consider the case of transitioning from a high period demand to a low period demand, then is expected to receive a high number of pallets in the facilities, but is not required to repair all these items as this may imply overtime, more workers and other additional costs.

2.2.2 Lack of standardization in the unloading process

Typically, RTI service providers attend multiple circular supply chains to achieve the benefits of economies of scale, however this also implies that pallets from different actors of the Supply

Chain may be contained in the same ship. To maintain the traceability and ownership of such items, as these RTIs may have different standard sizes, quality, weight capacity, and useful life, is possible to use lean manufacturing methods, for example color coding to differentiate the pallets from each supplier.

Another layer of complexity to consider is the type of work that an RTI will require inside the facility; for example, pallets may require repairs, simple sorting or may be marked for recycling. If pallets go through for the entire process, then workstations will concentrate all the work and become bottlenecks, in the other hand if the process for identifying which is the next step for each pallet takes too much time, then the risk is underutilization of the workstations. This trade-off is one key aspect of the simulations that will be shown in the following section.

2.2.3 Variability in time processes

The reparation process is the combination of three separate activities: Inspection, where the pallets are analyzed and the decision to repair or not a pallet is made, if the pallet is not going to be repaired then is sent for disposal; the Preparation, where the debris of pallets that are going to be repaired is cleaned; finally, the Reparation, where the broken boards of the pallet are replaced. Although the process is standard and relatively simple in practice it exhibit variability, a major part of the variability come from the time that workers employ to transport pallets, this is, workstations are not designed to minimize the walking distance; the other source of variability is that workstations do not have a standard set of tools to perform a reparation so if a specific tool is required a worker need to walk to another station to grab the missing instrument.

3. Methodology

The research presented herein adopts a case study methodology aimed at comprehending the dynamics of a pallet reparation company in the United States, which is part of a CLSC. The study focuses on the repair process of pallets obtained exclusively from distribution centers and begins with the pallets being unloaded from trailers sourced from various distribution centers within a specific state and concludes with the allocation plan of the pallets to a designated group of retailers within the same state. The study's main objective is to show the feasibility of leveraging the fundamental principles of the PI operations, particularly modularity and consolidation, to see operational improvements in a process.

Figure 3 illustrates a four-layer framework. The first layer involves system requirements which has three main sub requirements namely: functional requirements (demand, system capacity, and resource utilization), PI operational requirements (modularity and cargo consolidation concepts) and resource requirements (labor force and pallet inventory). The second layer consists of two subsections: the design parameters subsection, which provides design parameters and high-level assumptions for the system, such as facility used for the case, demand behavior over time, scheduled workforce; the second presents the proposed system architecture, comprising five types of agents:

- Job agents: representing pertinent information for processing the RTIs (product ID, job type, supplier, batch quantity)
- Worker agents: show the relationship between workstations and worker over time.
- Resource agents: reflect available resources in the system such as material availability, process cycle time, forklifts, and tools per workstation.
- Layout agents: take decision of the simulation layout that will be used.
- Operation agents: enable the operational aspect that will be used in each maturity level scenario (Considering modularity and cargo consolidation pertinently).

The third layer represents the simulation model which includes three maturity levels: Maturity Level 1 lacks the central elements of our study: modularization and consolidation. In Maturity Level 2, modular workstations are implemented, but cargo consolidation remains omitted. The inclusion of adaptable, flexible, ergonomic, and efficient modular workstations allows the system to effectively respond to changing demands (Babalou et al., 2021). This setting also provides insights into the adaptability of modular workstations in different RTI facility layouts. In Maturity Level 3, cargo consolidation is integrated into the operation of RTI facilities with modular workstations. This configuration ensures that only pallets requiring full processing undergo the consolidation process, accelerating the progress of pallets that do not require repairs for dispatch (Sallez et al., 2016). Finally, the fourth layer presents key performance indicators (KPIs) for comparing the models.

To ensure the accuracy of the findings, this study utilized a combination of data collection methods, including observation, document analysis, and expert consultations with industry professionals. To compare the effectiveness of the model, key metrics were obtained through the simulator.

