Modeling and performance analysis of an industrial transport platform manufacturing process

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***Abstract*—This contribution focuses on the modeling and performance analysis of the manufacturing process for *transport platforms* at the Alimak Group facility in La Muela, Spain. The objective is to leverage formal tools to gain insights into this complex manufacturing process and explore potential applications such as control and optimization. This work presents a preliminary study, where a *Generalized Stochastic Petri net* model of the manufacturing process is proposed to be used for simulation, performance analysis, and optimization of the system.**

***Index Terms*—manufacturing systems; modeling; timed Petri nets; performance analysis.**

I. Introduction

In the modern era of complex systems, industries face the challenge of effectively managing intricate processes while striving for efficiency and optimal performance. This is particularly evident in the manufacturing sector, where companies aim to deliver high-quality products within tight timelines, all while maintaining cost-effectiveness. To tackle these challenges, it has become imperative to employ formal tools that can provide valuable insights into the underlying processes and aid in the design of efficient operational techniques [1]–[3].

Alimak Group, a renowned player in the manufacturing industry, specializes in the production of vertical access solutions, including elevators and work platforms. The manufacturing process of such systems involves numerous interconnected stages, encompassing production, assembly, quality control, and logistics. To optimize this intricate process, Alimak Group acknowledges the importance of adopting formal tools that can aid in analysis and decision-making, ultimately leading to improved operational efficiency and product quality.

To showcase this, in this contribution, we propose a *Petri net-based formal model* to represent the manufacturing process of transport platforms, depicted in Fig. 1, at the Alimak Group facility in La Muela, Spain. In particular, we use *Generalized Stochastic Petri nets* (GSPNs) [4] to model the system under consideration. One key motivation for employing GSPN models is their ability to estimate essential performance

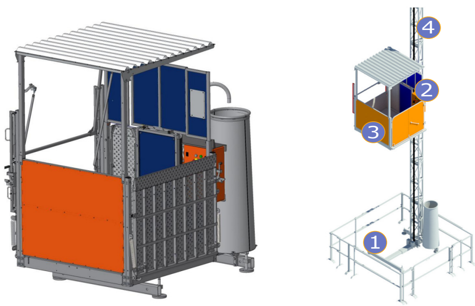

Fig. 1. The standard configuration of the transport platform and its main components: 1) the erection platform, 2) the drive unit, 3) the frame, 4) the mast unit.

measures that provide insights into system behavior [5]–[7]. Parameters such as *throughput*, *resource utilization*, and *system efficiency* can be accurately evaluated using *state-based techniques* and/or *event-driven simulation*, leveraging the capabilities of GSPN models [8]–[11]. These quantitative measures provide valuable information for decision-making and process optimization, such as identifying bottlenecks, optimizing resource allocation, the assessment of different scenarios, and evaluation of alternative strategies without disrupting the actual production process.

The remainder of the paper is organized as follows: Section II describes in detail the production process of transport platforms to be modelled. Section III outlines the GSPN model developed to represent the manufacturing process. Section IV presents a performance analysis of the system and the simulation results obtained through event-driven simulation using *GreatSPN*. We discuss and interpret the obtained results. Finally, Section V draws the main conclusions of the work and indicate possible future directions for the presented approach.

II. Production process of transport platforms

In this section, we describe the production process of the standard configuration of the transport platforms (TPL), which are produced at the Alimak Group facility in La Muela, Spain. The layout of the manufacturing process is depicted in Fig. 2: it consists of a storage area for the parts, four production spots for TPLs, an adjacent spot for assembling 4 drive units

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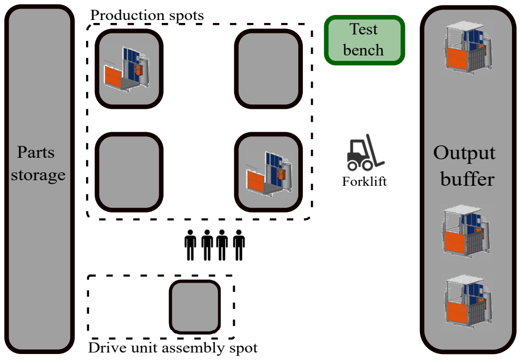

Fig. 2. General layout of the production process.

