PULL PRODUCTION POLICIES: COMPARATIVE STUDY THROUGH SIMULATIVE APPROACH

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ABSTRACT
Over the years, the JIT approach has highlighted some different types of pull production systems. Many researchers have developed control systems pull, based on a new strategy for managing production "pulled" from the market. They have proposed control policies such as: Kanban, CONWIP, Base Stock and different techniques arising from combination of two of these policies: Generalized Kanban, Extended Kanban, CONWIP-Kanban. In literature, there are several works on the analysis of each control systems, but there are few works that treat more extensive comparisons of different policies. In this study we have analyzed some different pull production policies to single-product multi-stage system to highlight similarities and differences in terms of performance, through the comparison of simulation models built with ARENA software.

Keywords: pull systems, lean manufacturing, discrete event simulation, Extended-CONWIP-Kanban System, decision support system.

1. INTRODUCTION
The events of recent years have shown some needs more and more widespread in the industrial world: the traditional business model is no longer suitable to the actual context in which companies are increasingly subjected to a fierce competition. Therefore we have to rethink the business model: it has to be able to perceive and manage change. Therefore, many researchers have developed control systems pull, based on a new strategy for managing production "pulled" from the market (i.e., the actual customers demand). These systems are against with the more traditional push-type systems (such as MRP), in which the production is "pushed" from forecasts of customer demand.

During the years, experts have developed and proposed several policies based on pull control logic from the model universally known as Lean Thinking. In particular, in literature they have proposed control policies such as: Kanban, CONWIP, Base Stock. We can also speak about different techniques arising from combination of two of these policies: Generalized Kanban, Extended Kanban, CONWIP-Kanban.

Finally, it is recently developed, the technique called Extended-CONWIP-Kanban, by a combination of the three basic policies. The main goal of lean management is to reduce and eliminate the "muda": only in this way we help to streamline the production system (less inventory, scrap, etc..).

In literature, there are many works on the analysis of each control systems, but there are few works that perform more extensive comparisons of different policies. It is difficult to identify and to analyze performance's parameters that quantify the goodness of these techniques: the difficulty lies in assessing which control system can give better performance depending on the type of production. This paper aims to analyze and compare the pull-type control policies in a multi-stage production system, highlighting differences and similarities of control actions in each policy.

2. PULL PRODUCTION CONTROL SYSTEMS
The pull control system is based on real events demand, rather than on its forecasts. The demand for each station in downstream is sent to the upper station on basis of the current consumption of the downstream station, since the demand for finished products required by consumers. So, in a pull control system, production is allowed by current demand and upstream station produces only what is needed to meet the demand of the downstream phase, which is controlled by the effective demand of end customers (Murino, Naviglio and Romano 2010).

Recently, many manufacturers have used the lean production as a strategy to increase their global competitiveness. Since the '80s, in fact, the Just-In-Time (JIT) approach has triggered the emergence of several "pull production systems": they emphasize the importance of production control systems that react to real demand, rather than to forecasts of future demand. In literature, there are a large number of variants of pull production systems (Lage, Filho 2010) that can be traced back to the pull techniques represented by the Kanban, Base Stock and CONWIP. From their combination some different hybrid systems derive. The Generalized Kanban system mixes Kanban and Base Stock policies , as well as the Extended Kanban policy. CONWIP-Kanban System mixes, however, the Kanban and CONWIP controls, while all the three basic logic define the Extended-CONWIP-Kanban system. These control policies have been described for a generic multi-stage production system, where each phase has been modeled as a production system characterized by a production process and an output buffer.

2.1. The Kanban control system (KCS)

The Kanban control system (KCS) is the most widespread pull control system: the information on the demand are transferred from downstream station to upstream station through the kanban cards. They allow synchronization between the release of parts to the downstream station and the transfer of demand to the upstream station. Then, the control kanban depends on one parameter per each phase, the number of k_i kanban at each i stage. This parameter limits the number of units in each stage of production.

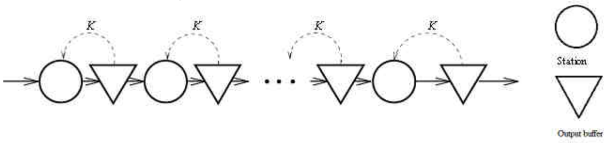


Figure 1: The Kanban control system

2.2. The CONWIP control system (CCS)

The CONWIP control system (CCS), however, limits the total number of parts inside the production system, using only one type of card that follows the pieces through the system. The production control is performed only at beginning of the production and the information about the demand are transferred only between the last and the first phase. Therefore, CONWIP control results from a single parameter for the complete system: the number of CONWIP cards C (Framinan, Gonzalez and Ruiz-Use, 2006).

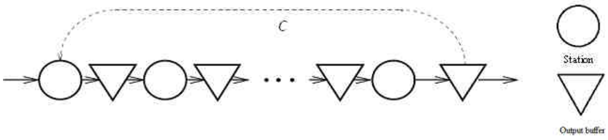


Figure 2: The CONWIP control system

2.3. The Base Stock control system (BSCS)

In the Base Stock control system (BSCS), however, are not physically present cards which allow the production: the information on the demand are sent to each stage as soon as available. The levels of WIP in each stage are unlimited, because every request that arrives to the system authorizes the release of new item. This request provides a safety stock level in any buffer system, defined as basic s_i stock level, which is the control parameter for any phase of this system (Du and Larsen, 2010).

