APEM journal
Advances in Production Engineering & Management
Volume 16 | Number 4 | December 2021 | pp 473–484
https://doi.org/10.14743/apem2021.4.414
ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

A comparative study of different pull control strategies in multi-product manufacturing systems using discrete event simulation

Xanthopoulos, A.S.[a,*], **Koulouriotis, D.E.**[b]

[a,b]Department of Production and Management Engineering, Democritus University of Thrace, V. Sofias 12, Xanthi, Greece

ABSTRACT

Pull production control strategies coordinate manufacturing operations based on actual demand. Up to now, relevant publications mostly examine manufacturing systems that produce a single type of a product. In this research, we examine the CONWIP, Base Stock, and CONWIP/Kanban Hybrid pull strategies in multi-product manufacturing systems. In a multi-product manufacturing system, several types of products are manufactured by utilizing the same resources. We develop queueing network models of multi-stage, multi-product manufacturing systems operating under the three aforementioned pull control strategies. Simulation models of the alternative production systems are implemented using an open-source software. A comparative evaluation of CONWIP, Base Stock and CONWIP/Kanban Hybrid in multi-product manufacturing is carried out in a series of simulation experiments with varying demand arrival rates, setup times and control parameters. The control strategies are compared based on average wait time of backordered demand, average finished products inventories, and average length of backorders queues. The Base Stock strategy excels when the manufacturing system is subjected to high demand arrival rates. The CONWIP strategy produced consistently the highest level of finished goods inventories. The CONWIP/Kanban Hybrid strategy is significantly affected by the workload that is imposed on the system.

ARTICLE INFO

Keywords:
Discrete event simulation (DES);
Open-source software;
JaamSim DES software;
Multi-product manufacturing;
Multi-stage production systems;
Pull-type production control strategies

**Corresponding author:*
axanthop@pme.duth.gr
(Xanthopoulos, A.S.)

Article history:
Received 17 September 2021
Revised 30 November 2021
Accepted 3 December 2021

1. Introduction

According to a common definition of pull-type production control, a pull system is one in which production operations are coordinated based on actual demand occurrences and not on advance demand information or forecasts [1]. In a pull system production, operations are triggered by the arrival of demands for finished goods. Whereas in a push system production is scheduled based on forecasts of demand for goods, i.e. production operations are launched before the actual demand arrival. An excellent review of pull control methods and critical comparisons with alternative production control paradigms is given in [2].

Numerous pull control strategies (or policies) have been proposed in the relevant literature and a considerable number of papers have been devoted to the modeling, evaluation and comparison of alternative pull systems.

The reader is referred to [3] and Xanthopoulos and [4] for some indicative examples. A relatively recent trend in this research field pertains to the study of adaptive, pull control policies, i.e. production control mechanisms that adapt to the current state of the demand and/or production processes [5].

Pull production control policies have been mostly studied in the context of single product type systems up to now. In recent years, a new research direction has emerged that examines multi-product systems [6, 7]. This paper advances the research on multi-product pull systems by examining the CONWIP, Base Stock and CONWIP/Kanban Hybrid strategies. The aforementioned systems are modeled as queueing network models with synchronization stations [4]. The models of the alternative manufacturing systems are implemented in the simulation software JaamSim [8]. The behavior of the examined control systems is studied in a series of simulation experiments.

The remainder of this paper is structured as follows. Section 2 contains a summary of relevant scholarly publications. The examined manufacturing system model is presented in section 3 together with the queueing network representations of the multi-product CONWIP, Base Stock and CONWIP/Kanban Hybrid systems. Section 4 contains the results of the simulation experiments together with their analysis. Finally, the paper is concluded in section 5, where some directions for future research are also provided.

2. Related work and contribution of research

In this section we offer a brief literature review of the most relevant published research to this article. Existing works on pull control strategies for systems that produce more than on part type can be classified based on the size of the underlying manufacturing system.

Single stage systems are studied in [9] and [10]. Multi-stage systems (typically consisting of 3 to 5 stages) are examined in the majority of relevant works [11-15]. A rather special case is the work of Krieg and Kuhn [16] who study a two-stage system analytically, i.e. by means of decomposition-based mathematical approximation methods.

With the exception of Krieg and Kuhn [16] who use the formalism of continuous-time Markov chains, the overwhelming majority of publications on multi-product, pull type production control systems uses simulation to model and analyze the manufacturing systems in question. Indicative software that are frequently employed for these purposes are Arena and ExtendSim (e.g. refer to [10] and [11]).

The relevant papers address either idealized, “synthetic” manufacturing systems [16, 9] or systems inspired by real-world applications. Case studies pertaining to the automotive industry are studied in [13] and [10]. Other, indicative, case studies are related to manufacturers of health-care products [12], drug process plants [11] and gear manufacturers [15].

Even though numerous pull production control strategies have been proposed in the literature, papers that focus on multi-product systems often address only a subset of them. For example, only the Kanban control approach is examined in [11], [16] and [9]. Existing comparative evaluations of alternative pull control policies typically involve two or three approaches (e.g. CONWIP, Kanban and Extended Kanban are compared in [15], Base Stock, Kanban and Extended Kanban are compared in [10] etc.). A noticeable exception is the work of Olaitan and Geraghty [12] where five alternative policies are compared (Kanban, CONWIP, Base Stock, Extended Kanban, Generalized Kanban).

Finally, and apart from the aforementioned categorizations, relevant published works are further differentiated in terms of several other features such as the existence of setups in the manufacturing system model, the performance metrics considered, and so forth.

The novelty and primary contribution of this research is the following:

- the queueing network models for the multi-stage, multi-product CONWIP, Base Stock and CONWIP/Kanban systems are developed,
- the alternative production control mechanisms are compared in a series of simulation experiments under the metrics of average number of backorders, average finished product inventories and average waiting time of backordered demand,

- insights on the behavior of the different pull production control methods are gained as well as the related managerial implications.

3. System description and production control policies

The system under investigation is comprised of several stages in tandem and manufactures a number of product types. In the remainder of this section, *i* and *j* will be used to denote an arbitrary production stage and product type, respectively.

Raw materials enter the system and are processed in all production stages starting from the first one and moving to the downstream stage. Finished products of type *j* are outputted by the last stage and stored in the respective finished goods inventory. Raw materials are assumed to be continuously available, i.e. the raw materials buffers are never empty. Demands for finished products arrive dynamically to the system and the times between successive demand arrivals are stochastic. Upon a demand arrival, one unit of type *j* product is requested instantly. If there are available finished products of type *j*, then the demand is satisfied immediately. If not, then the demand enters the, type *j*, backorders queue and waits until inventory is made available.

