Int J Adv Manuf Technol (2017) 93:3677–3691
DOI 10.1007/s00170-017-0430-y

ORIGINAL ARTICLE

Quantifying the advantage of a kitting system using Petri nets: a case study in Turkey, modeling, analysis, and insights

Reza Vatankhah Barenji[1] **· Banu Yuksel Ozkaya**[1] **· Ali Vatankhah Barenji**[2]

Received: 1 December 2016 / Accepted: 18 April 2017 / Published online: 25 July 2017

Abstract In case a paradigm is introduced to improve the operation of manufacturing systems, it is important to anticipate the performance of the system before expensive and time-consuming implementation. In this study, we provide the use of Petri nets in order to quantify the possible advantage of kitting feeding method in an assembly line through a case study. In particular, Petri nets have been developed through the integration of the resource-oriented and process-oriented modeling approaches and then a detailed quantitative analysis of the current and proposed system have been performed. The results and the analysis obtained from the Petri nets are used to give an idea about the anticipated performance of the proposed system before a possible implementation. Therefore, results can easily be used to aid decision-making.

Keywords Petri nets · Kitting · Simulation · Performance · Assembly line

1 Introduction

Manufacturers should adapt to changes and innovations in the production environment in order to achieve and maintain competitiveness and remain competent in the market. Particularly, companies employing mass-customization paradigm should stick to this idea in order to make each of their process effective, efficient, and lean. More specifically, production systems should be very careful about the design and operation of their assembly lines and should utilize the appropriate principles and tools that might enable the assembly processes more balanced on material feeding and handling [1]. Among material feeding methods, line side stocking, kanban, and kitting frequently used on assembly lines [2]. A special attention has recently been given to kitting method where the stations are feed by kits of components aiming to uninterrupted availability of components [3, 4]. Kitting in some cases were reported as appropriate feeding method for assembly lines [5–7].

One possible way for employing a new paradigm (particularly the kitting system of interest) before its implementation is the use of proper modeling and analysis methods to explore, predict, or foresee the behavior of the new system without disrupting ongoing operations of the real system or committing resources for its acquisition [8]. These methods should help understand how the real system will operate rather than how experts think and even whether the real system in operation needs a radical change or not. Petri net is a powerful graphical and mathematical tool, especially used to model and analyze concurrent, parallel, distributed and resource sharing systems, enabling easy visualization of complex systems [9]. Petri net is used to analyze various qualitative and quantitative aspects of the systems such as deadlocks or overflows and throughput or utilization [10, 11].

In this paper, through a case company, Petri nets are used to quantify the possible advantage of kitting feeding method in an assembly line. More specifically, Petri nets of the assembly line with current feeding method (i.e., line side stocking) are provided and give a deep situation analysis. Upon a detailed investigation of the processes and the results of the Petri nets,

✉ Reza Vatankhah Barenji
reza.vatankhah@hacettepe.edu.tr

[1] Department of Industrial Engineering, Hacettepe University, Ankara, Turkey

[2] Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA

kitting feeding method is offered to improve the processes of a station. The performances of the current and proposed system have been compared. For modeling, combination of process-oriented and resource-oriented modeling approaches are used. Using the results from the Petri nets of both systems, we quantify the advantage of using kitting method in our case company.

The rest of the paper is organized as follows: Section 2 provides a literature review on the Petri net models and the kitting systems, revealing the main contribution of the study. Section 3 presents the case study. In particular, a brief overview about the case organization, problems observed thereby, the Petri nets and the analysis of the current and the proposed system. Section 4 highlights the discussions on the results and some concluding remarks.

2 Literature review

2.1 Petri nets in assembly line

Petri net is a mathematical and graphical tool used to model, analyze, and design the discrete event systems [12]. Zhang et al. [10] and Moore and Gupta [11] discussed the use of Petri nets to provide a formal model for representing the internal relations, practical constraints, and monitor the current state in production environments. Moreover, Barenji et al. [13] claim that Petri nets have the capability to reflect all the physical details of a manufacturing system to a virtual testing platform and it is possible to use this testing platform in wide domain of applications. In some literature, Petri nets are used along with optimization algorithms and/or heuristics in assembly systems to find optimal/suboptimal solutions for the relevant problems. As examples, Kilincci and Bayhan [14] and Kilincci [15] proposed Petri nets based algorithms for two versions of the simple assembly line balancing problem aiming to minimize the number of workstations for a given cycle time and the cycle time given the number of workstations, respectively. In both studies, Petri nets were used to assign tasks to stations; the performance of the algorithms was found to be superior when compared with other heuristics in the literature. Weigert et al. [16] utilized Petri nets in mixed integer programs and heuristic simulation-based optimization methods for the optimal scheduling problem and emphasized the exploration of the combination of these two methods especially for large scale problems. Su et al. [17] proposed a Petri nets based heuristic for the line balancing problem of a mixed model assembly line. In particular, a P-invariant algorithm based on the Petri nets used to describe the task precedence relationship was presented to minimize the number of workstations, which was further used to minimize the cycle time.

Petri nets in some literature is used to deadlock analysis and deadlock prevention policies in assembly systems. Wu et al. [18] used the resource-oriented Petri nets to model the deadlock in assembly operations and proposed a deadlock control policy. Zhao and Li [19] developed a deadlock prevention policy for a class of Petri nets of a flexible manufacturing system with both assembly and disassembly operations. Weigert and Henlich [20] presented the use of Petri nets to simulate the scheduling of assembly operations to identify the potential deadlock situations and to improve the prediction of due date keeping as well as to optimize the workflow of the assembly systems. Hsieh [21] proposed a class of Petri nets for assembly/disassembly processes with unreliable resources where the failures are modeled by perturbations in a nominal marking and proposed conditions characterizing tolerable perturbations. Hu and Zhou [22] developed a new type of Petri nets to ensure the synchronization in the assembly operations of automated manufacturing systems. This Petri net was further utilized to develop a mathematical program in order to identify the deadlocks and remove them iteratively, eliminating the enumeration of huge size deadlocks. Recently, Hou et al. [23] developed a deadlock prevention policy for a class of generalized Petri nets modeling flexible manufacturing systems with machining, assembly, and disassembly operations. In particular, a polynomial complexity control policy for non-blocking supervisors was established by properly adjusting the resource allocation.

2.2 Kitting feeding method in assembly line

A kit is defined as “a specific collection of components and/or subassemblies that together (i.e., in the same container) and combined with other kits (if any) support one or more assembly operations for a given product” and is considered as an alternative feeding policy to line side stocking feeding system [24]. A traveling kit concept requires that the kits, transport to the first station on the line and then move along the line together with the product being assembled, whereas the stationary kit concept delivers the individual kits holding the required parts to the specific workstations [25]. The effect of the kitting feeding method on the assembly time and utilization of this effect to improve the kitting and/or assembly process was also widely investigated in the literature [26]. Hanson et al. [27] studied how kitting and the continuous supply differ in the time spent for picking up the parts and illustrated that the time associated with kitting is significantly shorter than that of continuous supply due to shorter distances between the assembly object and the parts presentation and shorter time spent for searching the parts. Hua and Zhou [28] proposed a clustering algorithm and a cluster assignment method based on filling curves to minimize the travel time to collect the parts in circuit board assembly operations and presented that their approach reduces travel distances and hence the travel time. Gunther et al. [29] focused on the problem of minimization of the total worker time in an assembly system using the kitting idea and presented a heuristic for the job and machine selection procedures for large scale problems. Christmansson et al. [30] proposed an effective material-to-picker approach as an alternative method to picker-to-material approach to reduce the time and physical workload. Hanson et al. [31] dealt with the design of kit preparation systems in small areas and showed that there is a strong advantage associated with batch preparation compared to single kit preparation in terms of man-hour efficiency. Hanson and Medbo [32] studied the impact of the proportion of parts included in kitting on the assembly time and illustrated through case studies that the potential reduction in the time picking up the parts by kitting does not always end with a reduction when only a proportion of parts are kitted.

Brynzer and Johanson [2] focused on the impact of work organization, location, and method of order picking activity, information system and equipment requirements on several performance measures, and illustrated that picking efficiency is mostly affected by the product structure during the design of picking information and decision of the storage assignments. On the other hand, Kilic and Durmusoglu [33] proposed a mathematical model to find the optimal number of workers and kits to be carried to the workstations subject to capacity constraints for kitting trailers, kit boxes, and area of kitting space.