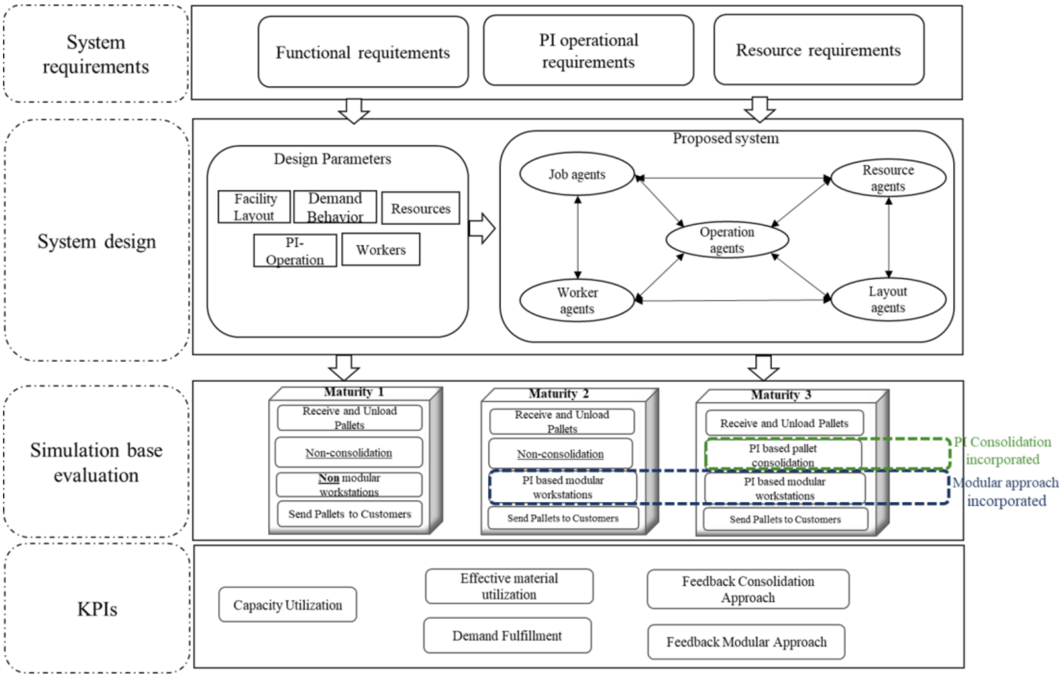

Figure 3. Designed framework to implement PI based operational process.

4. Simulation Implementation

As described in the preceding section, the object's study is to simulate three distinct maturity levels to different layouts of two RTIs facilities. Regarding the architecture of the simulation, for this study it is considered that the interarrival times for the trucks to each facility will follow a Poisson Process with mean: 31 and 59 trucks per week, the pallet loads of these trucks will be random and follow an Uniform Distribution with parameters [250, 310], the forecast demand of pallets associated for each of these RTI's service providers will be obtain via exponential smoothing based on the historical behavior of the previous year. The times considered for non-value generated activities will be automatically computed based on the distances using an event base simulation software called FlexSim. Lastly, when pallets reach a workstation, the work time will be generated with the assumptions pertinent for the case and that will be explained in more detail in the following section.

The simulations will follow general business rules (apply for all cases) and specific assumptions for each case modeled.

4.1. General assumptions

- Use of historical real data as the source of information that provides the number of pallets received per day and the number of trucks unloaded per day.