All production stages have a manufacturing facility that is composed of a single machine (with stochastic service times) and the associated input queue. A machine can process all product types; it processes products one-by-one and undergoes a setup when switching from one type to another. A type *j* product that completes its processing in the *i*-th stage is stored in output buffer *i,j*.

The flow of materials from one production stage to the next is coordinated by a pull-type production control policy. In broad terms, a production control policy determines when stage *i* should pull a type *j* part from the upstream output buffer in order to process it. In this paper, we examine the CONWIP, Base Stock and CONWIP/Kanban Hybrid policies for multi-product manufacturing. We develop the queueing network models of the respective systems in the following three sub-sections.

3.1 Multi-product CONWIP system

Fig. 1 shows a two-stage, two-product type CONWIP system (due to space limitations). Note that the properties of the CONWIP system presented here hold for any number of product types and production stages.

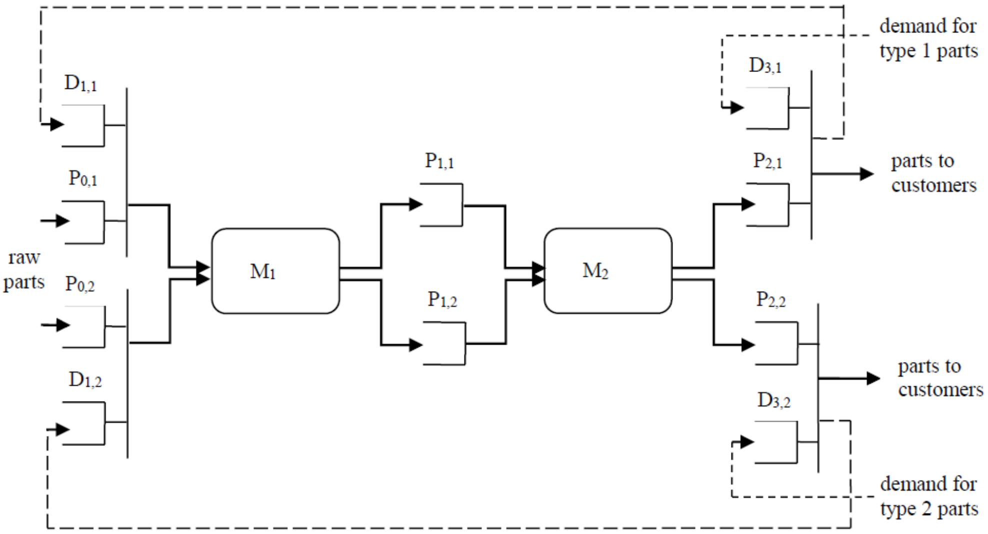

Fig. 1 A CONWIP system with two stages and two product types

In Fig. 1, M_i is the i-th manufacturing facility and $P_{0,j}$ is the raw materials buffer for product type j. The output buffer of stage i and type j is denoted as queue $P_{i,j}$ and queue $D_{3,j}$ contains demands for type j finished products. Finally, queue $D_{1,j}$ contains demands for stage – 1 products of type j. The discipline of all queues shown in Fig. 1 is First-Come-First-Served.

Initially, i.e. at time 0, all machines are idling and all queues are empty except $P_{0,j}$ (by definition) and $P_{i,j}$, for all i, j. At time 0, queue $P_{i,j}$ contains $S_{i,j}$ parts, where $S_{i,j}$ is the base stock (initial inventory) of stage-i and part-j products. The integers $S_{i,j}$, for all i,j, are the control parameters that characterize a multi-product CONWIP system. The sum of the $S_{i,j}$ parameters equals the constant number of parts that "circulate" in the manufacturing system.

The control logic of the CONWIP policy is the following. All stages except the first one are constantly authorized to produce. Consequently, it can be argued that production stages 2, 3, … operate according to a push strategy. The first stage receives an authorization to process a new type-j part at the moment when a type-j finished product exits output buffer $D_{3,j}$ (transmission of information is assumed to be instantaneous).

3.2 Multi-product Base Stock system

Fig. 2 depicts a two-stage Base Stock system that manufactures two product types. It is noted that the control logic of Base Stock, as explained in this sub-section, can be straightforwardly extended to a system with an arbitrary number of stages and products.

In Fig. 2, M_i denotes the i-th manufacturing facility and $P_{0,j}$ symbolizes the raw materials inventory for product type j. Queue $P_{i,j}$ contains stage-i completed parts of type j. $D_{i,j}$ contains demands for type-j parts; e.g. an element of queue $D_{3,j}$ is a demand for a finished product of type j and an element of queue $D_{2,j}$ authorizes the production of a new stage-2 part of type j. All queues shown in Fig. 2 operate according to the First-Come-First-Served rule.

At time 0, all machines are idle and all queues are empty with the exception of $P_{0,j}$ and $P_{i,j}$, for all i,j. It is reiterated that an infinite supply of raw materials is assumed. Initially, queue $P_{i,j}$ contains $S_{i,j}$ parts. Similarly to CONWIP, the base stocks $S_{i,j}$, for all i,j, are the only control parameters of a multi-product Base Stock system. However, in a Base Stock system, there are no limits on the Work-In-Process and finished goods inventory levels.

The Base Stock system operates as follows. At the time when a demand for a type-j finished product arrives to the system, an analogous demand is transmitted to all queues $D_{i,j}$ authorizing the production of a new type-j, stage-i part, for all i. This way, the production of a new part can commence even if no finished goods inventory has been consumed, allowing for increased flexibility in following demand fluctuations.