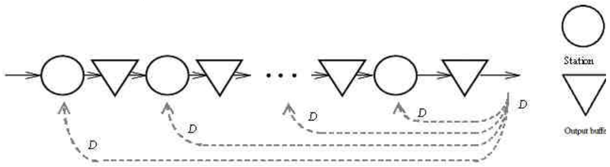


Figure 3: The Base Stock control system

2.4. The CONWIP-Kanban control system (CKCS)

In the hybrid CONWIP-Kanban control system (CKCS), the cards CONWIP limit the level of WIP in the full system, while the number of kanban available in each stage controls the inventory level. The information on demand are transferred to upstream station by a kanban signal and they are transferred to the first stage by the CONWIP signal. The CONWIP-Kanban system depends on one parameter for each phase (i.e. the number of kanban k_i) and it depends on one parameter for the entire system (i.e. the number of CONWIP cards C).

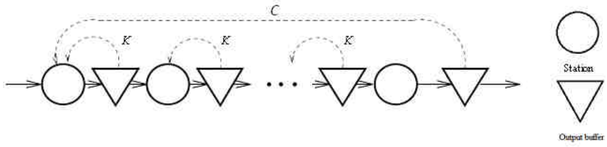


Figure 4: The CONWIP-Kanban control system

2.5. The Generalized Kanban control system (GKCS)

In Generalized Kanban control system (GKCS) the kanban cards are used as production licenses and the maximum number of parts in the output buffer of each stage is fixed by the base stock level. The demand, outside the system, is forwarded from upstream station to downstream station through all different stages, but the transfer of this information is not fully synchronized with the transfer of items to the next step: therefore the information flow matches only partially to kanban. This system results from two control parameters for each phase, the k_i kanban number and s_i base stock level.

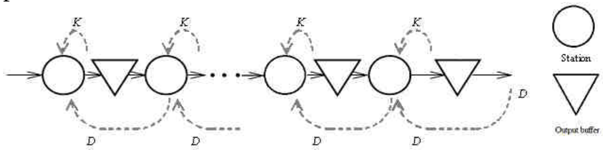


Figure 5: The Generalized Kanban control system

2.6. The Extended Kanban control system (EKCS)

The Extended Kanban control system (EKCS) as the GKCS, mixes the Kanban and Base Stock controls. In this case the information about the demand shall be forwarded immediately to each workstation, while the pieces are moving together with kanban: the transfer of information on demand and transfer of kanban are completely unmatched (Chaouiya, Liberopoulos and Dallery 2000). The Extended Kanban system is therefore characterized by two parameters control for each workstation: the k_i kanban number and s_i base stock level. EKCS imposes a constraint on the parameters: $k_i > s_i$ for each phase, so to have at each stage a s limited number of free kanban not attached to the finished pieces in the buffers (Dallery and Liberopoulos, 2000).

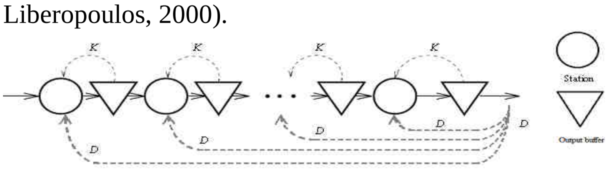


Figure 6: The Extended Kanban control system

2.7. The Extended-CONWIP-Kanban control system (ECKCS)

Finally, the Extended-CONWIP-Kanban System (ECKCS) mixes the features of the three pull logic. The information about the demand are immediately transferred to the different phases when those arrives to the system. The total level of WIP in the system is limited by the number of CONWIP cards, while the release of item in each phase is approved by the kanban cards. Also in this system the flow of information is completely unmatched to the transfer cards. This system results from two control parameters per phase (the k_i kanban number and s_i base stock level) and one parameter for the entire system (i.e. the number of CONWIP cards C), $C \geq \Sigma i\ s_i$, i = 1, ..., N-1, in order to have in the first phase a number of CONWIP s cards free not attached to the finished pieces in the buffer.

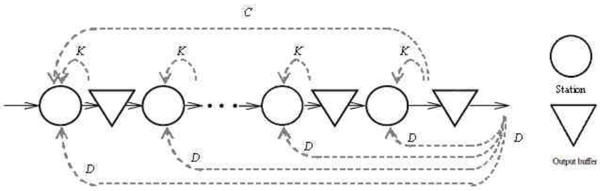


Figure 7: The Extended-CONWIP-Kanban System

3. LITERATURE REWIEW

In literature, many studies analyze the strategies of pull production control (Khojasteh Ghamari 2008), but only a few studies compare the several techniques, among them only few papers compare - all together - pull production control policies. This is due in part to the different contexts in which it was assumed to analyze the several control policies. This doesn't allow a simple and direct comparative study among the different techniques (Gallo, Guerra and Guizzi 2009).