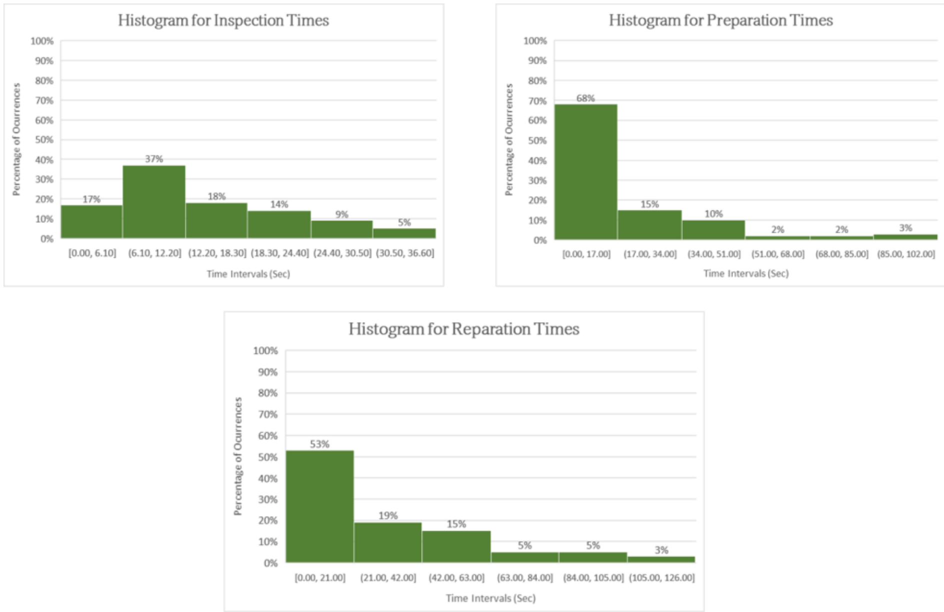

Figure 4. Empirical Distribution for different processing times (base case) plotted using a Histogram.

- For all the maturity levels, they will start with two operative workstations in the small RTI layout and four operative workstations for the larger facility.
- The study will consider that daily, the proportion of pallets received for reparation is 65%, 30% for pallets to be sorted and 5% for pallets to be recycled.
- The simulation will start assuming that on the system there already exist an amount of pallets equivalent to the capacity of one 35 ft truck. The next days will start with the number of pallets that were not processed the previous day.
- Pallets can be stacked, and each stack of pallets cannot contain more than ten pallets.
- The height of an operator will be 5 feet and 8 inches, and the speed of a worker will be 3 mph.

4.2 Maturity Level 1 (ML1): Non-modular workstations and non-consolidation process

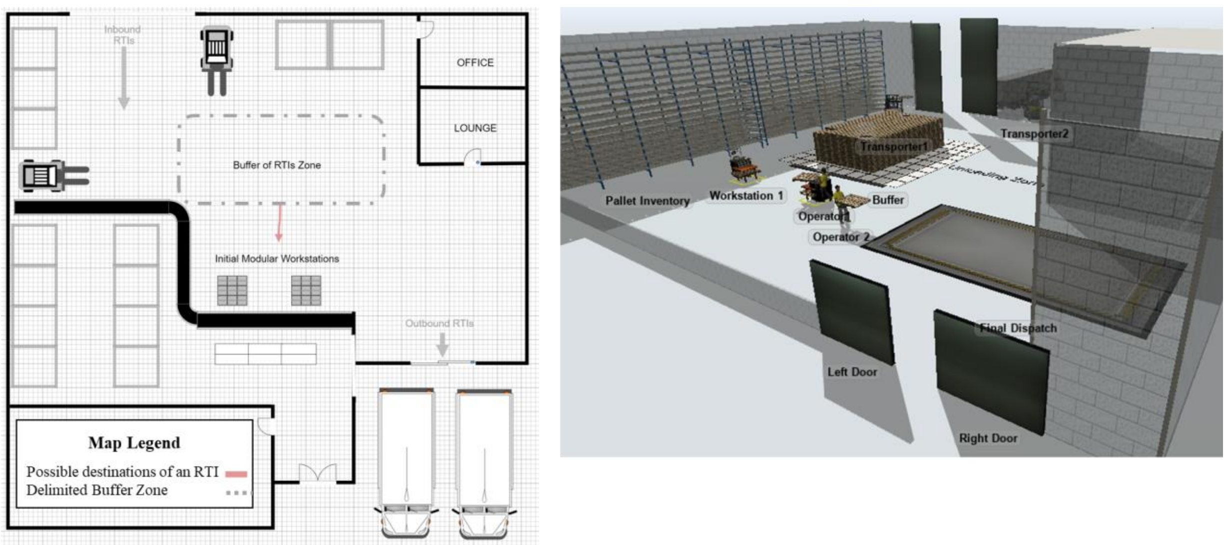

Figure 5. Non-modular and non-consolidation scenario (ML1).