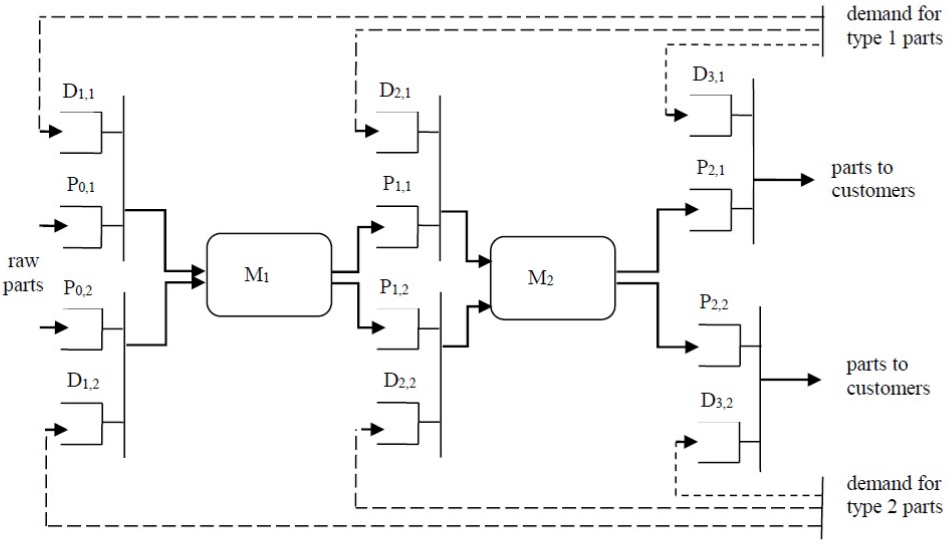

Fig. 2 A Base Stock system with two stages and two product types

3.3 Multi-product CONWIP/Kanban Hybrid system

The queueing network model of a two-stage, two-product CONWIP/Kanban Hybrid system is shown in Fig. 3. It is noted that the mechanics of this control policy, as illustrated in Fig. 3, also apply to systems with any number of stages and product types.

M_i symbolizes the manufacturing facility i and $P_{0,j}$ is the raw parts buffer for type j, in Fig. 3. Queue $PA_{i,j}$ contains stage-i, type-j completed parts with kanbans (production authorizations) attached on them. Queue $P_{2,j}$ has finished products of type j and queue $D_{3,j}$ contains demands for such products. CONWIP-type demands are held in queues D_1 and D_2. Finally, queues $DA_{1,j}$ contain kanban/demand pairs for stage-1 parts of type j. The discipline of all queues in Fig. 3 is First-Come-First-Served.

Initially, all machines are idling and all queues are empty except for the raw parts buffers, which are always non-empty by definition, and queues $PA_{1,j}$ and $P_{2,j}$, for all j. The latter contain $K_{1,j}$ and $S_{2,j}$ parts, respectively. The number of stage-1, type-j kanbans $K_{1,j}$ and the base stocks $S_{2,j}$ are the control parameters of the system shown in Fig. 3.

The CONWIP/Kanban Hybrid system operates as follows. The last stage has a perpetual authorization to produce, similarly to the pure CONWIP policy. At the time when a type-j finished product is delivered to a customer, a relevant demand is sent to queue D_j at the beginning of manufacturing line. The first stage is authorized to produce a new type-j part if there is at least one element in each of the D_j and $DA_{1,j}$ queues. All other stages operate under a Kanban control policy (for additional details refer to [3]). The rationale behind the philosophy of the CONWIP/Kanban Hybrid policy is to combine the swift turnaround of the CONWIP system with the tight coordination between production stages offered by Kanban.

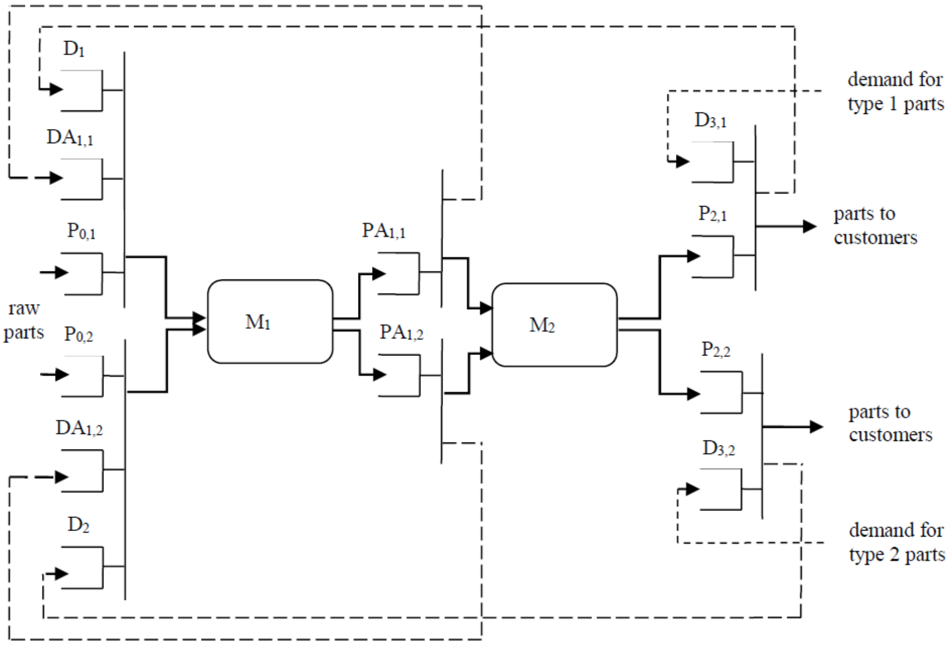

Fig. 3 A CONWIP/Kanban Hybrid system with two stages and two product types

4. Experimental results and discussion

The investigated control policies were compared in a series of simulation experiments that pertained to a manufacturing system with five stages and two product types. The simulation models that were developed for the purposes of this study can straightforwardly be extended to accommodate additional stages and/or product types. Nevertheless, this would increase substantially the effort for presenting/interpreting the results without necessarily providing additional insights on the behavior of the manufacturing systems. The implementation of the simulation models is outlined in the following section 4.1

4.1 Implementation of simulation models

All simulation models are built using the discrete event simulation [17-19] software JaamSim [8]. JaamSim is open-source and offers an intuitive GUI for building complex discrete event models with 3D graphics and animation as well as high execution speed of simulation experiments. These are some indicatives reasons that resulted in the growing adoption of the JaamSim software by the community of simulation practitioners and researchers in recent years [20].

Indicatively, the 2D simulation models of the Base Stock, and CONWIP/Kanban hybrid systems with five production stages and two product types are shown in Figs. 4-5. Note that, due to the complexity of the models, their finest details cannot be displayed accurately. Figs. 4-5 are intended to give an overall impression of the structure of the simulation models in question.