in parallel, and an output buffer. Additionally, the production process is supported by a test bench (consisting of a mobile mast unit and masses for the load tests) and a forklift, to be used during the different stages of the process. The production of a TPL is composed of the sequential assembly of its main components:

1) *Erection platform*: The erection platform is the base of the system. It serves as a facilitator for efficient mast fastening during erection and secure attachment of mast ties to the wall.
2) *Drive unit*: The drive unit is responsible for driving the TPL along the mast sections via a series of guide rollers. The gear motor, overload system, and safety device system are all installed in this unit.
3) *Frame of the unit*: It consists of the base platform (floor's self-supporting structure) to which the front panel, back panel (removable panel in front of machinery and safety device), and the falling object protection structure (roof) are attached.
4) *Electric control panel*: This panel acts as a centralized unit that integrates all the necessary commands for platform operation and the control of safety systems.

A. Assembly of the transport platforms

The production process can be divided into two main activities that are carried out in parallel:
On one hand, the drive units are built on the adjacent production spot, installing, the gear motor, overload system, and safety device system on the drive frame (Procedure 1, in Fig 3). Four drive units can be produced in parallel.
On the other hand, the TPLs are assembled on the 4 production spots (4 TPLs can be assembled in parallel). Firstly, the erection platform is installed on an available production spot, installing the cable basket and a mast section on it. Subsequently, one of the finished drive units and the control panel are installed (Procedure 2, in Fig 3). Finally, the four elements composing the frame are integrated to complete the assembly (Procedure 3, in Fig 3).

The parts that are required for the TPL assembly are stored in the general storage area. As the TPL production process progresses, operators carry the necessary parts from the storage area. Depending on the complexity of the different tasks (often requiring carrying heavy parts from the storage), they can be performed by either one, two operators or two operators utilizing a forklift, depending on its difficulty.

After assembly, the unit undergoes testing on a movable test bench. This test bench is transported to the production spot using a forklift, with the two operators ensuring its safe transfer. The test bench enables critical safety checks, including maximum velocity testing and assessment of safety device functionality through drop tests. Upon successful completion of the tests, the unit is transferred to the output buffer area (Procedure 4 in Fig. 3).

It is worth highlighting that, given the overall process throughput is relatively slow, the need to model the arrival of new parts to the storage area is deemed unnecessary as the slow utilization rate ensures consistent availability of parts at all times in the unit storage.

III. Petri net model of the manufacturing process

To model the manufacturing process, we propose a Generalized Stochastic Petri Net (GSPN) model. For a deeper insight on the formalism, the interested reader can consult [4]. The GSPN model serves as a powerful tool for accurately representing and analyzing the complex dynamics of the manufacturing system under investigation. Due to the complexity of the proposed model, we do not include it in this paper but it is available online in [12]. In order to give some general insight into the model, Fig. 3 depicts the main PN structures that model the different procedures described in the previous section:

P1 models the assembly of the drive units, which is carried out in parallel with the rest of the production process. As mentioned early, 4 drive units can be assembled in parallel, resulting in a PN structure with four branches, each resembling the assembly process represented by P1.

Similarly, the sequential procedures for completing a TPL are represented by the procedures depicted in P2, P3, and P4. The composition of these 3 structures represents the activities performed at a specific production spot. Since the system contains 4 production spots, the proposed model also exhibits four parallel branches, with each branch representing the sequential activities (P2 $\Longrightarrow$ P3 $\Longrightarrow$ P4) performed at different production spots within the system.

The model contains other places, representing the shared resources to be used during the process: available operators, available forklifts, available test bench availability of a production spot, output buffer, etcetera. Those places are pre-conditions for the different transitions of the system. Those places, however, are not depicted here for the sake of readability. Clearly, for each transition, these pre-conditions will depend on the complexity of each task. This is depicted clearly and without ambiguity on the complete model [12]

A. Model parameters

In order to assess the system performance, time delays must be associated with transitions. The mean time delay of