2.3 Contribution of the study

The current literature usually uses Petri nets as a supplementary tool in order to develop mathematical programs while trying to solve the well-known scheduling or line balancing problems in the manufacturing system or as a means for the development of new Petri nets usually for deadlock analysis. However, a detailed quantitative analysis of a manufacturing system is possible by Petri nets; this application is usually ignored in the literature. This study improves the previous works in several aspects. First, we provide a detailed investigation of the current manufacturing system using Petri nets, which highlights the problems and areas for improvement in the system. Although some of these problems and areas can also be observed very easily after a short examination of the manufacturing system at the case company; however, it is important to quantify these problems and give specific performance measures. Second, to the best of our knowledge, this is the first study that integrates Petri nets and kitting method on an assembly line. In particular, a model of an assembly line with kitting has been developed in this study. Last, the results and the analysis obtained from the Petri nets for the assembly line with kitting are used to give an idea about the anticipated performance of the proposed system before a possible implementation. Therefore, these results can easily be used to aid decision making.

3 Case study

3.1 General information about the case organization

Turkey is a developing country and hence, the demand for electricity is expected to increase in the near future. In a report prepared by Turkish Electricity Transmission Company, forecasts indicate that there will be an average 3.17% increase in the base demand for electricity between 2017 and 2026 [34].

XYZ Corporation with the exact name to be kept confidential is a manufacturer of medium voltage electrical equipment for distribution purposes. Having a relatively long industrial experience, it has a significant role in the Turkish electromechanical industry and due to the forecasted increase in demand for electricity, the operation of the company will be more important in the upcoming years. The company performs all its activities in an indoor production area of over 60,000 m^2 located in two countries. Since the company is producing on a make-to-order basis and specifications of customer orders vary, XYZ Corporation has a mass-customization philosophy. In this study, we have focused on switchgears assembly line since the processes on this line are not fully automated.

3.2 Problems

Having a glance at the switchgears assembly line highlights the following problems and associated wastes, which might be eliminated by employing appropriate lean production tools.

- Feeding and handling of components of the assembly line are subject to many wastes, mistakes, and problems about component order management. There is a line side stocking system in the line supported by a completely manual material handling system, although there are AS/RS systems to store the components. Since the variety of components is high and sizes are very small, AS/RS system is able to refund the components based on only sets. The refunded components from AS/RS must be stored at the station storages which are usually racks or cans. It is the responsibility of the warehouse operator to feed the components according to the pre-determined amount and periods. However, cans or racks are usually filled by the warehouse operator when operators see cans or racks almost empty. Since the exact number of components on the racks or cans is usually not clear, more parts than required are filled which might lead to starving at the other stations. Some cans allocated for small parts are not large enough for daily productions and hence, two or more trips are required for some parts in a day. If these trips cannot be caught up, the production stops and hence, operators sometimes themselves go to the warehouse to get the required parts.

- There is no structural assignment of tasks to the operators in this assembly line. The operators give their own decisions about the assignments. Sometimes, a single operator completes the assembly of one board and sometimes one board goes through a few operators in the flow. Since there is no regular work order for the processes, the operators themselves decide the next process to carry out.
- Unnecessary and non-value added processes are observed to be a source of waste of time. The work area is usually full of many unnecessary or unrelated components and tools. It is observed that operators usually lose a significant time to reach the necessary part.
- Some of sub-assembly processes can be performed only by specific expert operators. Hence, the performance of the system depends on the performance of these operators and an imbalance of the processes across the stations is observed. In addition, the assembly line has a bottleneck at the stations requiring expert operators such as electric board assembly station with a significant number of processes. Therefore, along with all problems explained above, the production amount is mainly determined by the capacity at the electric board station and cannot reach the target value.

It can also be concluded that all the above-mentioned wastes and problems are somehow related to some of the others. For instance, the first, third, and the fourth problems might arise from the lack of an appropriate "production environment" and absence of a "manufacturing execution system" and/or it may arise from an improper layout of the manufacturing system. The first and the third problems might be a negative outcome of an inappropriate "feeding system." In a production system of complex product with high variety of product in low volume with large number of components, the suggested feeding method is kitting [3, 4, 26]. The kitting method might also be a part of the solution to the second problem since in the kitting system; the required components in the station are loaded on a kit based on the order of the assembly process. In addition, the need for expert operators at some stations might also be expunged. Therefore, it is anticipated that, at the low level, the performance of the switchgears assembly line and, at the high level, the order management system of the case company can be improved by introducing a kitting system.

3.3 Description of the current system

After an initial look at the manufacturing system, the next task was to analyze the system and obtain performance measures of some stations so that the effect of these stations on the throughput and utilization of the assembly line can be explained. Stations with high and low utilization rate will be used as problematic stations that need improvement and possibilities to enhance the performance will be identified.

The layout of the switchgears assembly line is presented in Fig. 1. Most of the 19 stations on the assembly line operate manually; only the metal sheet workstations are fully automated. Manual stations are located at two circular assembly lines, through which the workpieces have to go sequentially. Workpieces are transported on automatic conveyors and manual carriers. The red lines represent the transfer of the workpieces or components between the storage areas or warehouse, whereas arrows depict the material transportation directions between the stations. It should be noted that, due to space limitations, the system is presented here with slight simplifications. Detailed description and processing tasks of the stations are not considered at this level of abstraction.

On the assembly line, 24 types of products with almost similar shapes, but different specifications are produced. The differentiated module on all products is the "Electric Board" (EB). The specifications of the EBs vary depending on the customer orders, but EBs of all types are produced in the EB station by only a few specific operators. Table 1 presents the yearly demand of the products and related average processing times in the EB station. Product 1, product 2, and product 3 are the common standard parts. The demands for these products are relatively high, and because of the repetitive structure, the operation time is lower when compared with the other products.

3.4 Modeling and analysis of the manufacturing system using Petri nets

Petri nets are used as a tool to model and simulate the corresponding processes and material flow on the assembly line and information flow between the low and the high level of the company. A Petri net is a directed bipartite graph, in which the nodes represent transitions (i.e., represented by bars) and places (i.e., represented by circles). The directed arcs describe places as pre/post-conditions for transitions (signified by arrows). In addition, tokens (dotes within the places) are used to simulate the dynamic and concurrent activities (firing process). The weight of the arcs represents the number of tokens to be removed from places in firing a transaction. There are mainly two approaches for modeling manufacturing systems with Petri nets: resource-oriented and process-oriented methods.