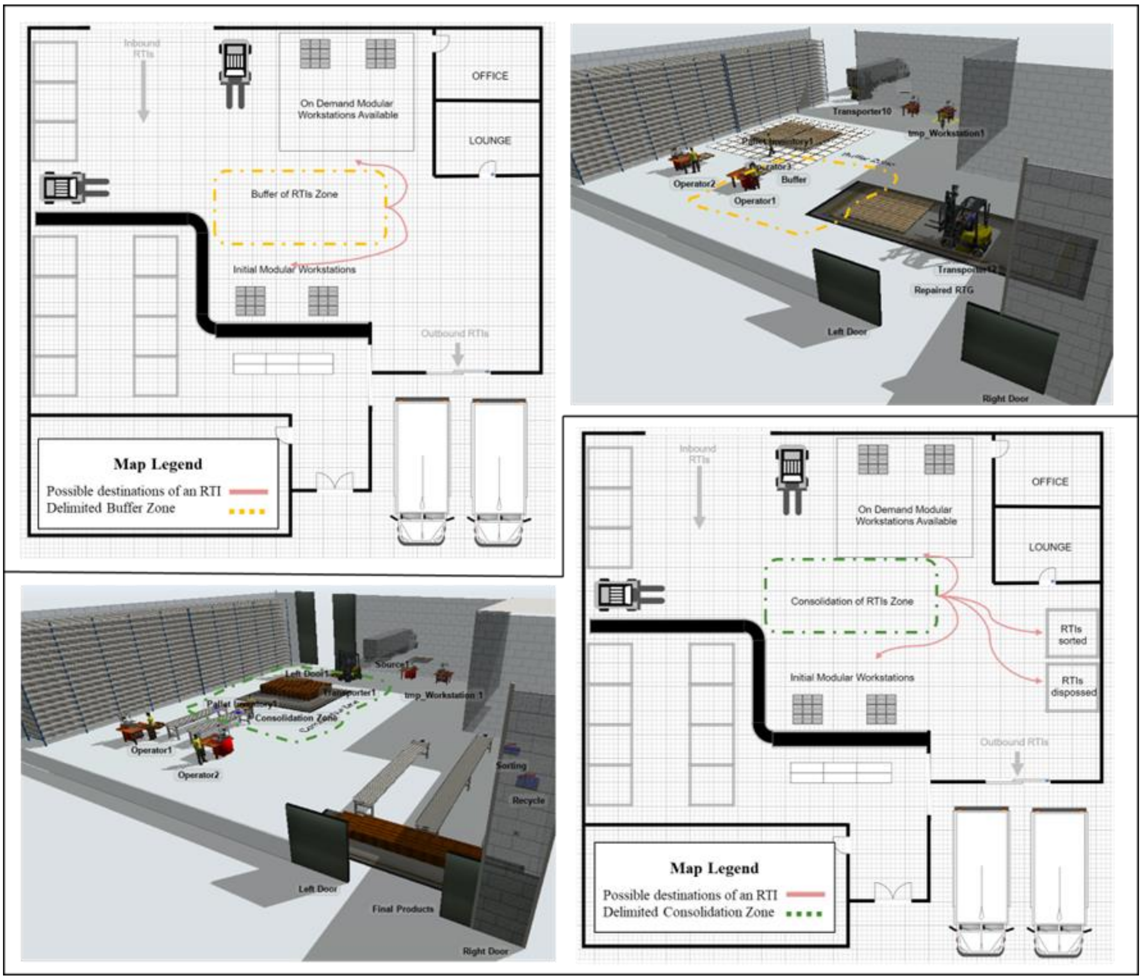

Figure 6. Layout proposed for ML2 (top) and ML3 (bottom)