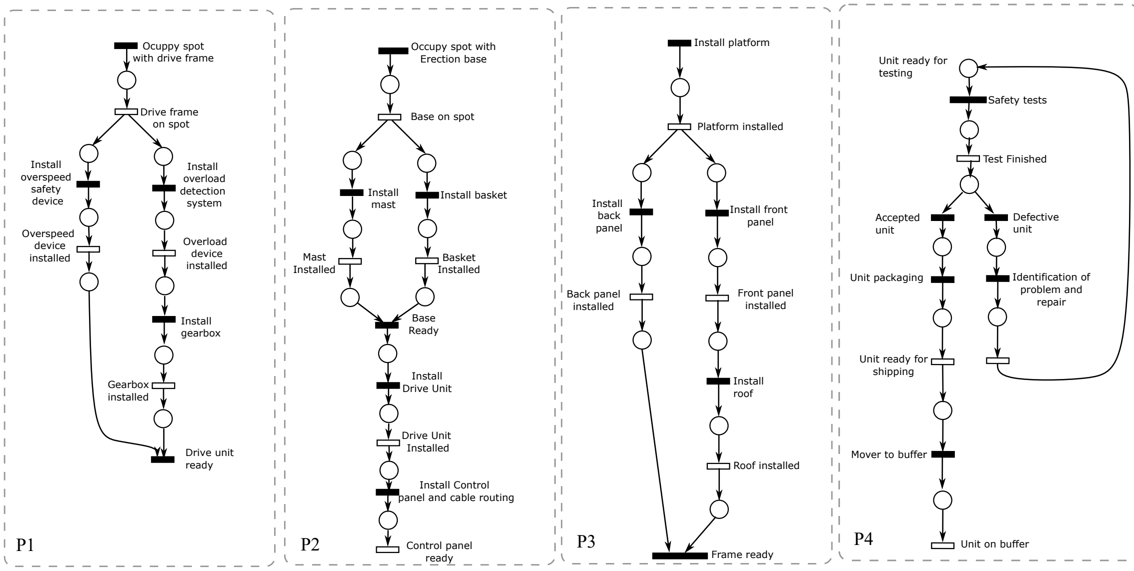

Fig. 3. Main procedures involved in the assembly of a TPL, represented by Petri net structures. P1 is carried out in parallel to the rest, which are carried out in a sequential manner P2 $\Longrightarrow$ P3 $\Longrightarrow$ P4.

each transition is defined according to the time interval it takes to accomplish the task it represents. This information is obtained in collaboration with the expert engineers of Alimak and is summarized in Table I. The model has two types of transitions: immediate and timed. The former type represents events that occur instantaneously, such as the allocation of resources and the decisions that can be taken during the process (depicted as black transitions in Fig. 3). The latter represents the completion of the different stages of the process. (depicted as white transitions in Fig. 3).

TABLE I
DELAY TIMES OF EACH OF THE EVENTS INCLUDED IN THE MANUFACTURING PROCESS.

Event	**Time delay**
Base on spot	40 min
Basket installed	60 min
Mast installed	60 min
Drive frame on spot	40 min
Overspeed device installed	60 min
Overload device installed	60 min
Gearbox installed	80 min
Drive unit installed	80 min
Control panel + cable routing ready	90 min
Platform installed	80 min
Back panel installed	60 min
Front panel installed	60 min
Roof installed	60 min
Test finished	80 min
Unit ready for shipping	40 min
Unit on buffer	30 min

The initial marking distribution of the system is determined by the number of available resources: number of operators, number of production spots (4), output buffer size (8 units)[1], number of forklifts and, number of test benches. Initially, the marking in the rest of the places is 0, representing that no unit is being processed.

IV. PERFORMANCE ANALYSIS OF THE SYSTEM

In this section, we present a performance analysis of the system. In particular, Alimak aims to optimize the process to reduce production time while maintaining or improving quality. Currently, they can produce, on average, four TPLs in 40 hours using 4 operators, 1 forklift, and 1 test bench. Therefore, the selected goal of this contribution is to study how different distributions of resources (operators and forklifts) may affect the production time of the TPLs. We simulated 6 scenarios, considering different personnel/resource cases.

In order to carry out the performance analysis, we use event-driven simulation techniques (GreatSPN). The considered performance index was the *throughput* of the output transition of the system, χ_{out}, i.e., a measure of how many units of TPLs can be processed in a given amount of time. This was obtained by simulating[2] the behavior of the system until it reached a steady state, using the *steady state simulation* module of GreatSPN (solver: *GreatSPN Legacy*; confidence: 95%).