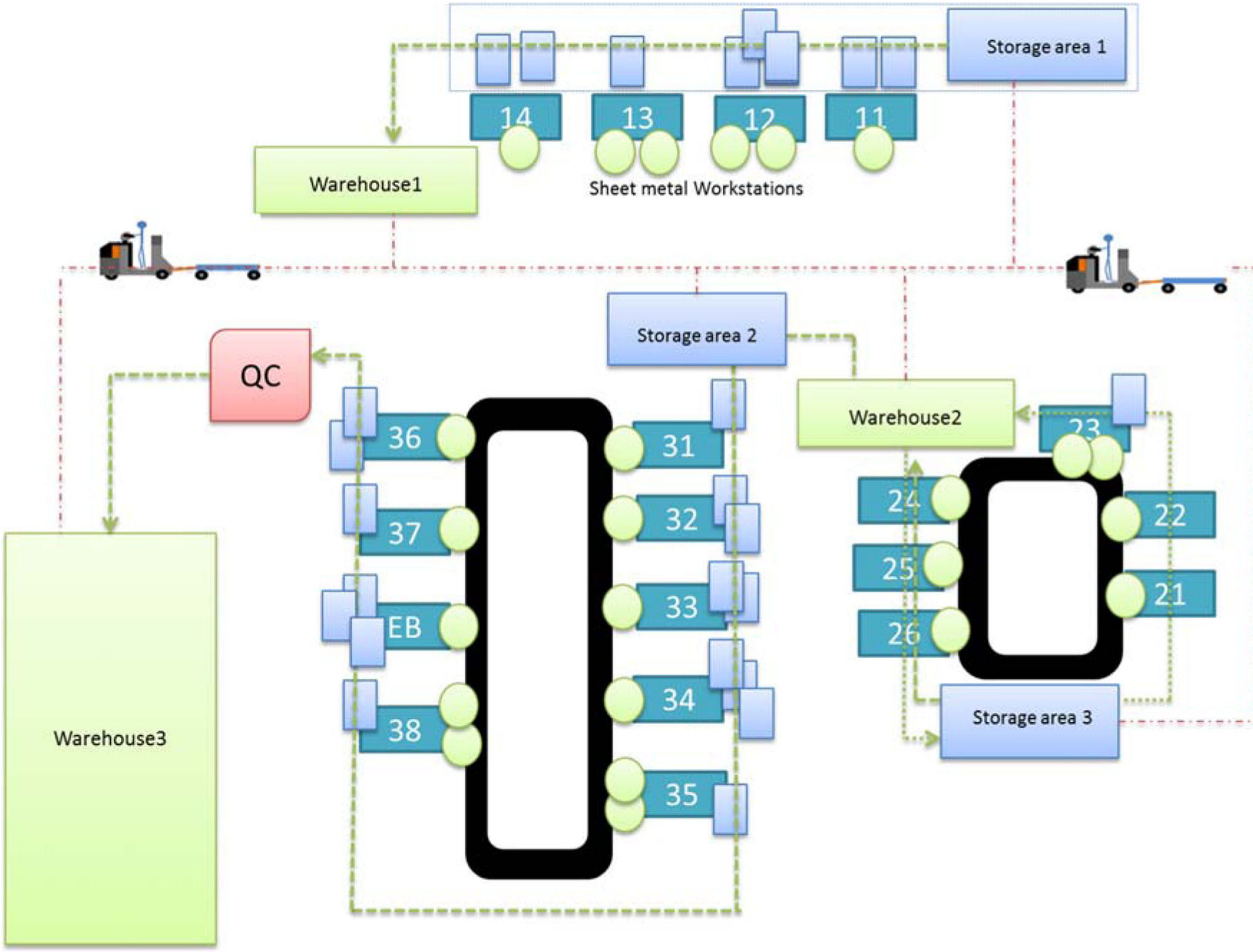


Fig. 1 Current layout of the manufacturing system

In resource-oriented method, the operations are represented by transactions and places represent the location of the corresponding operation. Tokens show the raw materials and/or products that will enter the place or depart as an output. Resource-oriented modeling is an applicable method, especially to model information flow in a company and appropriate to model close loop sequential flow manufacturing system without decision points. Process-oriented method, dedicates

Table 1 Demand of products in year 2015 and processing times in EB station

Product type	Demand	Processing time (seconds)	Product type	Demand	Processing time (seconds)
Product 1	2450	379	Product 13	531	580
Product 2	1888	407	Product 14	499	699
Product 3	1631	387	Product 15	487	653
Product 4	888	511	Product 16	457	639
Product 5	823	520	Product 17	401	718
Product 6	792	494	Product 18	374	679
Product 7	734	562	Product 19	374	638
Product 8	731	538	Product 20	351	652
Product 9	621	567	Product 21	305	614
Product 10	602	580	Product 22	299	601
Product 11	578	542	Product 23	274	581
Product 12	550	610	Product 24	248	645

places to processes in connection with input and output transactions. Firing in input and output transactions indicates the beginning and end of the operation in the corresponding place, respectively. Places in parallel with the operation place of the stations are used for the availability of the resources (machine, tools, operator, etc.) to ensure the realization of the operation. Process-oriented modeling is a proper method, especially to model the material flow in a flexible manufacturing system where the material flow is on a close and/or open loop of value adding processes and the decision points are available in many nodes. The system independently must take decisions based on WIP in these nodes to fowl up the parts to the manufacturing lines. Process-oriented is able to show the control points such as sensors. However, the integration of the control system to manufacturing system is not possible and must be modeled separately. Therefore, the effect of the decision on the control points on the material flow is not possible to simulate.

To overcome the issue, the approach used here is an integrated version of the resource-oriented and process-oriented methods. In this approach, the information flow, i.e., the control system of the manufacturing system, is modeled by the resource-oriented method, whereas the process-oriented method is employed to model the material flow within the shop floor. In order to integrate these two models, a new type of place, namely "control place" is used in the shop floor model. The "control place" represented by two concentric circles is directly connected to a transaction as an input place in the shop floor model. Therefore, the "control places" in the model act as signals from the control system and whenever the control system wants to run an operation, a token will be charged to the corresponding "control place" so that the transaction will be enabled or will be fired. Furthermore, in shop floor modeling, in order to make the model simpler and clearer, places are grouped under four categories, namely, input, output, operation, and resource availability places. In the model, input places are used to demonstrate the storages and buffers that hold the raw materials. Output places are used to represent the storages of the products. Operation places are used to demonstrate processes in the manufacturing system, and resource places are used to indicate the availability of the resources for the corresponding operation. The details of resource-oriented and process-oriented methods along with the developed approach are presented in Table 2.

Table 2 Details about Petri net modeling approaches

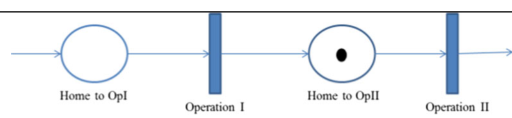
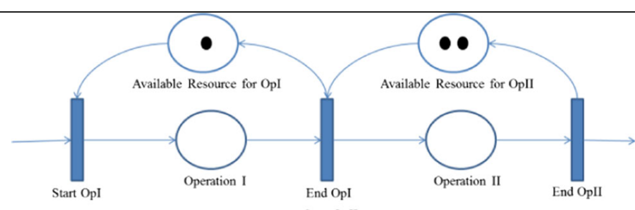
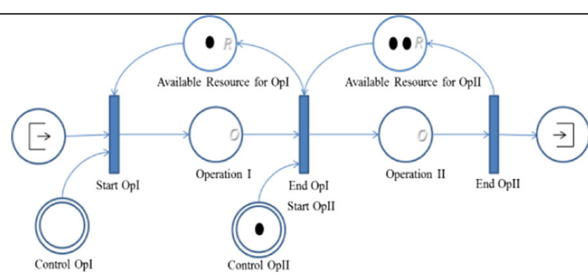
Modeling approach	Graphical representation	Application area
Resource-oriented		General application and control system (information flow)
Process-oriented		Shop floor (material flow)
Used approach		Integration of shop floor and control system

Figure 2 presents the structural Petri net model of the switchgear assembly line. It should be noted that only workpieces to be processed are considered as tokens in the model and no resource availability places are used at this level of abstraction.

In the model, P7, P13, and P20 represent storage areas 1, 2, and 3, respectively, whereas P6, P30, and P12 indicate the warehouses. As indicated above, all stations are represented by a resource place and a transaction which are connected by two reverse arcs. Places of different stations are connected using transactions which model the handling processes among these stations. Twenty-four types of tokens each demonstrating a different product type are defined for P7, P13, and P20 places. The processing times for all tokens in the stations are fixed except for the EB station (i.e., P22 and T35). Recall that, as presented in Table 1, the demand for different product types are different and in the simulation model, the demand for the products and hence the processing times at the EB station for the tokens are generated randomly according to the empirical distribution determined by the demands. The simulation model is run for 700 days as the warm-up period determined by the Welch method and additionally 7000 days as the steady-state period to estimate the average lead time, average throughput rate, and average repeatability. The results obtained from the Petri nets were verified through the comparison with the real performance measures and hence the robustness of the developed model was validated to represent the real system since it was confirmed that the model works as specified in the regular operation of the assembly line. The results of the Petri net simulation are summarized in Table 3.

The results of the simulation model helped us draw some conclusions about the operation and performance of the switchgear assembly line. Firstly, the EB station and station 14 have the lowest and the highest average throughput rate, respectively (54.49 and 74.32). In contrast, the EB station and station 14 have the highest and lowest value of average repeatability (67.31 and 33.56%). Therefore, it is obvious that the processes at the EB station and station 14 need improvements.