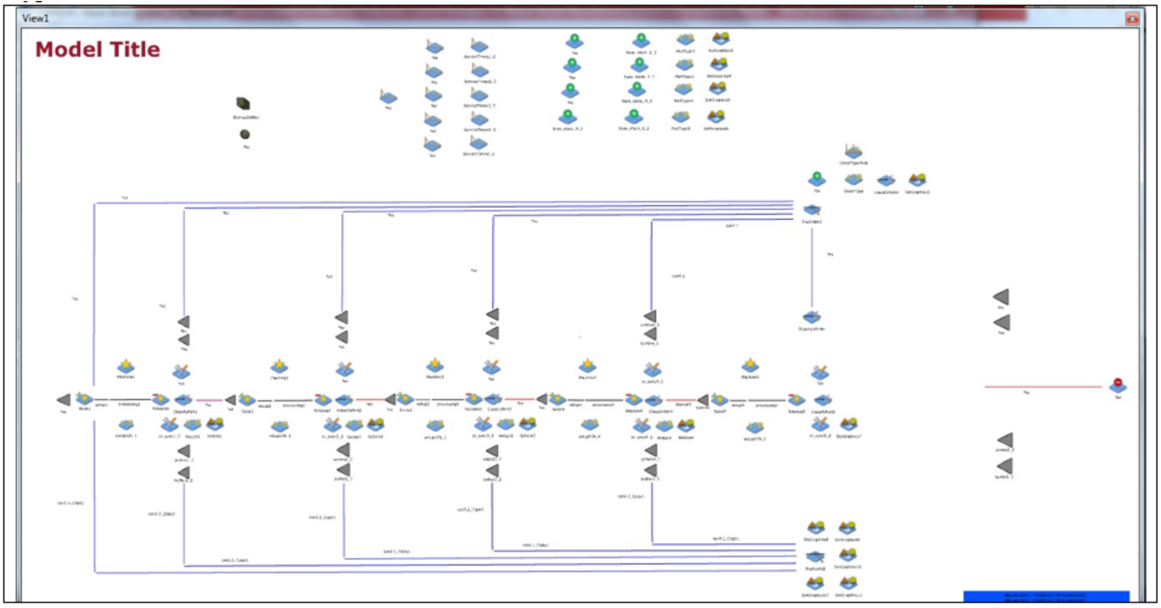

Fig. 4 JaamSim simulation model of Base Stock system with five production stages and two product types

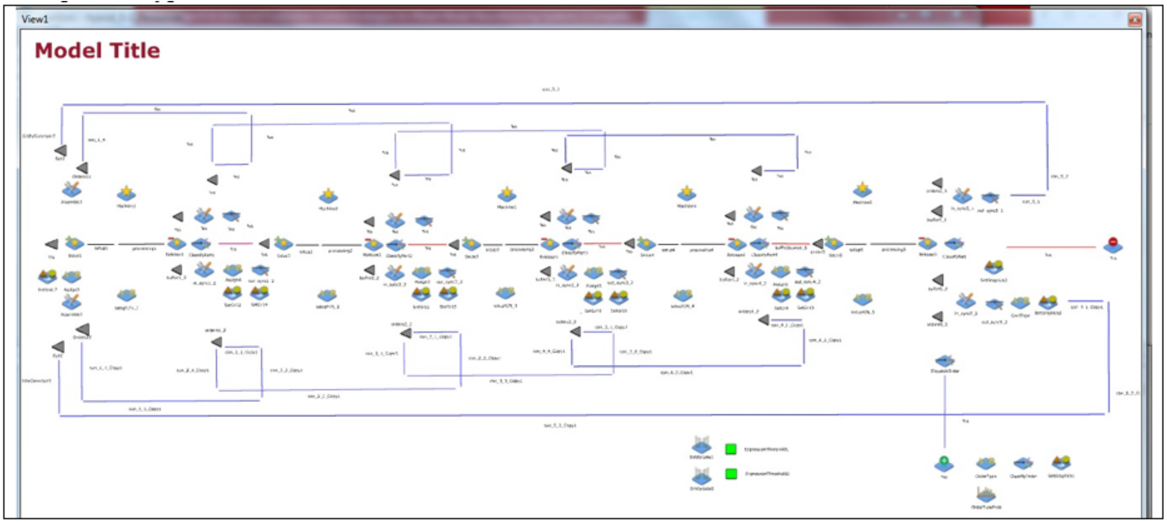

Fig. 5 Simulation model of CONWIP/Kanban Hybrid system with five production stages and two product types

4.2 Configuration of simulation experiments

We defined a base simulation case as the starting point of our analysis and then varied i) the average time between arrivals, ii) the setup time for switching from one product type to another, and iii) the policies' control parameters, in order to study the behavior of the alternative control mechanisms.

The base simulation case is defined as follows: times between arrivals are exponentially distributed with mean 1.26 time units. Upon a demand arrival, a type 1 (or type 2) finished product is requested with probability 0.5. The service times of all machines are exponential with mean 0.8 and 1.2 for type 1 and type 2 products, respectively. When a machine switches from one part type to another, a setup with duration 0.25 time units is incurred. The control parameters (i.e. base stocks and/or kanbans) for all policies, stages and products are set to the value of 5. For all simulation models, the length of a replication is set to 10000 time units and the number of independent replications for all models is 20.

In all simulation experiments we monitored the i) average finished product inventories, ii) the average number of backorders and iii) the average waiting time of backordered demands for each product type. The experimental results are presented in Figs. 6-8.

4.3 Comparing performance metrics of different product types

It is observed from Figs. 6-8 that the monitored performance metrics (i.e. average finished product inventory/average number of backorders/average waiting time of backordered demands for product type 1 and 2) do not vary substantially from one product type to another. E.g. for the CONWIP/Kanban Hybrid system with average time between arrivals equal to 1.38 the average finished product inventory is 14.11 and 13.97 for product type 1 and 2, respectively (refer to Fig. 6f).

This can be attributed to the following reasons. First, the incoming demand is “distributed” equally among the two product types (50 % for product type 1 and 50 % for type 2 as mentioned in section 4.2). Secondly, the number of kanbans/base stocks in each manufacturing stage for product type 1 is identical to that of product type 2. Finally, and most importantly, all parts are processed according to the FCFS queue discipline rule in all manufacturing facilities (M_i elements in Figs. 1-3) regardless of their type or required processing time.

The observed differences between the performance metrics for product type 1 and 2 are caused only by the different service times. Recall from section 4.2 that the mean service time of all machines for product type 1 and 2 is 0.8 and 1.2, respectively. As a result, the total processing time of a type 1 product is smaller than that of a type 2 product. Consequently, for all control policies and simulation cases, type 1 demands are serviced more quickly than type 2 demands, and this consistently leads to slightly higher finished product 1 inventories and smaller waiting times/backorders for type 1 (refer to Figs. 6-8).