Once this performance index is obtained, we can compare its performance with the real production plant. To compare it with the current layout, the performance index chosen for our analysis was the time required to produce four TPLs. This production time, PT, can be computed as $PT = \frac{1}{\chi_{out}} \times 4$ (the amount it takes to produce one TPL multiplied by four, i.e., the amount it takes to produce 4 TPLs).

To ensure the reliability of our model, we validated it by considering Case 1 as the baseline scenario (which represents the existing production implementation currently employed at

[1]In the following, the number of production spots and output buffer size is considered constant since redesign of the layout and production plant is neither desirable nor feasible.

[2]The simulations were performed using a computer with an 11th Gen Intel(R) Core(TM) i7-1165G7 @ 2.80GHz processor and 16GB RAM.

	Resources				
Case	#Op	#FkL	PT (Hrs.)	Avg. #Idle_Op	Avg. #Idle_FkL
1	4	1	37.68	1.078	0.083
2	6	1	35.19	2.868	0.016
3	8	1	34.63	4.823	0.003
4	4	2	29.11	0.223	0.810
5	6	2	20.78	0.721	0.339
6	8	2	18.50	2.043	0.128

Fig. 4. Production time (PT) values estimated using GreatSPN for different resource situations. PT values are given in hours. The second (#Op) and third (#FkL) columns indicate the number of operators and the number of forklifts considered in each case, respectively. Moreover, the fifth and sixth columns indicate the average number of idle operators and idle forklifts, respectively

the manufacturing plant). By comparing the model's predictions with the actual performance data obtained from Case 1, we were able to assess the accuracy and validity of our model. After this, we simulated different cases to study how different distributions of resources may affect the production time of the TPLs, compared to the baseline scenario. These results are summarized in Fig. 4.

Other performance indices considered were the number of average idle operators and average idle forklifts, i.e., the number of operators or forklifts that, on average, were not actively engaged in productive tasks. This information is useful to understand if a resource might be underutilized or if there are potential bottlenecks in the system. For instance, if the average idle operators value is consistently high, it suggests that there may be an imbalance between the available workforce and the workload, indicating a potential excess of operators. On the other hand, a low average idle forklifts value signifies efficient utilization of forklifts, indicating that they are effectively supporting the production process.

A. Discussion

The results obtained from the event-driven simulation provide insights into the impact of resource allocation on the system performance. For instance, in this particular case, the obtained results reveal that the availability of forklifts plays a crucial role in determining the production time. Scenarios with limited forklift capacity (cases 1-3), even with an increased number of operators, experienced prolonged production times due to a lack of ability to perform parallel task execution (since most of the parallelizable tasks during the production process require the use of the forklift). This can be seen also in the number of average idle operators of case 3 (8 operators and 1 forklift), indicating that the lack of resources to carry out the operations does not allow to parallelize tasks in the system, even with a high amount of personnel. Therefore, minimal improvements in efficiency were obtained in these cases.

On the other hand, an increase in the number of forklifts shows a significant improvement in production times, even in the case of only 4 operators. This is due to the fact that this improvement allows the operators to perform several tasks in parallel, reducing production times. Clearly, it is imperative to establish a balanced allocation of both operators and forklifts. This ensures improved coordination among resources, enables parallel task execution, and enhances overall efficiency.

V. Conclusions

This paper proposes a *Generalized Stochastic Petri net* (GSPN) model to analyze and optimize the manufacturing process for *transport platforms* at the Alimak Group facility in La Muela, Spain. It was shown that the GSPN model can be used to perform the analysis of the production time and resource utilization dynamics of the system under consideration. In addition, a preliminary study was conducted to examine how different resource plans can affect the productivity of the system. Through this study, it was observed that the GSPN model effectively enables the identification of the specific resources that have a greater impact on the overall productivity of the system.

Future research can focus on: • Collaborating closely with Alimak and gathering comprehensive data to enhance the accuracy and reliability of the GSPN model. Rigorous validation against real production data will verify the model's fidelity. • Exploring and adapting existing optimization algorithms and resource allocation tools developed for GSPNs, identifying efficient resource allocation strategies to maximize productivity. • Implementation of the optimization results in the actual manufacturing process, achieving tangible improvements.

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