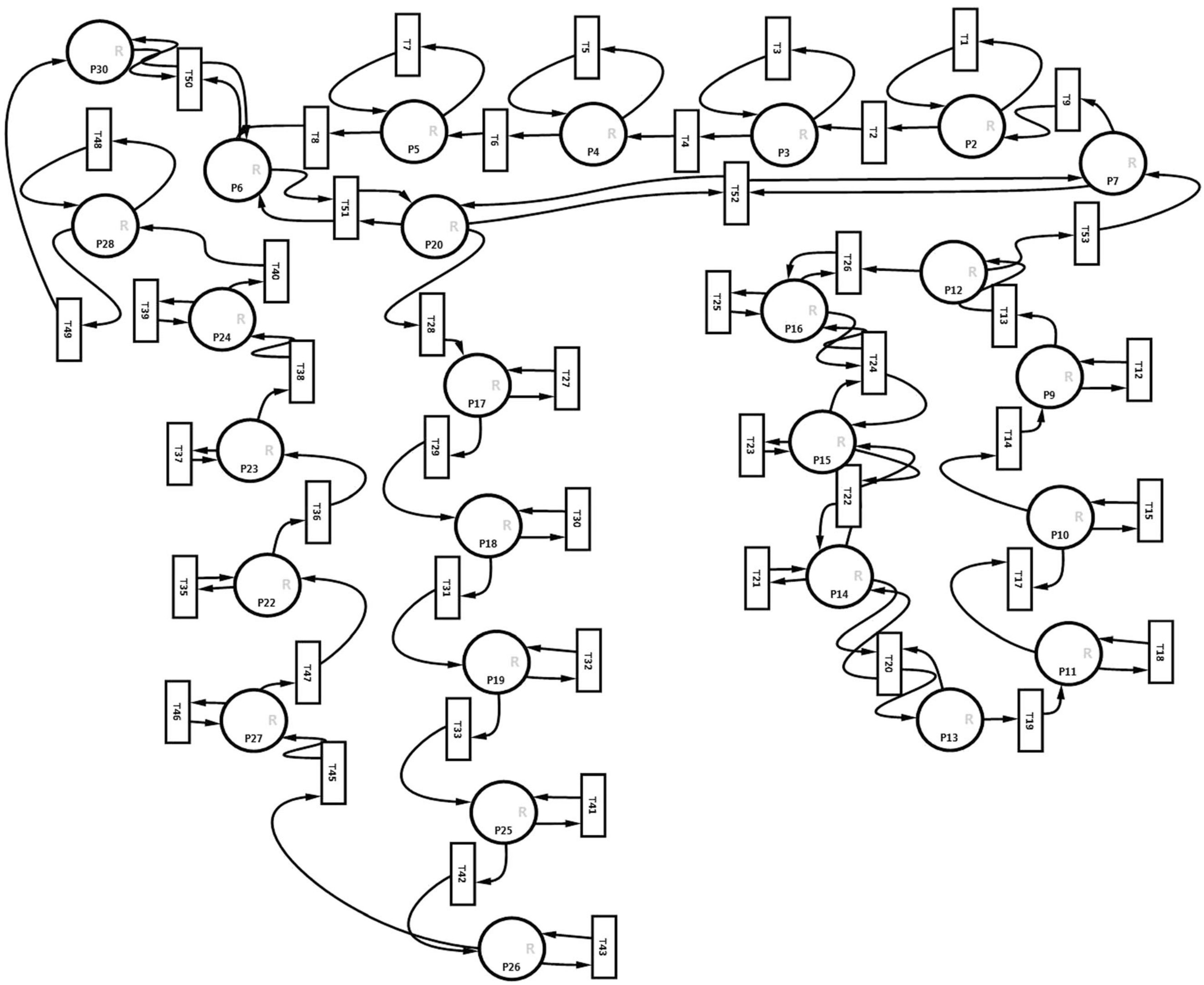


Fig. 2 Petri net model of the switchgears assembly line

Table 3 Performance measures of stations in switchgear assembly line

Station name	Average throughput rate (parts/day)	Average repeatability (%)	Station name	Average throughput rate (parts/day)	Average repeatability (%)
11	69.88	40.32	31	67.23	41.35
12	67.61	45.78	32	64.37	43.95
13	63.46	43.68	33	66.35	46.78
14	74.32	33.56	34	67.34	40.91
21	69.73	58.96	35	68.64	43.78
22	68.88	40.44	36	66.37	47.35
23	69.10	43.93	37	69.98	42.98
24	65.32	40.35	EB	54.49	67.31
25	67.95	46.37	38	66.66	47.31
26	68.58	46.98			

Since station 14 is fully automated, the reconfiguration of this station is a very tough task. Hence, one possible way to improve the assembly line is to change the feeding method of the EB station form "line stock" to "kitting method."

3.5 Modeling and analysis of the current and proposed EB Station

The current EB station consists of seven process cells (cell 1 through cell 7) with resources (resource 1 through resource 7), two input storages to load the hug size components (input 1 and input 2), a single input storage for cables (input 3), one output storage (output) for storing the final products, and five buffers (buffer 1 through buffer 5) for the work-in-process inventory. Each cell has a storage area to feed the required components and associated resources. The work flow of any product is straightforward: "Base" must be processed by cell 1 and cell 2 followed by cell 4 or cell 5 and "Cover" must be processed by cell 6. Cell 3 is in charge of sorting the "cables" and loading these cables to cell 4 or cell 5. Cell 7 is the final assembly process of the products. The developed model of the current EB station is presented in Fig. 3 with a summary of the details in Table 4.

As mentioned earlier, a kitting system is proposed to improve the performance of the EB station and hence, a universal kit with an extension side is designed so that it can be adjusted to different products. The kit is designed such that cavities are placed according to the process order. This helps decrease the processing time at the cells since the operator does not have to spend time to decide the next task or component or to search for the required part.

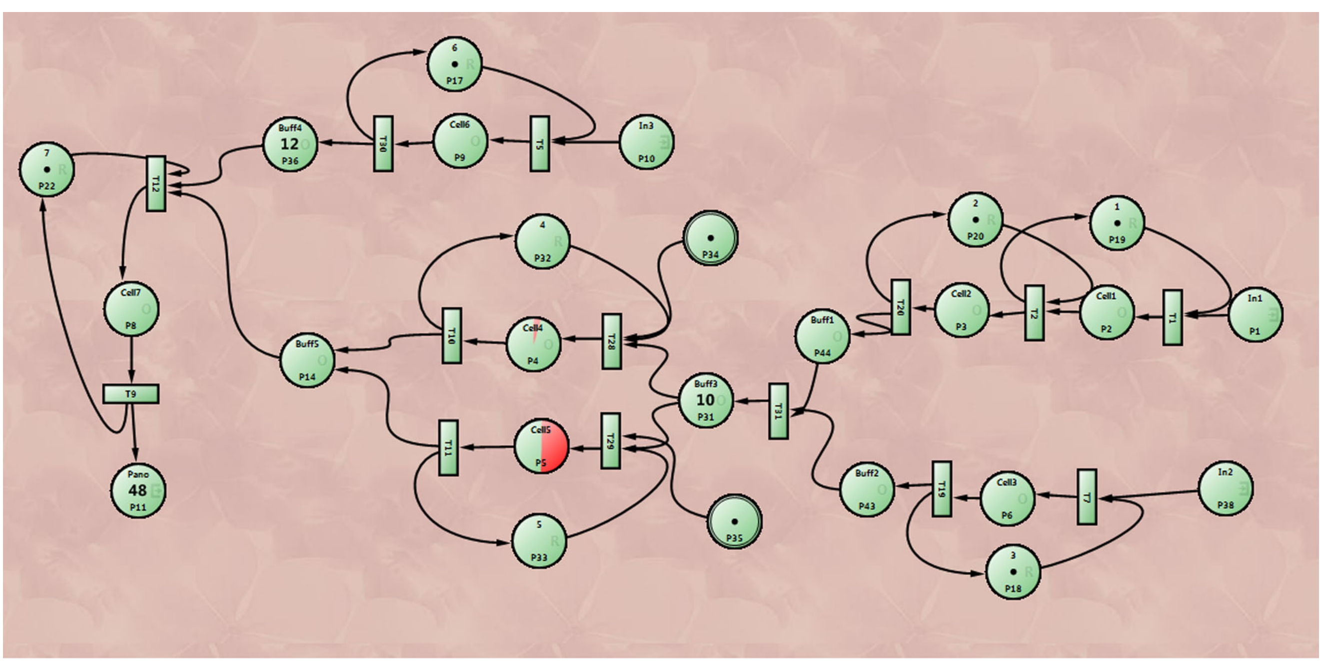


Fig. 3 Petri nets of the current EB station

Table 4 Details of places in the Petri net model of the current system

Place name	Notation	Place definition	Type of place	Place name	Notation	Place definition	Type of place
Cell 1	P2	Install power on base	Operation	Buffer 3	P31	Buffer for base with cables	Operation
Cell 2	P3	Install fan on base	Operation	Buffer 4	P14	Buffer for a WIP	Operation
Cell 3	P6	Sort cables	Operation	Buffer 5	P36	Buffer for a WIP	Operation
Cell 4/ Cell 5	P4/P5	Install cables to base	Operation	Resource 1	P19	Resources/tools for cell 1	Resource availability
Cell 6	P9	Install switches to cover	Operation	Resource 2	P20	Resources/tools for cell 2	Resource availability
Cell 7	P8	Final assembly process	Operation	Resource 3	P18	Resources/tools for cell 3	Resource availability
Input 1	P1	Storage for plate of the base	Input	Resource 4	P32	Resources/tools for cell 4	Resource availability
Input 2	P7	Storage for cables	Input	Resource 5	P33	Resources/tools for cell 5	Resource availability
Input 3	P10	Storage for plate of the cover	Input	Resource 6	P17	Resources/tools for cell 6	Resource availability
Output	P11	Storage for final product	Output	Resource 7	P22	Resources/tools for cell 7	Resource availability
Buffer 1	P27	Buffer for base	Operation	Control 4	P34	Decision point for cell 4	Control
Buffer 2	P28	Buffer for cables	Operation	Control 5	P35	Decision point for cell 5	Control