The hybrid policy CONWIP-Kanban is compared with the basic policies CONWIP and Kanban, but also with the Base Stock (Bonvik et al., 1996). The several logics are compared in a system consisting of four stages in series, simulating the behavior of different systems with steady and variable demand: the hybrid control policy reduces the inventory level of the system by 10-20% compared to Kanban policy with the same level of service, while the performance of the Base Stock and CONWIP are intermediate between the two previous results. Geraghty and Heavey (2003) have, however, compared the optimal control policy for hybrid push / pull proposed by Hodgson and Wang (1991) with the hybrid control policy CONWIP-Kanban proposed Bonvik et al. (1996), showing that, under certain conditions, the two logics are equivalent. Indeed, simulation tests gave the same results in terms of average WIP, service level, holding and backlog costs. Also the studies related to hybrid systems Kanban / Base Stock, or Generalized Kanban Control and Extended Kanban Control policies, show better results than each policies basic (Karaesmen and Dallery, 1998).

Recent comparative studies among hybrid control policies show, finally, that the Extended-CONWIP-Kanban policy is better than all other policies based on the pull logic (basic and hybrid) because it mixes all the advantages resulting from several techniques (Lavoie, Gharbi and Kenne, 2010). It's been obtained, by simulation techniques, the better results in terms of performance (trade-off between service level and inventory level) and in terms of stability of solutions to changing conditions both within and outside the system. Boonlertvanich (2005) has simulated the different pull systems in three different scenarios, starting from a basic case, characterized by a variability of demand and process time. These parameters are expressed in terms of variation of the Mean Time To Failure (MTTF) and Mean Time To Repair (MTTR). He has evaluated the performance of these systems when the parameters changes.

In all examined cases, the performance of hybrid policies (CONWIP-Kanban, GKCS, EKCS, ECKCS) are better than the basic logic to reach a high level of service at the lowest levels of stocks.

Similar results are also obtained by Xu and Miao (2009), when the demand and processing times change. In particular, the pull policy is compared with an MRP system: once again the ECKCS policy gives us the best results in terms of WIP, while inventory levels are obviously higher for the MRP system. The purpose of this study is to compare the different pull production systems through a simulation approach. Thus we can help companies choose the best policy according to the characteristics and priorities, which the company decides to pursue.

4. PRODUCTION MODEL AND BASE HYPOTHESIS

We have considered sequential multistage systems: the first stage is fed from the raw materials buffer while each subsequent station is fed from the output buffer of its upstream stage.

The assumptions underlying the construction of our models can be summarized as follows:

- the system has five stages, each modeled as a single station;
- a single type of finished product is considered (there are not set-up times);
- the net system demand is deterministic and it occurs every eight hours;
- the unmet demand in a certain day is postponed to the following days;
- the system is operated for 240 days a year with an 8-hour shift per day (= 1920 hours/year);
- the machine failures are not considered;
- the transfer time is negligible;
- the kanban size is set at one
- there is infinite availability of raw material.

To highlight the differences between the different production control systems, we have defined some performance indicators. In particular, the models have been compared using four benchmarks:

- the service level: the degree at which customer requirements are met;
- the average WIP (the average number of parts in the system);
- the average delay of orders (hours);
- the system total cost considering backlog costs and holding costs.

The above described systems have been modeled using ARENA software, which supports the modeling of different scenarios using a discrete event simulation approach. The ARENA models of the seven systems are showed in the figures 8, 9, 10, 11, 12, 13 and 14.