- Assume a fixed capacity through the whole simulation (the assumption of two/four workstations is fixed).
- As we are working with no cargo consolidation all pallets will feed the system.
- Under this setting, the study case will use real data for the **inspection, preparation,** and **reparation** times (before any change), such times will vary between 0.00 and 36.60 sec, 0.00 and 102.00 sec and 0.00 and 126.00, respectively. Also, the times will be chosen randomly based on the histograms plotted for the real data (see Figure 4).
- The time spend in non-value activities like walking to other stations to retrieve a tool, the time to grab a pallet, the time from workstation to final buffer will be the ones that FlexSim calculate based on the average speed of the worker and the average height.

4.3 Maturity Level 2 (ML2): Modular workstations and non-consolidation process

- With the inclusion of modular workstations, we now assume that it is feasible to adapt the capacity of the plant according to the demand and the required changes can be made in less than an hour (the assumption of fix capacity will no longer hold). Modular workstations also imply that it is possible to rotate, move and adjust such terminals inside any facility.
- The modularity of the workstations also includes that all terminals have a standard set of tools to perform the operations and therefore the intervals of time are also reduced.
- The process times are now under statistical control with a 95% confidence interval and the mean times are 15 sec, 45 sec and 60 sec for the **inspection**, **preparation**, and **reparation,** respectively.
- As the no cargo consolidation assumption remains, all pallets will feed the system.

4.4 Maturity Level 3 (ML3): Modular workstations and cargo consolidation process

- Cargo consolidation now imply that the pallets received are going to be divided into groups: Pallets for disposal, Pallets that just require to be classified (sorted) and Pallets to be repaired, these last group will be the only items that feed the entire system. As sorted pallets will not require reparation is possible to consolidate them as soon as they are unloaded and send them as a package to the desired location, the same logic applies for pallets to be disposed.
- The assumption that it is possible to adapt the capacity of the plant on demand holds because of the modular terminals. Similarly, the process times from the previous point will also apply to this case.

Table 1. Summary of the assumptions used for the different maturity levels.

Assumptions for the Proposed Models	**Simulated Maturity Level 1**	**Simulated Maturity Level 2**	**Simulated Maturity Level 3**
Demand Behavior	Historical data Forecast	Historical data Forecast	Historical data Forecast
Capacity of the Facility	Fix	Flexible	Flexible
Workstation adaptability to a layout	Not feasible	Feasible	Feasible
Inspection Times	Empirical Distribution [0.00-36.60]	Normal (15,1) 95% CI	Normal (15,1) 95% CI
Preparation Times	Empirical Distribution [0.00-95.00]	Normal (45,2) 95% CI	Normal (45,2) 95% CI
Reparation Times	Empirical Distribution [0.00-120.00]	Normal (60,5) 95% CI	Normal (60,5) 95% CI
Pallet Organization	Pallets are not categorized	Pallets are not categorized	Pallets are categorized
Pallets in repair system	All pallets unloaded	All pallets unloaded	Pallets identified for reparation

5. Simulation Results

The information presented below is based on the results of the simulation of 65 weeks (to cover an entire year and the seasonality effect during that time). In all the cases the study does not consider a warm-up period and the results are obtained as an average after 1000 replicas.

Table 2. Key Performance Indicators measured for different maturity levels (MLs).