In the proposed EB station, all stocks of the cells are detached to cell 3 and the components required at cell 1, cell 2, cell 4/cell 5, and cell 7 are loaded to the kit at cell 3. This obviously provides a decrease in the operation time at these cells whereas an increase at cell 3 is realized. The Petri nets of the proposed EB station with kitting are presented in Fig. 4. In this model, all details of the places are the same as presented in Table 4 except with an additional input place (P7) presenting the components of the kit.

The Petri nets of the current and the proposed EB stations are run using the process time of the product 1 for which the individual processing times are available and the total simulation time is 29,700 s which correspond to the total daily working time of the operators at the EB station.

Figure 5 demonstrates the operational performance of the cells of the current and proposed EB station with kitting and presents the occupancy of the cells by the tokens over time.

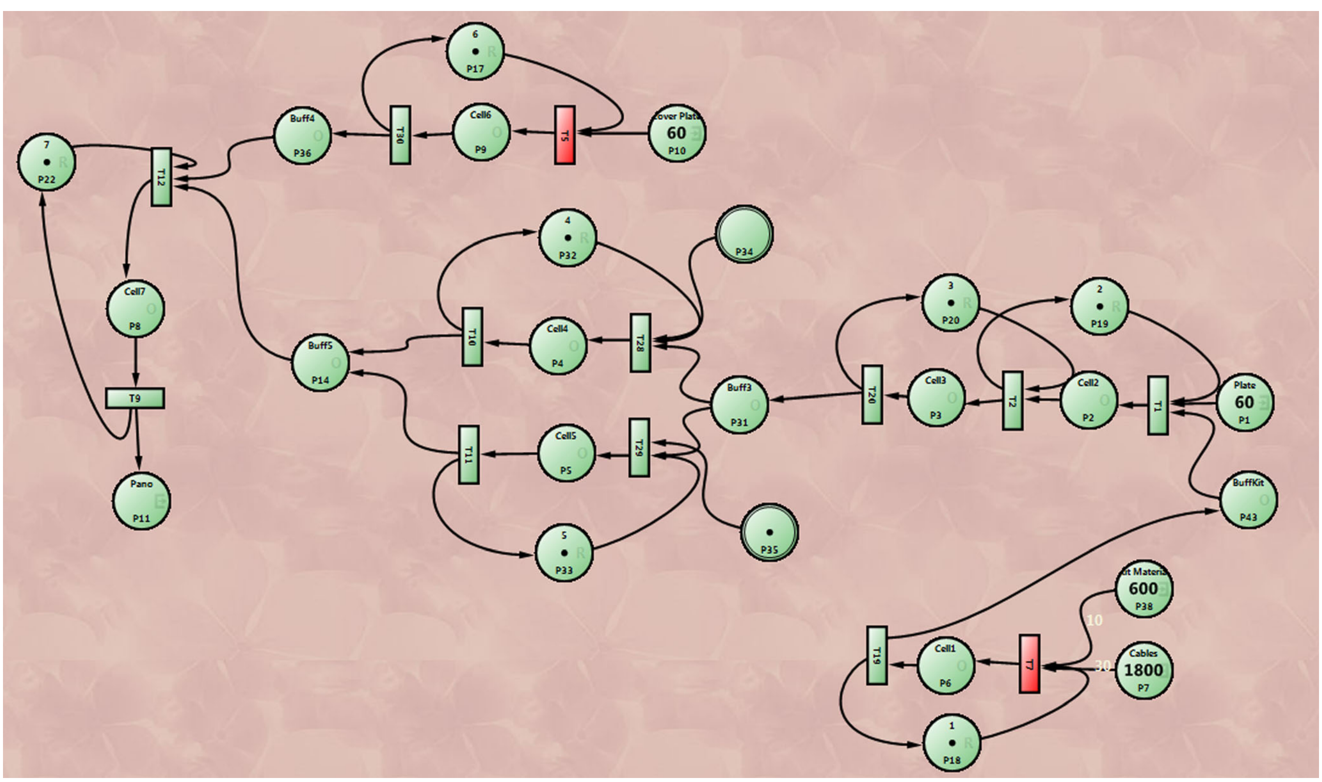


Fig. 4 Petri net model of the proposed EB station with kitting

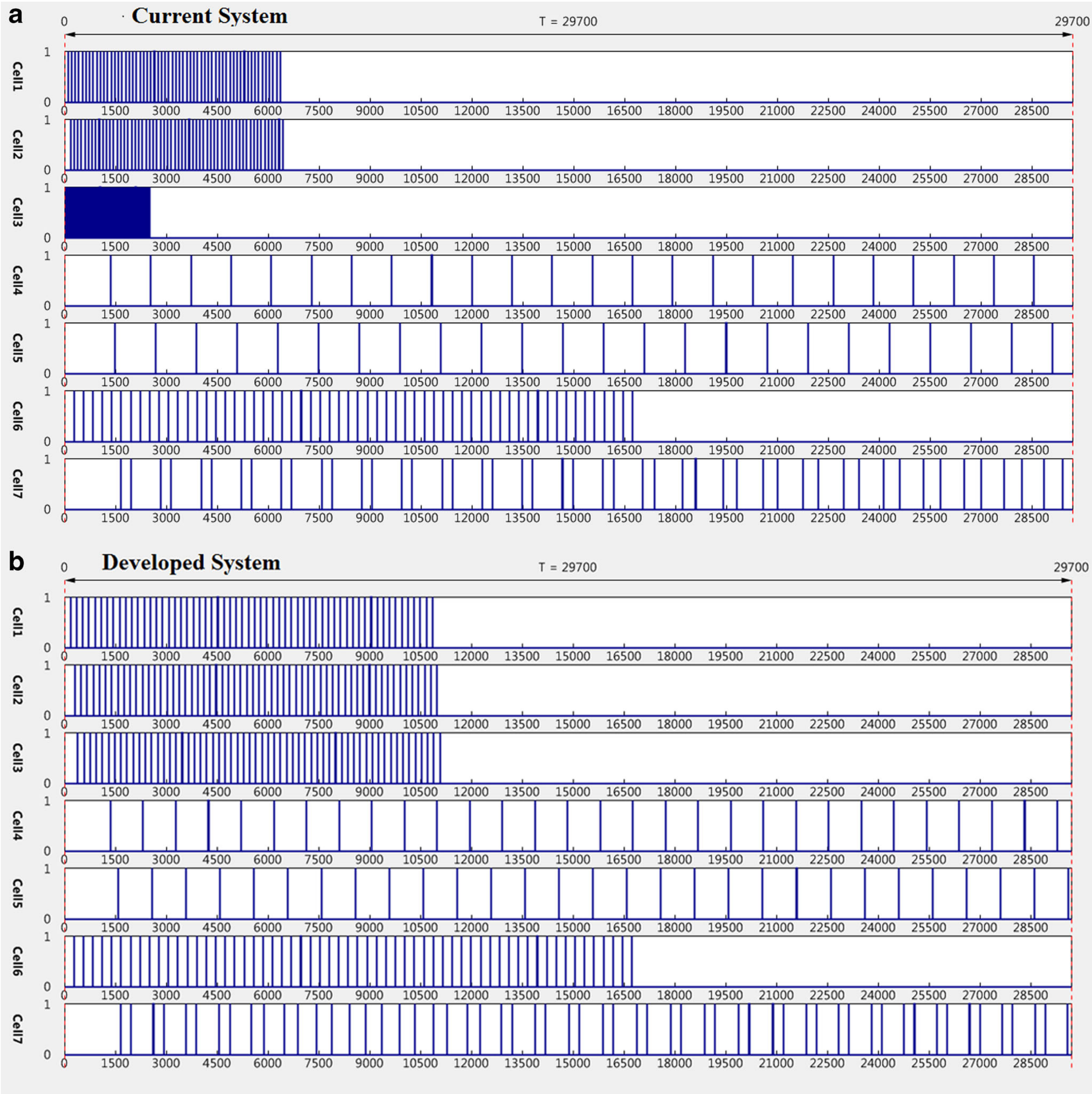


Fig. 5 Performance of the cells of the current and developed EB station with kitting

In the current EB station, cells 1–3 and cell 6 finalize their jobs after 6700th, 6700th, 1700th, and 16800th seconds in the day whereas the other cells work throughout the whole day. In the proposed EB station with kitting, some of the initial operations of cells 4 and 5 were shifted to cells 1 and 2 and hence, the time for finalization of jobs at cells 1 and 2 on the day increased to 11,000 s. In the current EB station, this allocation was not possible since operations were already engaged to the components. The occupancy at cell 6 is the same in the proposed EB station since the component size of this cell is already big and hence, it is not possible to use kitting.