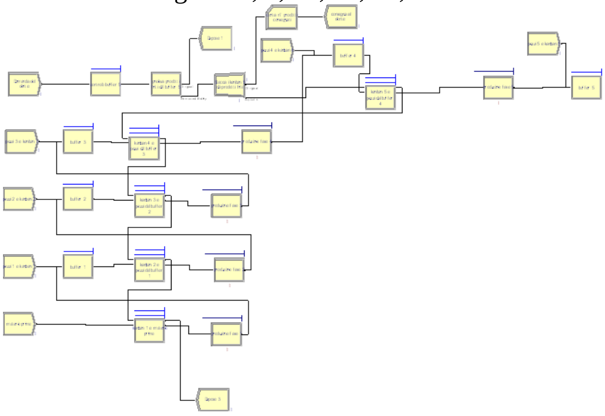


Figure 8: The ARENA model of KCS

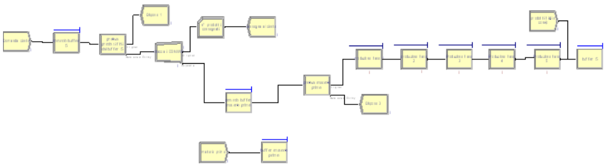


Figure 9: The ARENA model of CCS

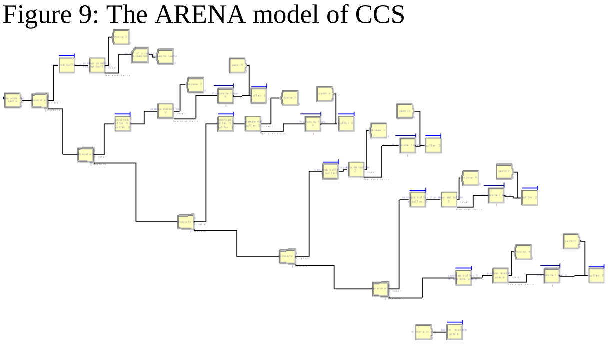


Figure 10: The ARENA model of BSCS

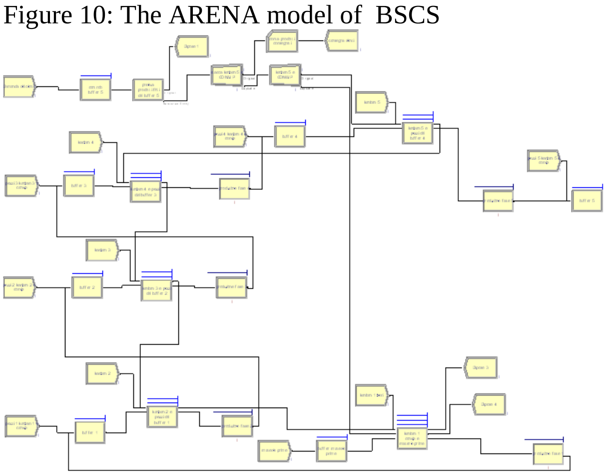


Figure 11: The ARENA model of CKCS

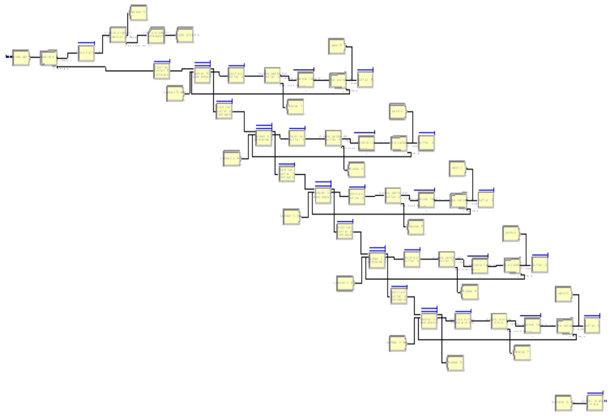


Figure 12: The ARENA model of GKCS

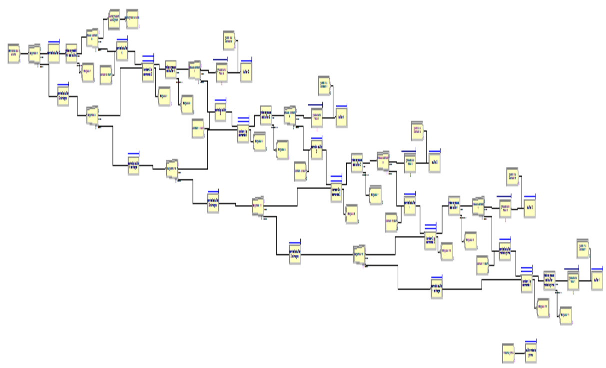


Figure 13: The ARENA model of EKCS

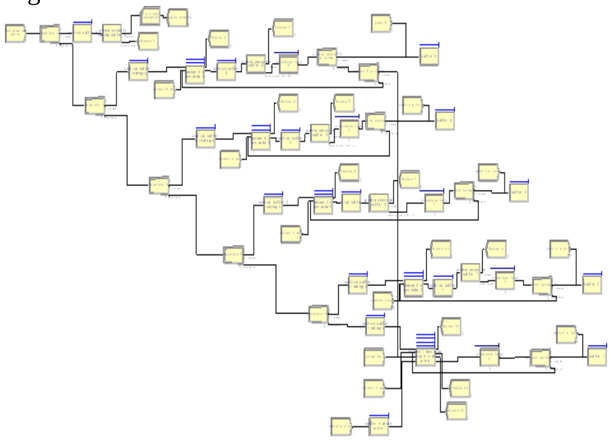


Figure 14: The ARENA model of ECKCS

5. MODELS PARAMETERS DEFINITION AND VERIFICATION

For a proper comparison between the different control policies, it has been necessary to identify the most appropriate range of values for their control parameters. We decided to use for each model those control parameters values that guarantee a fairly high service level. Identifying these ranges has showed to be easier for systems characterized by a single parameter (*basic systems*) rather than for those characterized by multiple, and in some cases interlinked, parameters (*hybrid systems*).

In the basic systems, the range of each parameter has been chosen considering the values most frequently used in literature. In the hybrid system, where there is no link between the control parameters, namely CONWIP-Kanban and Generalized Kanban, we have considered the same range of values used for basic systems, and considering all the possible combinations of parameters' values. In the Extended-Kanban Systems and Extended-CONWIP-Kanban Systems, instead, the constraints between the various parameters have to be taken into account. In the EKCS model we have decided to vary the basic stock level in the range considered in the BSCS model and, for each of these values, we have varied the number of kanban always in the same interval and respecting the relationship between the parameters’ values. In the Extended-CONWIP-Kanban model the number of kanban and the base stock level, among which there is no relationship, have been varied in the same intervals considered for the basic control policies, while for the variation range of the CONWIP level the relationship between C and s must be taken into account: as the base stock level varies, the variation ranges for C have been chosen of the same width and respecting the aforesaid constraint. We have analyzed the simulation results constructing some experimental curves, for each model, reporting the trend of the benchmark parameter to the change of the various control parameters. For systems depending on more than one control parameter, we decided to evaluate, initially, the trend of benchmarks as each control parameter varies individually, and then considering the joint variation by constructing a family of curves.