An important observation that stems from this analysis is that the “sharing” of the production resources (manufacturing facilities) amongst multiple product types does not affect significantly the observed behavior of the various control policies (in contrast to the single product type case and under the aforementioned production system settings). However, this situation would probably change dramatically in the presence of batching or sequencing rules. For example, in our simulation case, the adoption of the SPT (Shortest Processing Time) rule for part sequencing would probably “favor” part 1 types (due to their smaller mean processing time) leading to a significant change in the performance metrics of product type 1 and 2. Nonetheless, this investigation is beyond the scope of this research.

4.4 Varying average arrival rate

Fig. 6 shows the performance metrics of each control policy for average time between arrivals that varies in the range [1.2, 1.38]. It is observed that the average waiting time of pending orders and the average lengths of the backorders queues are increasing functions of the arrival rate. On the contrary, the average finished product inventories are decreasing functions of the demand arrival rate. For relatively low arrival rates, it is observed that the performance of the alternative control policies is practically the same in respect to the average waiting time/number of backorders. However, for relatively high arrival rates the Base Stock (as well as the CONWIP) and the CONWIP/Kanban Hybrid policies are clearly the best and worst performing mechanisms in terms of the two aforementioned performance measures, respectively.

This can be attributed to the following qualitative characteristics of these control policies: the CONWIP/Kanban Hybrid system has a very tight coordination between the various production stages whereas the Base Stock does not coordinate at all production operations at different stages. On the other hand, in a CONWIP system, parts flow without interruptions towards the downstream production stages. Consequently, the Base Stock and the CONWIP systems respond rapidly to demand fluctuations, compared to CONWIP/Kanban Hybrid.

From Figs. 6e and 6f, we observe that the CONWIP system causes the highest levels of finished goods inventories followed by the CONWIP/Kanban Hybrid mechanism. An interesting observation is the relative "insensitivity" of the Base Stock system regarding this performance metric and in relation to changes in the average time between arrivals.

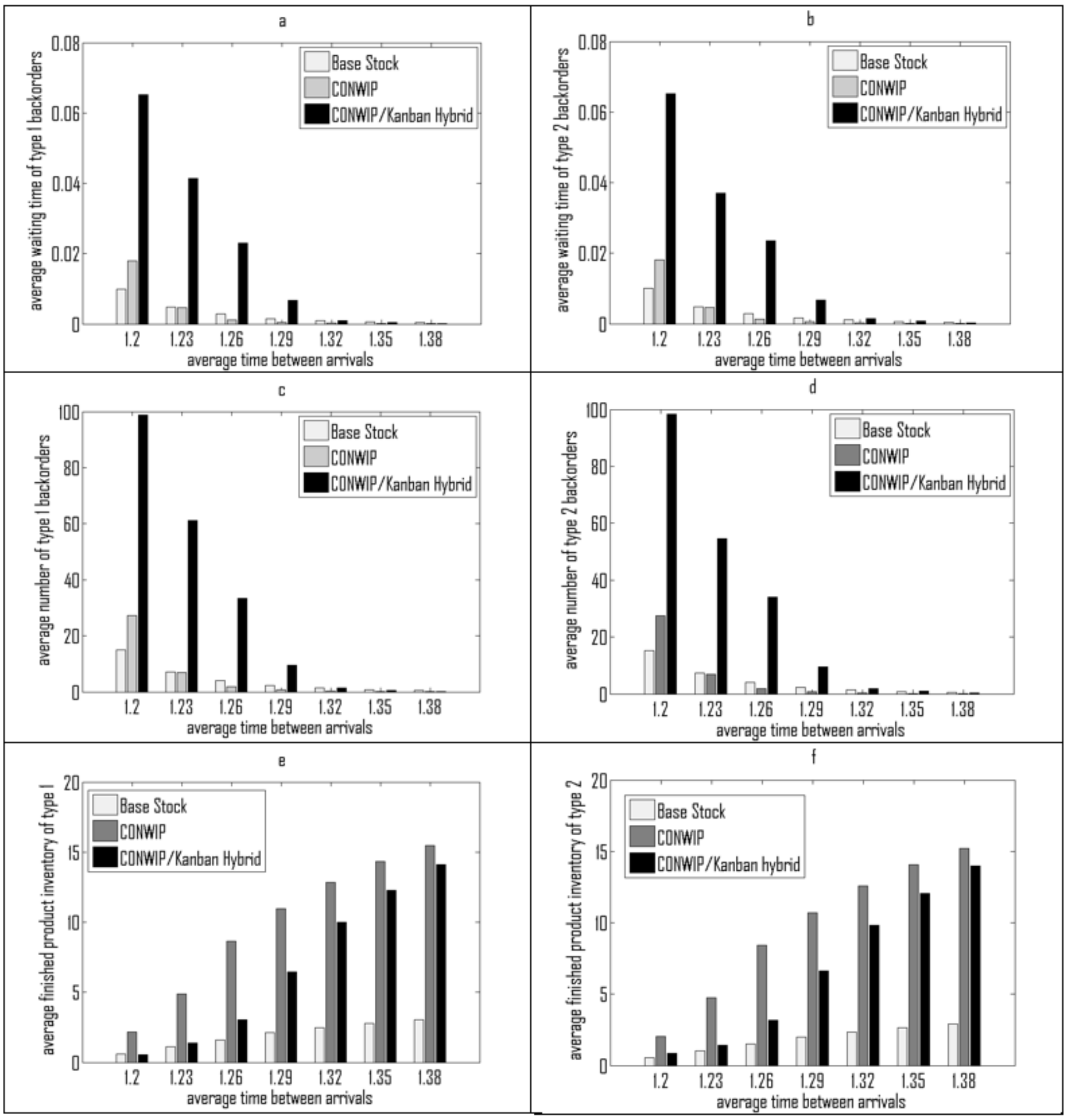

Fig. 6 Performance metrics of alternative production control policies for varying arrival rates. The time units of the *y*-axis in Figs. 7a-7f are multiplied by a factor of 3.6×10^3

4.5 Varying setup time

Fig. 7 shows the performance metrics of each control policy and product type for setup time equal to 0.1, 0.15, 0.2, 0.25, 0.3, 0.35 and 0.4 time units. It is seen that the average number/waiting time of backorders is an increasing function of the setup time. On the contrary, the average finished product inventories are decreasing functions of the setup time. Increasing the setup time has a similar effect to the system as increasing the arrival rate or decreasing the service rate, i.e. the workload imposed on the manufacturing system increases. However, note that this happens because the part sequencing in all manufacturing facilities is done by means of the FCFS rule and no special sequencing/batching takes place (refer to section 4.3 also).