The operation of the input places for the current and proposed EB stations is presented in Fig. 6. The raw material in inputs 1, 2, and 3 decreases in a piecewise linear fashion until 6500th, 1700th, and 16400th seconds, respectively. Thereafter, the token values are always zero, indicating that there is no raw material in inventory. The analysis of the output indicates that the first EB is produced in the 1800th second and after that, the number of produced EBs increase in a piecewise linear way whereas the end of the day production quantity reaches 59 boards. From the historical data of the XYZ Corporation, it was observed that daily achieved production amount of product

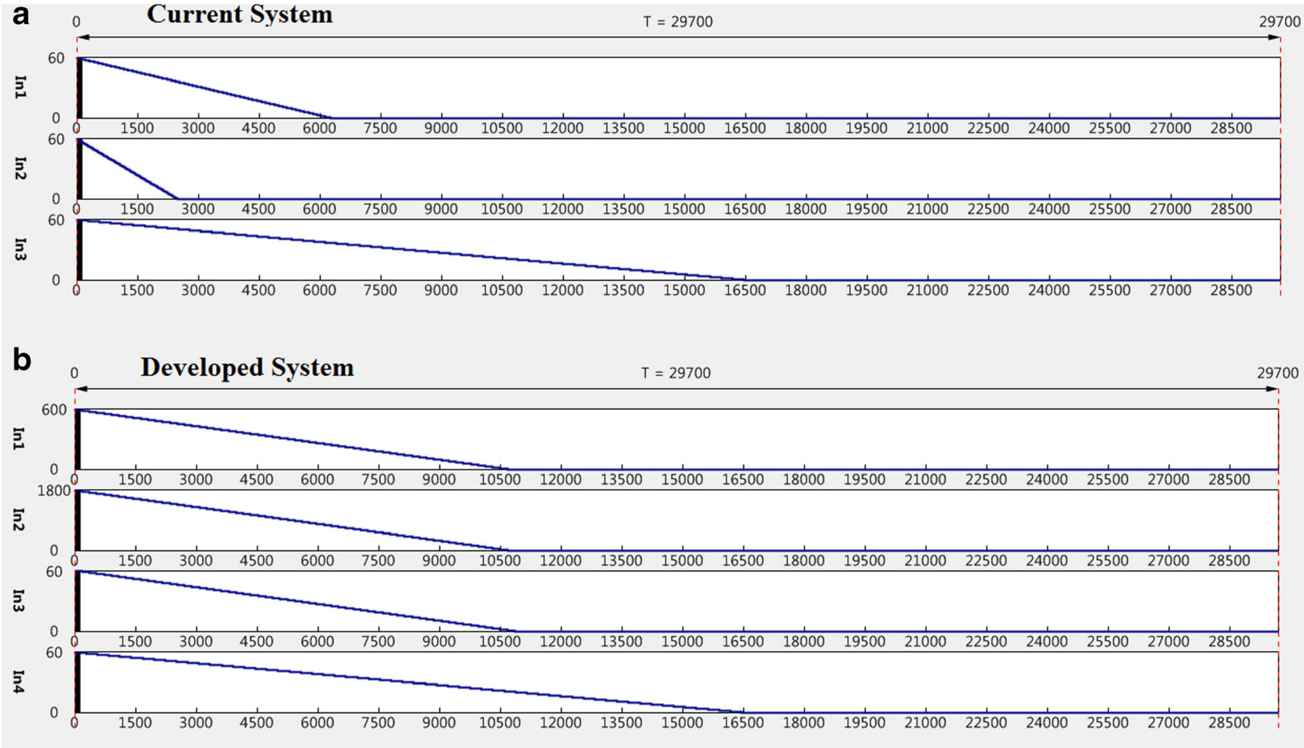


Fig. 6 Performance of the input places of the current and proposed EB station with kitting

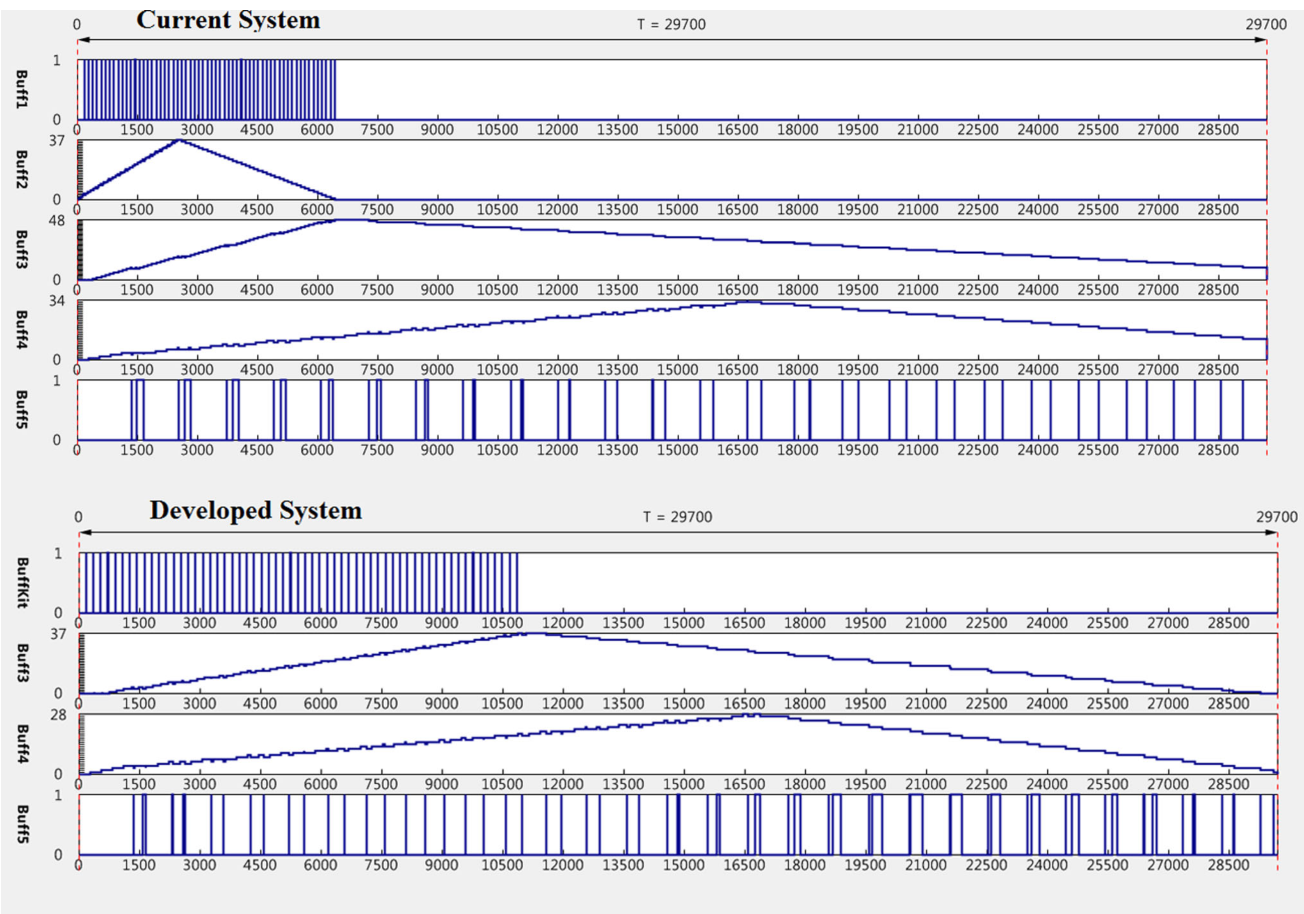


Fig. 7 Performance of the buffers of the current and proposed EB station with kitting