In KCS model as the number of kanban cards for each stage increases, the WIP in each stage and, consequently, the WIP of the system increases too (figure 15.a). As the number of parts circulating in the system grows, of course, the probability and the speed of the system to meet the demand, which translates in an increased service level (figure 15.b) and in a reduced average delay of orders (figure 15.c). The rising total cost is due to the increasing holding cost (figure 15.d).

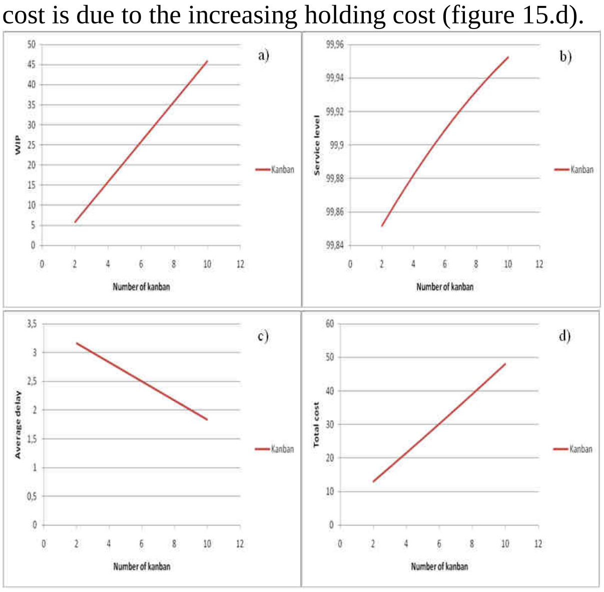


Figure 15: Performance parameters variation with respect to the kanban number in the KCS model

Also in the CONWIP system, the average WIP increases with the number of kanban available in the system (figure 16.a), but the service level increases rapidly only at the beginning: for high values of C, in fact, increases only the number of parts into the input buffers of the system (figure 16.b). Consistent with this result, the average delay of orders has a very fast downward trend first and then much slower (figure 16.c). The total cost is initially influenced by the backlog cost and then for higher values of C by the holding cost (figure 16.d).

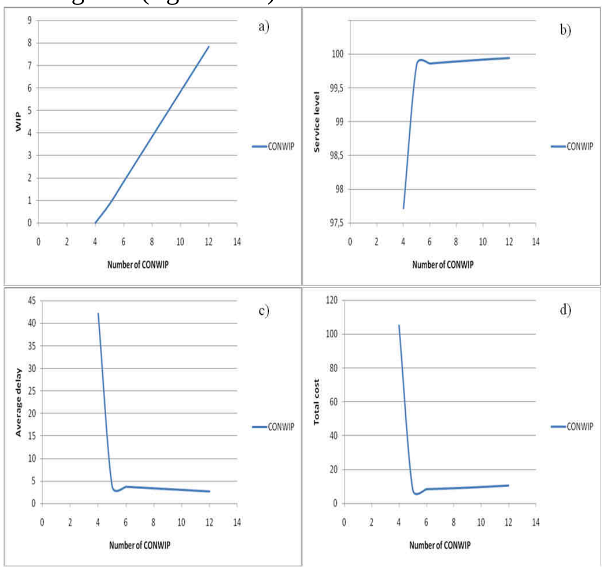


Figure 16: Performance parameters variation with respect to the kanban number in the Conwip model

In BSCS model the increase of s increases the number of parts in each buffer and, consequently, the average WIP of the system (figure 17.a). The availability of a greater number of finished parts pushes toward ever greater service level values, and allows to meet customer demand more quickly (figure 17.b). The total cost is more influenced by the holding cost than by the backlog cost (figure 17.d).

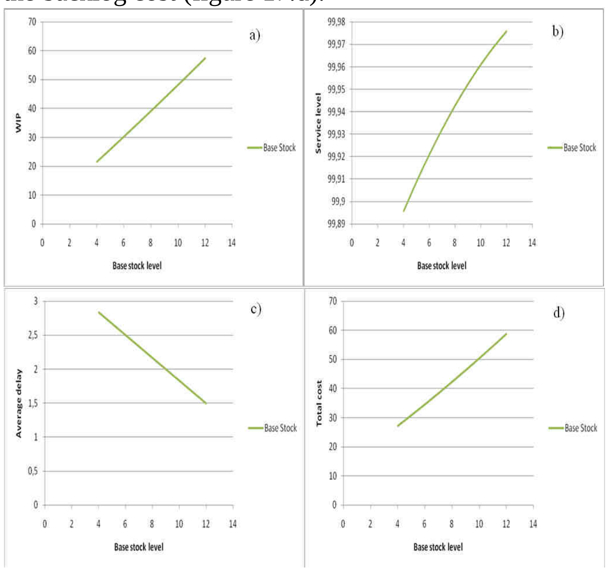


Figure 17: Performance parameters variation with respect to the base stock level in the BSCS model