Again, for relatively small setup times, the differences between the alternative control policies are rather negligible in respect to the average waiting time/number of backorders. For relatively large setup times the ranking of the policies is Base Stock, CONWIP, CONWIP/Kanban Hybrid for these two performance measures. The CONWIP system causes the highest levels of finished goods inventories followed by the CONWIP/Kanban Hybrid mechanism (refer to Figs. 7e-f). Overall, we can argue that CONWIP/Kanban Hybrid is significantly, and adversely, affected by the magnitude of the workload that is imposed on the system whereas the Base Stock system is relatively insensitive to changes in the workload. The Base Stock policy appears to be a good choice when the manufacturing system operates close to its capacity. Finally, an inherent characteristic of the CONWIP mechanism is that it consistently yields the highest finished goods inventories.

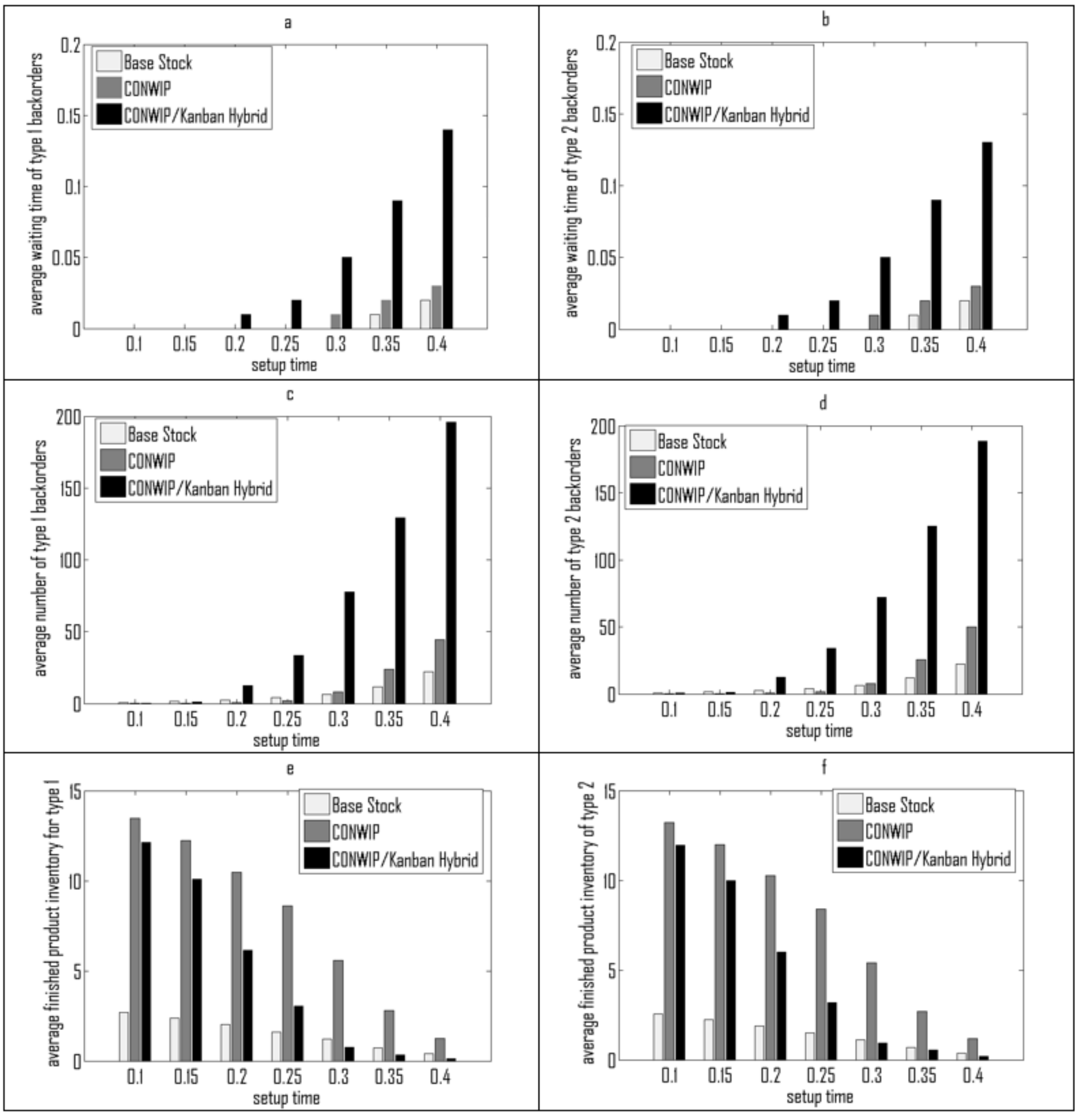

Fig. 7 Performance metrics of alternative production control policies for varying setup times. The time units of the y-axis in Figs. 8a-8f are multiplied by a factor of 3.6×10^3

4.6 Varying control parameters

To examine the effect of the control parameters to the performance of the investigated control mechanisms we used a fractional factorial design. The factors (parameters) of the experimental design are the base stocks or number of kanbans for each production stage and product type.