Table 5 Comparison of cells under the current and proposed EB station with kitting

Cell name	Average throughput rate (parts/day)		Average repeatability (%)	
	Current system	Proposed system	Current system	Proposed system
Cell 1	97.53	76.65	22.2	56.1
Cell 2	102.53	77.65	13.3	57.2
Cell 3	149.45	79.62	5.9	61.2
Cell 4	29.95	35.95	99.2	68.5
Cell 5	30.23	35.88	97.5	67.5
Cell 6	74.56	74.52	56.0	56.0
Cell 7	72.32	73.25	59.4	68.7

1 is only 50 and hence, the company deviates by approximately 20% from their plans. In the proposed EB station, no change is observed for input 3. Since the kitting system increases the raw material feed speed from 6500 to 10,500 in input 1 and input 2, the proposed EB station is more reconfigurable for order changes and WIP is lower than the current EB station. The output in the proposed EB station indicates that the first EB is produced before 1800th second and increasing in a piecewise linear fashion, the production quantity reaches 74 boards at the end of the day.

Figure 7 presents the performance of the buffers of the current and proposed EB station. If the value becomes 1 instantaneously and zero immediately after (buffer 1 and 5 in the current, buffer 5 and kit buffer in the proposed EB station), the intermediate part or WIP will never wait at that station. In the current EB station, buffer 2 and 3 require high capacities of 44 and 46, respectively. In the proposed EB station, buffer 2 is not required and the capacity of buffer 3 significantly decreased. A significant difference in the capacity of buffer 4 was not observed.

In addition to the above comparison, the current and proposed EB stations were also compared through the average lead time of product 1, average throughput rate, and average repeatability of the cells. As presented in Table 5, in current EB station, cell 1, cell 2, and cell 3 have low; cell 6 and cell 7 have moderate; and cell 4 and cell 5 have very high average repeatability and this obviously indicates that the workload in the EB station is not well distributed evenly among the cells and the average repeatability of the cells is calculated as 50.5%. On the other hand, the average repeatability of the cells in the proposed EB station with kitting is much closer to each other. This highlights the workload and is well distributed evenly among the cells. Additionally, the average repeatability of the cells increases up to 62.17%.

Finally, the current and the proposed EB station were compared through the model for all three overall performance measures. As presented in Table 6, the proposed EB station with kitting system provides a lower average lead time and average repeatability whereas the average throughput rate is higher. Therefore, it is anticipated that XYZ Corporation would benefit from implementing the kitting system.

3.6 Estimation of the performance of the switchgears assembly line using kitting feeding method

The anticipated performance (i.e., lower average lead time and average repeatability and a higher throughput rate) for EB station indicates that switchgear assembly line might get benefits from employing kitting feeding method on EB station. In switchgear assembly line simulation, the processing time for "as is" EB station are given randomly according to the empirical data. However, the processing time of the "to be" model is obtained empirically as 305 s for product 1. Therefore, the processing times of the "to be" model for all the products must be estimated. In order to estimate the average processing time, the learning curve is utilized since the manufacturing system deals with highly repetitive tasks and the cumulative average (CA) version of the learning curve is used to estimate the processing time on proposed EB station [35, 36].

Let A_n be the average time required to produce the first n units where A_1 refers to the time to produce the first unit. Then, denoting the slope of the curve by b, the CA version of the learning curve states that $A_n = A_1 n^b$. To estimate the factors A_1 and b from the available data presented in Table 1, it is assumed that the learning proceeds at the same rate for all these products and the processing times to produce the first unit of these products are the same. Using a logarithmic transformation for the CA version and performing a simple linear regression, the estimators of A_1 and b were significantly found to be 2945.400 s and −0.2590, respectively, with an R^2 value of 0.782. Hence, the learning curve function for the current manufacturing system can be expressed as$A_n = 2945.4n^{-0.2590}$. Similar method is used to predict the average processing time of products on the

Table 6 Comparison of the current and proposed EB station with kitting

System	Average lead time (minutes)	Average throughput rate (parts/day)	Average repeatability (%)
Current	11.83	54.49	67.31
Proposed (with kitting)	10.22	67.32	49.31

proposed EB station. It is assumed that the average processing time of product 1 (i.e., 305 s) on proposed EB station is obtained for a production quantity of the yearly demand. In addition, it is assumed that the time required to produce the first unit of the standard products in proposed EB station (i.e., A_1 = 2945.400) to be the same as the current EB station. Based on these assumptions, the slope of the learning curve with kitting is calculated as $b = -0.2906$ indicating that the CA learning curve for the proposed system with kitting is $A_n = 2945.4n^{-0.2906}$. When compared with the CA learning curve model of the current system, since the absolute value of the b factor is larger in the proposed system—indicating a faster learning rate—it seems that the kitting will help us more as we produce more and more units. The comparison of the CA learning curves for the current and proposed system is illustrated in Fig. 8. Table 7 shows the estimated processing times for the proposed EB station.

The estimated processing time for EB station is used for simulating the Petri nets of switchgear assembly line. For constructing same status in assembly line the randomly generated products order used on “as is” model is used on “to be” model. “To be” model is run for 700 days as the warm-up period and additionally ten times 7000 days as the steady-state period to estimate the average lead time, average throughput rate, and average repeatability. The results obtained from “to be” model were verified with the results of “as is” model. The results of the Petri net simulation are summarized in Table 8.

Comparing the results in Tables 3 and 8, only the performance measures of EB station, 36 and 37 stations have changed significantly, as expected. A significant decrease in the average repeatability of the EB station has been observed resulting in a significant increase in the average throughput rate. Due to the higher average throughput rate of the EB station, the average input rates for the stations 36 and 37 following the EB stations increase by kitting and hence the average repeatability of these stations and average throughput rate both increase significantly. In conclusion, the performance of the EB station whose performance was not satisfactory is expected to get better by the implementation of the kitting as a feeding method. Additionally, the average throughput rate of subsequent stations is also expected to increase having the resources more utilized.

Table 7 Estimated processing time for the proposed EB station

Product type	Processing time (seconds)	Product	Processing time (seconds)
Product 1	305	Product 13	476
Product 2	329	Product 14	484
Product 3	343	Product 15	488
Product 4	410	Product 16	497
Product 5	419	Product 17	516
Product 6	423	Product 18	527
Product 7	433	Product 19	527
Product 8	433	Product 20	536
Product 9	454	Product 21	559
Product 10	459	Product 22	562
Product 11	464	Product 23	576
Product 12	471	Product 24	593

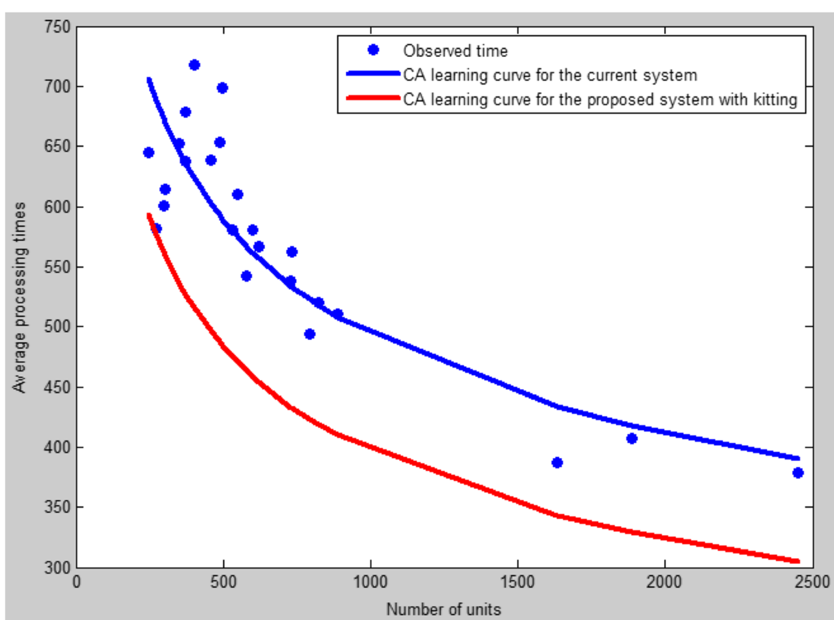


Fig. 8 Comparison of learning curves for current and proposed system with kitting