KPI's	MLs	Max. Value	Average Value	Min Value
1. Number of pallets repaired per week (Smaller Layout)	Level 1 Level 2 Level 3	8,120 11,388 12,294	7,710 9,051 9,051	7,281 6,215 6,215
2. Number of pallets repaired per week (Larger Layout)	Level 1 Level 2 Level 3	16,010 22,472 24,638	14,298 18,154 18,154	13,440 10,353 10,353
3. Inventory on Hand Utilization (Smaller Layout)	Level 1 Level 2 Level 3	95.21% 97.68% 99.63%	63.06% 92.93% 99.38%	52.79% 88.83% 99.17%
4. Inventory on Hand Utilization (Larger Layout)	Level 1 Level 2 Level 3	92.01% 96.14% 98.77%	59.66% 91.88% 98.57%	49.31% 85.59% 98.25%

5. Cycle Time of Repair Process in Small Layout (Min/Pallet)	Level 1 Level 2 Level 3	0.46 0.54 0.54	0.43 0.37 0.37	0.41 0.29 0.27
5. Cycle Time of Repair Process in Large Layout (Min/Pallet)	Level 1 Level 2 Level 3	0.50 0.65 0.65	0.47 0.39 0.39	0.42 0.31 0.28

To show the robustness and flexibility of the models it is possible to plot the following figures:

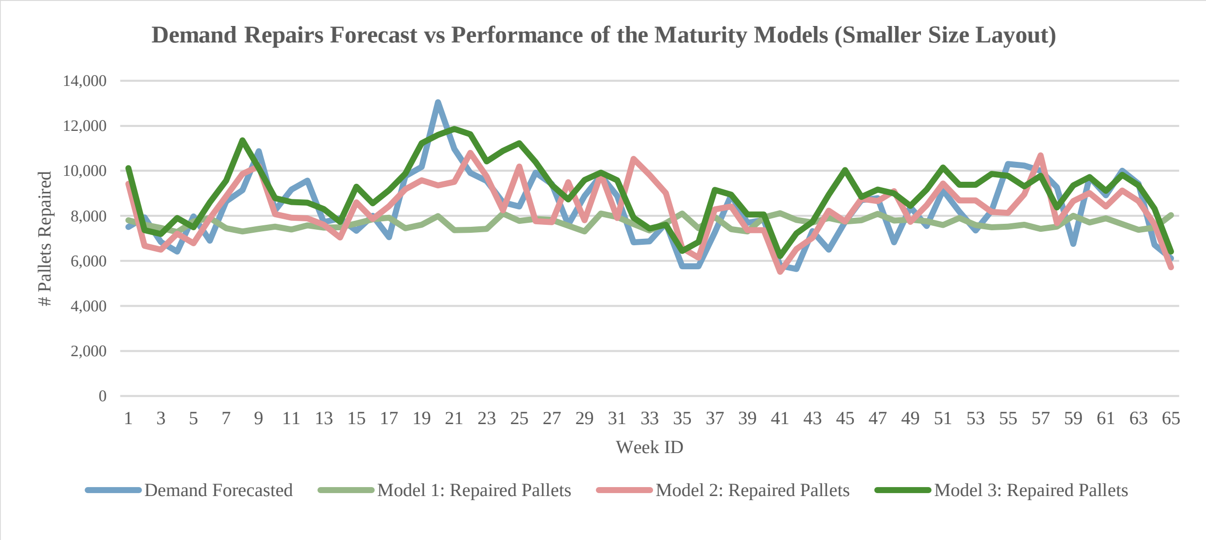

Figure 7. Demand of pallets to repair vs the results of the three generated models (small size).