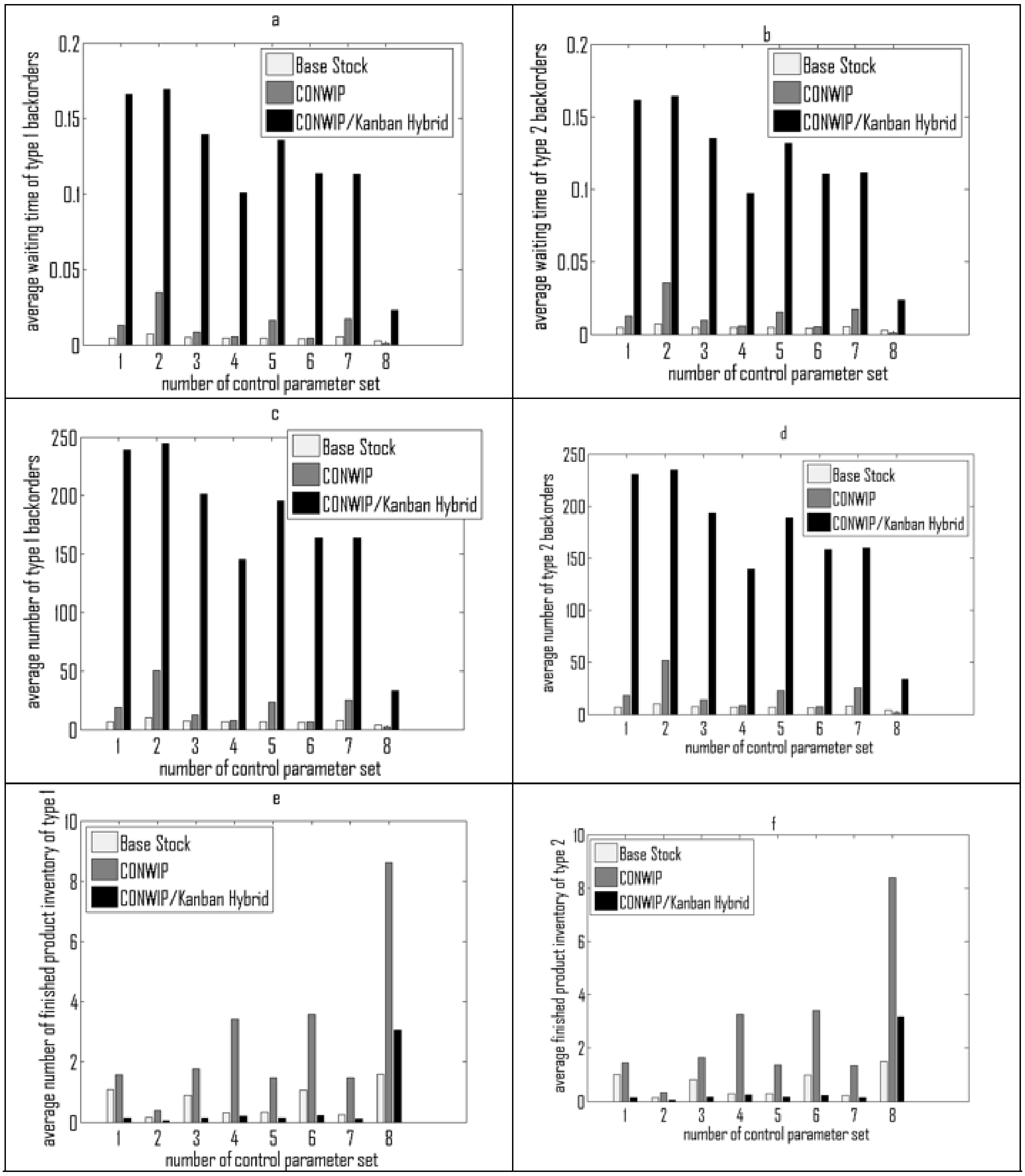

Fig. 8 Performance metrics of alternative production control policies for varying control parameters The time units of the *y*-axis in Figs. 9a-9f are multiplied by a factor of 3.6 × 10^3

The low and high level for all factors was set to 2 and 5 respectively. A 2^{4-1} fractional factorial design of resolution IV was generated [3] and it is presented in Table 1.

Fig. 8 shows the average waiting times/number of backorders and the average finished product inventories of all investigated manufacturing systems, for alternative control parameter sets. It is observed that, in order for the CONWIP/Kanban Hybrid system to be "competitive" or at least comparable to Base Stock and CONWIP, its control parameters need to be set to relatively high values. Fig. 8 shows that the CONWIP/Kanban Hybrid mechanism manages to satisfy incoming demand adequately only for the control parameter vector (5, 5, 5, 5, 5). It is observed that this hybrid policy is by far the most sensitive control strategy in respect to changes of parameters $K_{i,j}/S_{i,j}$; for example refer to the difference in the average number of backorders between control parameter set 4 and 8.

Table 1 Examined sets of control parameters (j = 1,2). Parameters $K_{i,j}$ apply only to the Hybrid system

Parameter set	$S_{1,j}$ ($K_{1,j}$)	$S_{2,j}$ ($K_{2,j}$)	$S_{3,j}$ ($K_{3,j}$)	$S_{4,j}$ ($K_{4,j}$)	$S_{5,j}$
No 1	2	2	2	5	5
No 2	5	2	2	2	2
No 3	2	5	2	2	5
No 4	5	5	2	5	2
No 5	2	2	5	5	2
No 6	5	2	5	2	5
No 7	2	5	5	2	2
No 8	5	5	5	5	5

An interesting characteristic of CONWIP and Base Stock regarding the relationship between their control parameters and the resulting finished product inventories is seen in Figs. 8e-f. The average finished goods inventories in a Base Stock system depend primarily on the base stocks of the last stage (parameter sets with $S_{5,j}$ = 5 yield higher inventories compared to parameter sets with $S_{5,j}$ = 2). However, in a CONWIP system the average inventories of finished products depend mostly to the sum of base stocks in all production stages. This clearly can be attributed to the fact that in a CONWIP system, Work-In-Process constantly flows without interruption to the last stage.

Finally, in respect to the metrics of average waiting time/number of backorders, the CONWIP system is found to be significantly more sensitive to changes in the control parameters compared to Base Stock.

5. Conclusion

We developed the queueing network models of the CONWIP, Base Stock and CONWIP/Kanban Hybrid control policies for multi-product manufacturing systems. The conversion from a single-type to a multi-type system is rather straightforward however, the model complexity increases dramatically for more than one product types.

The results of the simulation experiments indicated that the defining characteristics of the CONWIP, Base Stock and CONWIP/Kanban Hybrid policies for single-type systems are largely retained in multi-product type systems provided that all parts are processed according to the FCFS queue discipline rule in all manufacturing facilities. Our findings indicate that, when the system operates under a moderate workload, the performance differences between the alternative control policies are rather small.

The Base Stock control strategy offers a rather loose synchronization of the production operations in different stages and responds rapidly to demand fluctuations. These features render it to be a good choice when the manufacturing system is subjected to high demand arrival rates and operates close to its capacity. The behavior of the Base Stock mechanism was reported to be rather insensitive in respect to changes in the imposed workload and the control parameters. Finally, the average finished goods inventories in a Base Stock system were found to depend primarily on the initial stock of the last stage.

In a CONWIP system, parts flow without interruptions towards the downstream production stages. As a result, this control strategy responds rapidly to incoming demand, it is well-suited in situations with relatively high arrival rates and produces consistently the highest level of finished goods inventories. In a CONWIP system the average inventories of finished products depend mostly on the sum of base stocks in all production stages. The CONWIP system is found to be significantly more sensitive to changes in the control parameters compared to Base Stock.

The CONWIP/Kanban Hybrid system offers a very tight coordination between the various production stages compared to CONWIP and Base Stock. Consequently, and in this experimental trial, it was found to be the worst performing control mechanism in situations with high arrival rates. Its performance is significantly affected by the workload that is imposed on the system and by the values of the control parameters. For the CONWIP/Kanban Hybrid system to perform well, its control parameters need to be set to relatively high values, in comparison to CONWIP and Base Stock.