In the CONWIP-Kanban model as k increases the average WIP is at first slightly increasing and then remains constant, since it is possible to increase the number of units at each stage only up to the limit imposed by the CONWIP control (figure 18.a). By increasing of C the service level increases very rapidly initially and then remain constant at higher values of the parameter C, at which we have only a greater number of parts in the input buffers (figure 18.b). By varying k, the service level initially grows slowly and then remain constant, consistent with constrained changes in WIP. Considering the joint variation of C and k, we obtain curves that start from the same point, but delivering an increasing service level: as C increases it is possible to use a larger number of kanban cards (figure 18.c). In the same way, also delivery delays decrease (figure 18.d). As C increases, the total cost is at first more sensitive to the backlog cost, and then to the holding cost (figure 18.e). Considering also the variation of k, the curve is at first slightly decreasing due to the positive effect of reduced backlog, and then it remains stable. The growth of C moves the curve upward due to the increasing holding cost (figure 18.f).

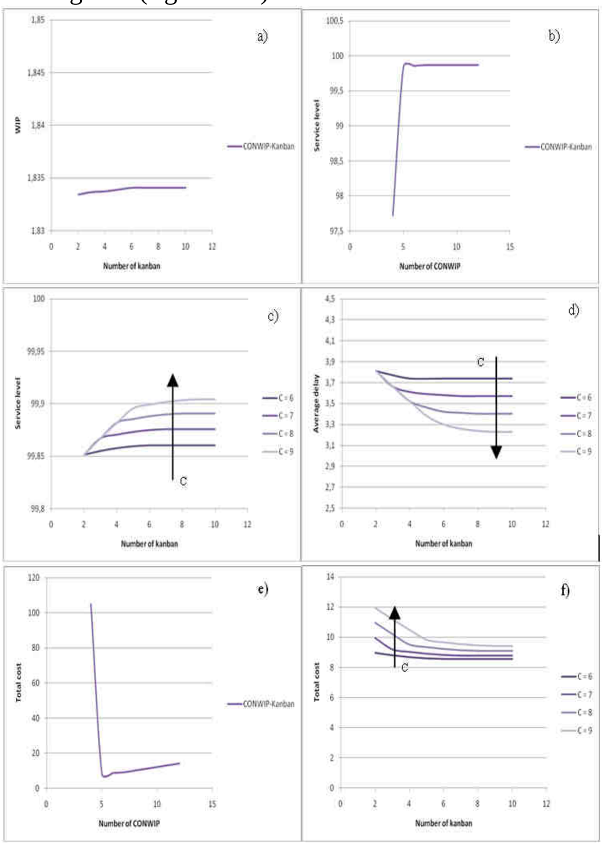


Figure 18: Performance parameters variation with respect to the kanban and Conwip kanban number in the CKCS model

In the GKCS model the average WIP increases both to the rise in k and s, a faster increase occurs in the second case because of the greater amount of finished parts in the various output buffers (figures 19.a and 19.b). The service level increases with s, but it is independent of the number of kanban (figure 19.c), and, consequently, also the delay in deliveries is independent of k (figure 19.d). The total cost is more influenced by the holding cost considering both k and s: the upward trend in both cases has different slopes, consistent with different growth rates of WIP (figures 19.e and 19.f).

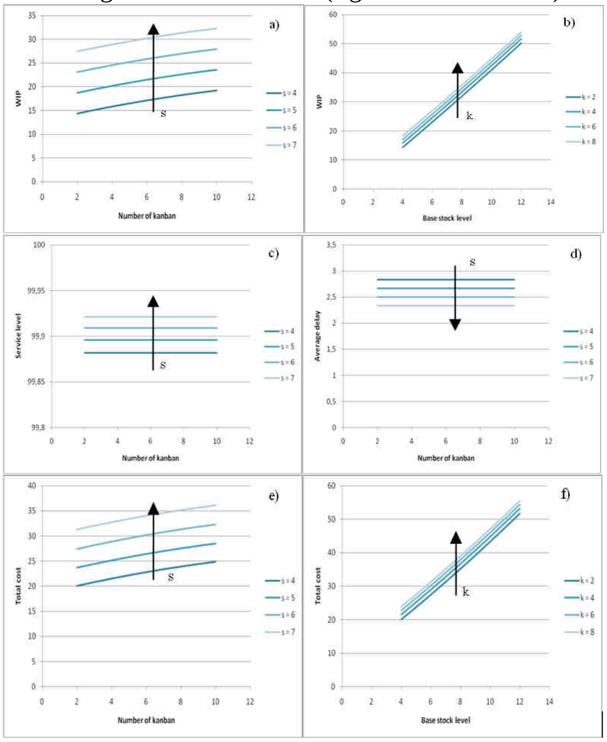
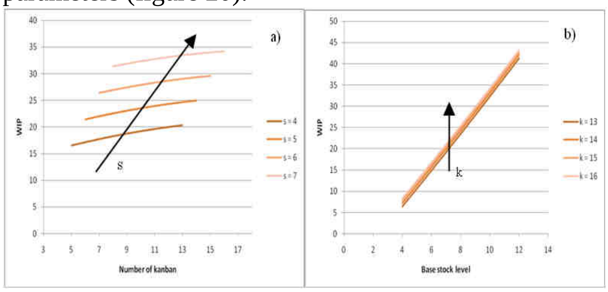


Figure 19: Performance parameters variation with respect to the kanban number and the base stock level in the GCKS model

In the EKCS model, the trend of benchmarks parameters is similar to previous model, with different values of the control parameters, consistent with the model's logic that allows to release downstream the parts more quickly decoupling completely the demand and the kanban cycle. Moreover, the curves having s as parameter move to the right with increasing s in accordance with the relationship between the control parameters (figure 20).