Table 8 Performance measures of stations in switchgear assembly line with EB station using kitting

Station name	Average throughput rate (parts/day)	Average repeatability (%)	Station name	Average throughput rate (parts/day)	Average repeatability (%)
11	69.86	40.28	31	67.20	41.25
12	67.59	45.82	32	64.40	43.85
13	63.49	43.75	33	66.39	46.65
14	74.31	33.60	34	67.38	40.85
21	69.75	58.91	35	68.65	43.80
22	68.84	40.58	36	69.52	49.35
23	69.16	43.85	37	74.21	45.98
24	65.32	40.52	EB	63.35	56.21
25	67.91	46.38	38	66.68	47.35
26	68.60	47.08			

4 Conclusion

In this study, we provide the use of Petri nets in order to anticipate possible advantage of kitting feeding method in an assembly line using a case in Turkey. In particular, the Petri nets have been developed through the integration of the resource-oriented and process-oriented methods and a detailed quantitative analysis of the current manufacturing system has been performed. The problems of the case company on switch gear assembly line observed after some investigations, since it was very important to quantify the problems and found specific performance measures. Petri nets are used as tool for quantitative analysis the assembly line, which is a usually ignored application area in the literature. Upon the detailed analyses of the results, kitting feeding method was suggested as a feeding method at a manual station whose performance was not satisfactory. In order to foresee the advantage of the kitting method, the Petri nets of the station (i.e., EB station) were also developed. The simulation results indicated that the proposed system with kitting performs better than the current system with a pronounced difference at the particular EB and subsequent stations and it is anticipated that the switchgear assembly line will benefit from implementing the kitting system. The effect of the random processing times on the performance of a manufacturing system with kitting feeding method still needs further analysis.

Acknowledgements The authors would like to thank Erkay Özbek and Barış Karakaş who did a part of this study as their graduation project.

References

1. Barenji RV, Barenji AV, Hashemipour M (2014) A multi-agent RFID-enabled distributed control system for a flexible manufacturing shop. Int J Adv Manuf Technol 71(9–12):1773–1791
2. Brynzer H, Johansson MI (1995) Design and performance of kitting and order picking systems. Int J Prod Econ 41:115–125
3. Fathi M, Rodriguez V, Alvarez MJ (2014) A novel memetic ant colony optimization-based heuristic algorithm for solving the assembly line part feeding problem. Int J Adv Manuf Technol 75:629–643
4. Faccio M (2014) The impact of production mix variations and models varieties on the parts-feeding policy selection in a JIT assembly system. Int J Adv Manuf Technol 75:543–560
5. Sali M, Sahin E, Patchong A (2015) An empirical assessment of the performances of three line feeding modes used in the automotive sector: line stocking vs. kitting vs. sequencing. Int J Prod Res 53:1439–1459
6. Sali M, Sahin E (2016) Line feeding optimization for just in time assembly lines: an application to the automotive industry. Int J Prod Econ 174:54–67
7. Hanson R, Brolin A (2013) A comparison of kitting and continuous supply in in-plant materials supply. Int J Prod Res 51:979–992. doi:10.1080/00207543.2012.657806
8. Barenji AV, Barenji RV, Roudi D, & Hashemipour M (2016) A dynamic multi-agent-based scheduling approach for SMEs. The International Journal of Advanced Manufacturing Technology, 1–15
9. Salmi A, David P, Summers JD, Blanco E (2014) A modelling language for assembly sequences representation, scheduling and analyses. Int J Prod Res 52(13):3986–4006. doi:10.1080/00207543.2014.916432
10. Zhang W, Freiheit T, Yang H (2005) Dynamic scheduling in flexible assembly system based on timed Petri nets model. Robot Comput Integr Manuf 21:550–558
11. Moore KE, Gupta SM (1996) Petri net models of flexible and automated manufacturing systems: a survey. Int J Prod Res 34:3001–3035
12. Zurawski R, Zhou MC (1994) Petri nets and industrial applications—a tutorial. IEEE Trans Ind Electron 41:567–583
13. Barenji AV, Barenji RV, Hashemipour M (2016) Flexible testing platform for employment of RFID-enabled multi-agent system on flexible assembly line. Adv Eng Softw 91:1–11
14. Kilincci O, Bayhan GM (2006) A Petri net approach for simple assembly line balancing problems. International Journal of Advanced Manufacturing Technology 30:1165–1173. doi:10.1007/s00170-005-0154-2
15. Kilincci O (2010) A Petri net-based heuristic for simple assembly line balancing problem of type 2. International Journal of Advenced Manufacturing Technology (2010) 46:329–338. doi:10.1007/s00170-009-2082-z.
16. Weigert G, Henlich T, Klemmt A (2011) Modelling and optimisation of assembly processes. Int J Prod Res 49(14):4317–4333. doi:10.1080/00207543.2010.544338

17. Su P, Wu NQ, Yu ZQ (2014) A Petri net-based heuristic for mixed-model assembly line balancing problem of type-E. Int J Prod Res 52:1542–1556. doi:10.1080/00207543.2013.849010
18. Wu N, Zhou MC, Li ZW (2008) Resource-oriented Petri net for deadlock avoidance in flexible assembly systems. IEEE Transactions on Systems, Man and Cybernetics —Part A: Systems and Humans 38:56–69
19. Zhao M, Li Z (2009) On deadlock control for a class of generalized Petri net models of flexible manufacturing systems. Int J Prod Res 47:6085–6107. doi:10.1080/00207540802101945
20. Weigert G, Henlich T (2009) Simulation-based scheduling of assembly operations. Int J Comput Integr Manuf 22:325–333. doi:10.1080/09511920802225914
21. Hsieh FS (2006) Robustness analysis of Petri nets for assembly/disassembly processes with unreliable resources. Automatica 42:1159–1166
22. Hu H, Zhou MC (2015) A Petri net-based discrete-event control of automated manufacturing systems with assembly operations. IEEE Trans Control Syst Technol 23:513–524
23. Hou YF, Zhao M, Liu D (2016) Deadlock control for a class of generalized Petri nets based on proper resource allocation. Asian Journal of Control 18:206–223
24. Bozer YA, McGinnis LF (1992) Kitting versus line stocking—a conceptual framework and a descriptive model. Int J Prod Econ 28:1–19
25. Caputo AC, Pelagagge PM, Salini P (2015) A decision model for selecting parts feeding policies in assembly lines. Industrial Management and Data Systems 115:974–1003
26. Kilic HS, Durmusoglu MB (2015) Advances in assembly line parts feeding policies: a literature review. Assem Autom 35:57–68. doi:10.1108/AA-05-2014-047
27. Hanson R, Medbo L, Medbo P (2012) Assembly station design: a quantitative comparison of the effects of kitting and continuous supply. J Manuf Technol Manag 23:315–327. doi:10.1108/17410381211217399
28. Hua W, Zhou C (2008) Clusters and filling-curve-based storage assignment in a circuit board assembly kitting area. IIE Trans 40:569–585. doi:10.1080/07408170701503462
29. Gunther HO, Gronalt M, Piller F (1996) Component kitting in semi-automated printed circuit board assembly. Int J Prod Econ 43:213–226
30. Christmansson M, Medbo L, Hansson GA, Ohlsson K, Byström JU, Möller T, Forsman M (2002) A case study of a principally new way of materials kitting—an evaluation of time consumption and physical workload. Int J Prod Econ 30:49–65
31. Hanson R, Medbo L, Johansson MI (2015) Order batching and time efficiency in kit preparation. Assem Autom 35:143–148. doi:10.1108/AA-05-2014-046
32. Hanson R, Medbo L (2012) Kitting and time efficiency in manual assembly. Int J Prod Res 50:1115–1125. doi:10.1080/00207543.2011.555786
33. Kilic HS, Durmusoglu MB (2012) Design of kitting system in lean-based assembly lines. Assem Autom 32:226–234
34. Türkiye Elektrik İletim AŞ Genel Müdürlüğü, Planlama ve Stratejik Yönetim Dairesi Başkanlığı (2016) 10 Yıllık Talep Tahminleri Raporu (2017–2026). *http://www.teias.gov.tr/Dosyalar/10YıllıkTalepTahminleriRaporu2016.pdf*
35. Jaber MY (2011) Learning curves: theory, models and applications. CRC Press, Boca Raton
36. Argote L, Epple D (1990) Learning curves in manufacturing. Science 247:920–924