The managerial implications of this research pertain to the design and analysis of efficient production and material control approaches for complex manufacturing systems. This is particularly relevant in the modern and highly competitive manufacturing environment that dictates the elimination of waste in all production processes due to shortened product life cycles, diverse customer needs, and so forth.

There are several ways to extend this research. A straightforward extension is to consider additional pull control policies and conduct larger scale simulation experiments. An even more interesting extension would be to study the synergy of applying specific priority rules for Work-In-Process sequencing and production control policies in mixed-model systems.

References

[1] Puchkova, A., Le Romancer, J., McFarlane, D. (2016). Balancing push and pull strategies within the production system, *IFAC-PapersOnLine,* Vol. 49, No. 2, 66-71, doi: 10.1016/j.ifacol.2016.03.012.

[2] Liberopoulos, G. (2013). Production release control: Paced, WIP-based or demand driven? Revisiting the push/pull and make-to-order/make-to-stock distinctions, In: Smith, J., Tan, B. (eds.), *Handbook of stochastic models and analysis of manufacturing system operations*, International Series in Operations Research & Management Science, Vol. 192, Springer, New York, USA, 211-247, doi: 10.1007/978-1-4614-6777-9_7.

[3] Koulouriotis, D.E., Xanthopoulos, A.S., Tourassis, V.D. (2010). Simulation optimization of pull control policies for serial manufacturing lines and assembly manufacturing systems using genetic algorithms, *International Journal of Production Research*, Vol. 48, No. 10, 2887-2912, doi: 10.1080/00207540802603759.

[4] Xanthopoulos, A.S., Koulouriotis, D.E. (2014). Multi-objective optimization of production control mechanisms for multi-stage serial manufacturing-inventory systems, *International Journal of Advanced Manufacturing Technology*, Vol. 74, 1507-1519, doi: 10.1007/s00170-014-6052-8.

[5] Xanthopoulos, A.S., Koulouriotis, D.E., Gasteratos, A. (2017). Adaptive card-based production control policies, *Computers & Industrial Engineering*, Vol. 103, 131-144, doi: 10.1016/j.cie.2016.11.019.

[6] Onyeocha, C.E., Wang, J., Khoury, J., Geraghty, J. (2015). A comparison of HK-Conwip and BK-Conwip control strategies in a multi-product manufacturing system, *Operations Research Perspectives*, Vol. 2, 137-149, doi: 10.1016/j.orp.2015.07.001.

[7] Renna, P. (2018). BK-Conwip adaptive control strategies in a multi-product manufacturing system, In: Khojasteh, Y. (ed.), *Production Management: Advanced Models, Tools, and Applications for Pull Systems*, CRC Press, Taylor & Francis Group, New York, USA, 45-62, doi: 10.1201/b21810-3.

[8] King, D.H., Harrison, H.S. (2013). Open-source simulation software "JaamSim", In: *Proceedings of the 2013 Winter Simulation Conference (WSC),* Washington, D.C., USA, 2163-2171, doi: 10.1109/WSC.2013.6721593.

[9] Murino, T., Naviglio, G., Romano, E., Zoppoli, P. (2009). Single stage multi product kanban system. Optimization and parametric analysis, In: *Proceedings of the 8th WSEAS International Conference on System Science and Simulation in Engineering*, Genova, Italy, 313-318.

[10] Piplani, R., Ang, A.W.H. (2018). Performance comparison of multiple product kanban control systems, *International Journal of Production Research*, Vol. 56, No. 3, 1299-1312, doi: 10.1080/00207543.2017.1332436.

[11] Ezema, C.N., Okafor, E.C., Okezie, C.C. (2017). Kanban based scheduling in a multistage and multiproduct system, *Global Journal of Computer Science and Technology: C Software & Data Engineering*, Vol. 17, No. 1, Version 1, 6-13.

[12] Olaitan, O.A., Geraghty, J. (2013). Evaluation of production control strategies for negligible-setup, multi-product, serial lines with consideration for robustness, *Journal of Manufacturing Technology Management*, Vol. 24, No. 3, 331-357, doi: 10.1108/17410381311318864.

[13] Onyeocha, C.E., Khoury, J., Geraghty, J. (2015). Evaluation of multi-product lean manufacturing systems with setup and erratic demand, *Computers & Industrial Engineering*, Vol. 87, 465-480, doi: 10.1016/j.cie.2015.05.029.

[14] Onyeocha, C.E., Khoury, J., Geraghty, J. (2015). Robustness analysis of pull strategies in multi-product systems, *Journal of Industrial Engineering and Management*, Vol. 8, No. 4, 1125-1161, doi: 10.3926/jiem.1407.

[15] Sastry, G.G., Garg, R. (2017). Analysis of single flow line multi stage multi-product pull control systems, *Journal of Scientific & Industrial Research*, Vol. 76, 289-293.

[16] Krieg, G.N., Kuhn, H. (2008). Performance evaluation of two-stage multi-product kanban systems, *IIE Transactions*, Vol. 40, No. 3, 265-283, doi: 10.1080/07408170701499554.

[17] Yang, S.L., Xu, Z.G., Li, G.Z., Wang, J.Y. (2020). Assembly transport optimization for a reconfigurable flow shop based on a discrete event simulation, *Advances in Production Engineering & Management,* Vol. 15, No. 1, 69-80, doi: 10.14743/apem2020.1.350.

[18] Li, G.Z., Xu, Z.G., Yang, S.L., Wang, H.Y., Bai, X.L., Ren, Z.H. (2020). Bottleneck identification and alleviation in a blocked serial production line with discrete event simulation: A case study, *Advances in Production Engineering & Management,* Vol. 15, No. 2, 125-136, doi: 10.14743/apem2020.2.353.

[19] Ištoković, D., Perinić, M., Borić, A. (2021). Determining the minimum waiting times in a hybrid flow shop using simulation-optimization approach, *Tehnički Vjesnik – Technical Gazette,* Vol. 28, No. 2, 568-575, doi: 10.17559/TV-20210216132702.

[20] Katsios, D, Xanthopoulos, A.S., Koulouriotis, D.E., Kiatipis, A. (2018). A simulation optimisation tool and its production/inventory control application, *International Journal of Simulation Modelling,* Vol. 17, No. 2, 257-270, doi: 10.2507/IJSIMM17(2)425.