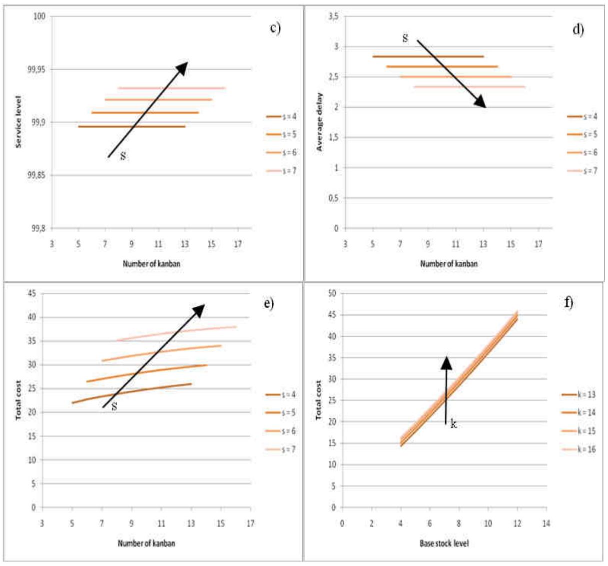


Figure 20: Performance parameters variation with respect to the kanban number and the base stock level in the EKCS model

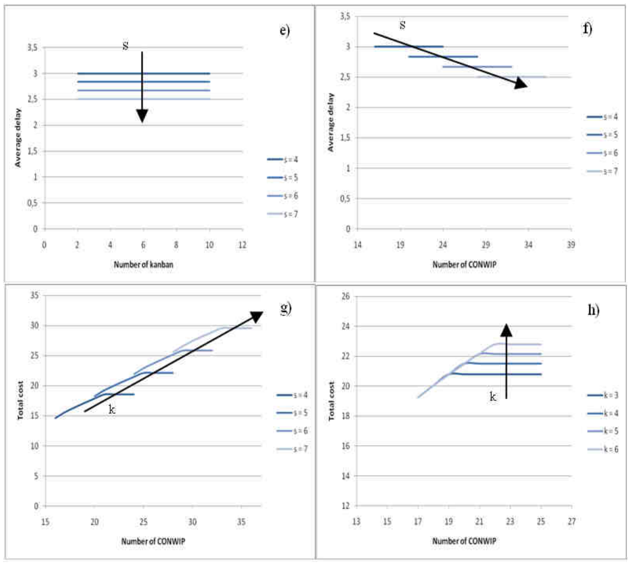
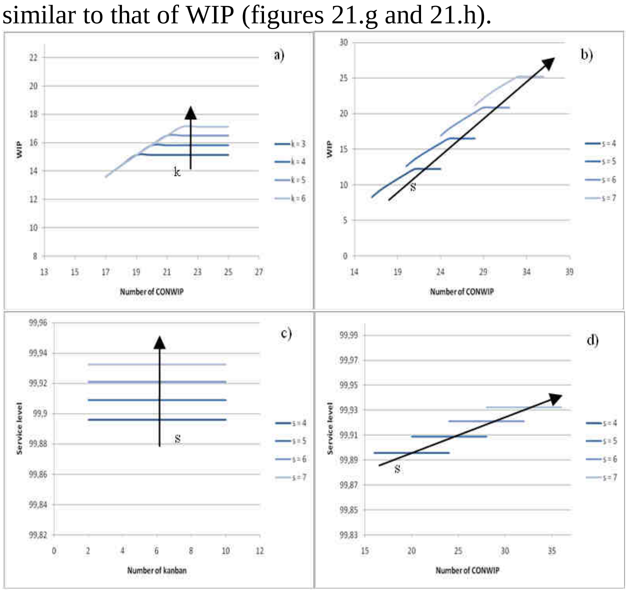


Figure 21: Performance parameters variation with respect to the kanban number, the conwip kanban number and the base stock level in the EKCS model

Considering the ECKCS model, the average WIP as a function of C has a different trend with s or k raising. In the first case the curve moves upward, because of the increase of finished parts in the output buffers, and to the right in respect of the constraint between the parameters (figure 21.a). In the second case, all curves start from the same point, but grow up to higher values of WIP with k increasing (figure 21.b). Again the service level depends only on s: so if s increases, the service level lines move upward, and to the right in the case of C varying (figures 21.c and 21.d). The average delay, of course, has a behavior opposite to that observed for the service level (figures 21.e and 21.f), while the total cost is mainly impacted by the holding cost that produces a trend of the curves similar to that of WIP (figures 21.g and 21.h).