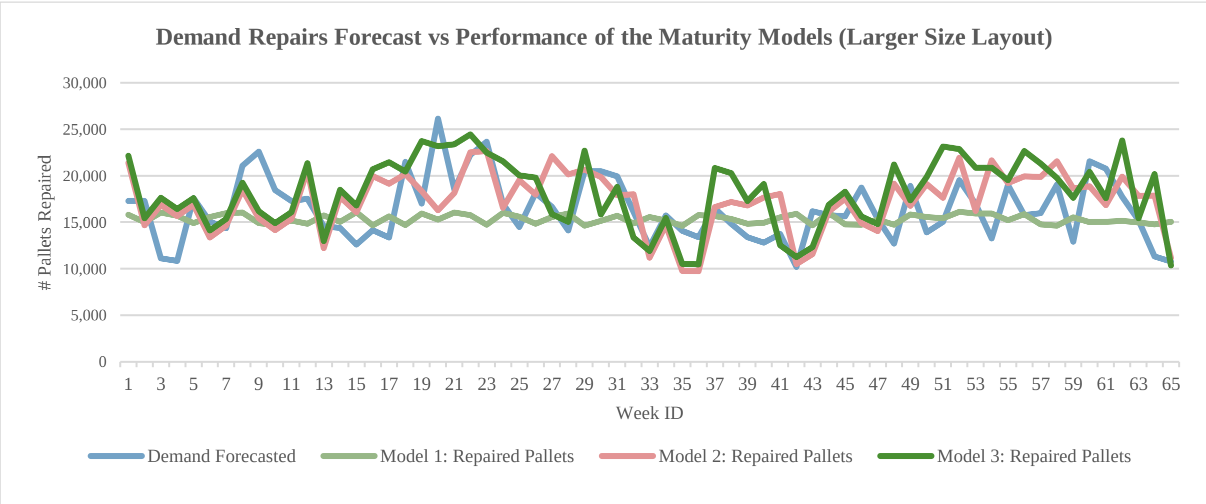

Figure 8. Demand of pallets to repair vs the results of the three generated models (large size).

The first point to discuss is the adaptability to random demand behavior. Maturity Level 1 exhibits a relatively stable and consistent flow of pallet repair, which is why the weekly throughput falls short in meeting demand during spikes, therefore, to avoid shortages it will necessitate high inventory levels, larger storage areas, and increasing holding costs. With Maturity Level 2, the addition of modular workstations upon request enables a more flexible throughput pattern, attempting to mimic demand behavior. Nonetheless, this improvement is constrained by the unresolved operational flow issues. With Maturity Level 3, considering cargo consolidation, the throughput behavior not only closely aligns with forecasted demand but also allows for anticipation of future demand, preventing strain on the production line during periods of heavy demand.

The second aspect to explore pertains to the effectiveness in processing received pallets and allocating them to their final destinations. In the case of Level 1, it becomes evident that even when operating at maximum capacity each week, the system fails to meet the forecasted demand. In the Level 2 scenario, an increase in capacity is observed, although it is not optimal. Nevertheless, it consistently meets the demand in each period. However, during periods of high demand, the system continues to heavily rely on inventory accumulated from previous periods of low demand. Lastly, within Level 3 it is evident that the system's capacity enables it to produce a surplus of pallets compared to the forecasted demand. Moreover, the primary constraint within the system shifts from capacity to the availability of incoming materials. This demonstrates that it is possible to serve more clients by increasing the supply of materials.

The last point for discussion is related to the variations observed when applying PI concepts to layouts of varied sizes. The experiment revealed that regardless of the size of the RTIs service provider, the findings remain consistent, that is, the company experiences enhanced throughput, reduced cycle times, decreased inventory levels, and improved adaptability to demand, because the system consistently adjusts as required.

6. Conclusions

The case study presented shows the potential advantages that the adoption of PI principles can provide for RTI service providers, and this claim can be extended to companies in general, when demand is variable, and flexibility is needed to manage this variability promptly. Modularity provides the required degree of freedom to adjust production levels in response to changes in demand, reducing the risk of shortages and overproduction. The information presented in Table 2 illustrates that the most significant performance improvements were accomplished with modularity, resulting in higher throughput per week, lower cycle times of the process and an increase in the ability to transform inventory on hand to final products ready to be dispatched.

In addition to modularity, cargo consolidation also plays a significant role. By consolidating cargo, workers can focus on activities that truly generate value rather than simply moving RTIs across the process. Consolidation enables a more strategic flow of RTIs, thereby minimizing the distance traveled by workers and facilitating smoother operations within the service provider. This reduction in congestion enhances overall productivity. It is important to remark that the improvements achieved, in this case, through cargo consolidation were limited by the incoming flow of materials; this presents an opportunity to extend the case study and explore the impact of receiving enough incoming pallets to fulfill additional demand.

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