6. COMPARISON OF THE CONSIDERED PULL CONTROL POLICIES

Identified the ranges of variability for the parameters of each model, it is possible to compare their performance considering two specific scenarios. In the first scenario we evaluate how the various model react to changes in final demand, in the second one the systems' response to sudden changes in production times. In both cases, we have considered a just in time procurement policy to meet the daily demand.

In the first case, demand has been increased up to 30 % from an initial rate of 20 parts per day . All models manage well changes in demand up to 20%. The models that deliver the highest service level are the Base Stock, the Extended kanban and the Extended-CONWIP-Kanban. A slightly lower service level is delivered by the Kanban systems, the Generalized Kanban and the CONWIP-Kanban, while the lowest service level is delivered by the CONWIP system.

It is necessary, however, to associate these results in terms of service level to the corresponding performance in terms of total cost. Among the three first models, at the same service level, the lowest total cost is reached by the ECKCS model. In the second set of models, the CKCS one produces the lowest total cost. The basic CONWIP system, instead, while reaching the lowest total cost among all the considered policies, delivers, however, the lowest service level. So the CONWIP-Kanban and the Extended CONWIP Kanban models globally react better to the change in demand (figure 22).

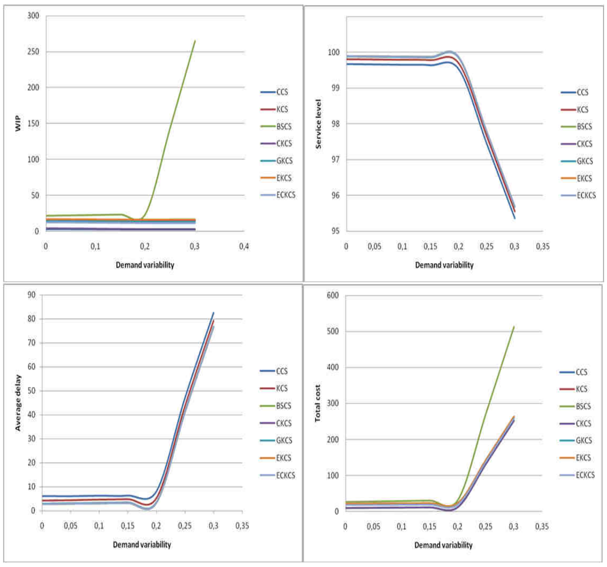


Figure 22: Comparison of the performance parameters for the various pull production models with the demand varying

In the second scenario, the production time has been increased up to 50% from an initial value of 20 minutes. Again, all systems respond well to changes in production time for increments lower than 20%. Even in this scenario the systems ensuring the highest service level are the Base Stock, the Extended Kanban and the Extended-CONWIP-Kanban, the last one getting the lowest total cost. A slightly lower service level is reached by the Kanban, the Generalized Kanban and the CONWIP-Kanban system: with the last one getting the lowest total cost. Again, the CONWIP model gets the lowest total cost but with the lowest service level. So the Extended-CONWIP-Kanban and the CONWIP-Kanban system respond better than the others also to variations in production times (figure 23).

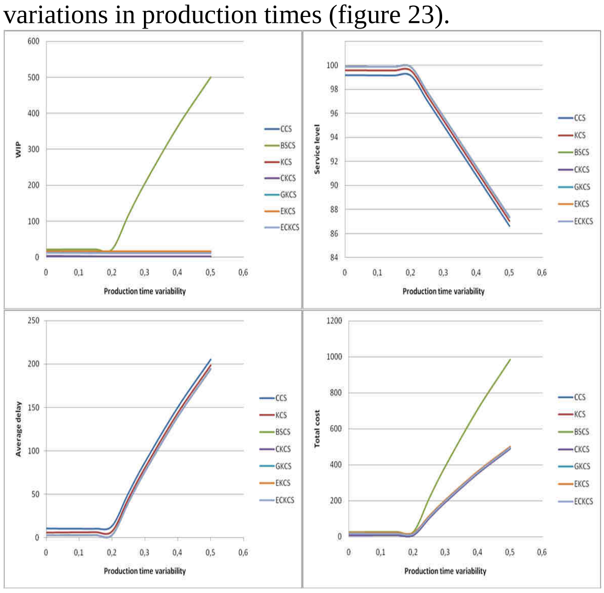


Figure 23: Comparison of the performance parameters for the various pull models with the production time varying

7. CONCLUSIONS

In general, all simulation runs have led to results consistent with the logic of the control policies. All models are more responsive to changes in production time that a change in demand, but in both cases the models that perform better are the CKCS and the ECKCS system. This is also reflected in the results proposed by various authors in literature, so the simplifying assumptions underlying the models do not undermine the validity of the models themselves. These models can be considered a valid instrument to support strategic business decisions to maximize efficiency. In fact, reducing production wastes lowers the cost and the environmental impact. However, the ECK policy, despite its superiority, is rather difficult to implement being a combination of the three basic control mechanisms. Therefore, the decision on the right control policy to implement has to be guided by its characteristics and by the priorities that the company decides to pursue. Possible future developments of this work could be to evaluate these policies in other scenarios: modeling, for example, assembly and/or multi-product systems with stochastic data, in order to make these models more adaptable to various production realities and ever more flexible in responding to fluctuations that inevitably characterize the production context.

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