Using multiple criteria decision-making method to analyze optimum push/pull junction point location for TFT-LCD manufacturing

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Abstract

This research’s aim is to implement a hybrid push/pull production system that can satisfy both high service-levels and low inventory cost. Simultaneously, we consider sophisticated variability, such as multi-products, random setup, indiscriminate break-downs, yield loss, batch processes, and other contingencies. The problem can be solved by a multiple criteria decision-making method (MCDM). A technique for order-preference by similarity-to-ideal solution (TOPSIS) is used to select a suitable option. The optimization involves evaluation of stochastic performance measures within alternative scenarios among potential junction point locations using a discrete event simulation model. A practical thin film transistor-liquid crystal display (TFT-LCD) process case study is utilized to illustrate the proposed method. Simulation results indicate that the inventory cost was reduced by over 46% after implementing a hybrid push/pull production strategy.

Keywords: Hybrid push/pull; Multiple criteria decision-making; Simulation; TOPSIS.

1. Introduction

An effective production control strategy is a critical factor in achieving superior manufacturing performance. Production control strategies can be classified into push-type strategies and pull-type strategies (Cochran and Kaylani, 2008). Push-type and pull-type control strategies have been compared and contrasted by numerous researchers (Geraghty and Heavey, 2005; Spearman and Zazanis, 1992).

To leverage the benefits of the two strategies, researchers studied a hybrid push and pull strategy (Hodgson and Wang, 1991). In a hybrid paradigm, it is important to identify where to locate the transition points for multi-stage manufacturing processes. Several studies reported that adopting a hybrid push/pull strategy can result in tradeoff benefits (Pandey and Khokhajaikiat, 1996; Ion and Nyberg, 2000). Cochran and Kim (1998)
defined the transition process at the last push stage as the junction point (JP). Previous research identified that an appropriate junction point location will significantly affect hybrid push/pull performance (Cochran and Kaylani, 2008; Geraghty and Heavey, 2004). However, the main question remains, where is the appropriate junction point to improve the system, and how can it be identified among numerous processes characteristics? Figure 1 shows a multi-product, with only one JP example of multistage system.

Figure 1. Proposed hybrid push/pull model

The model showing multistage (M stages) producing N product type is considered. The machine of each stage has identical parallel machines at each stage. The raw material supply for stage 1 is considered as infinite and all transportation times are considered as null. A single JP located at stage p stands for the transition from the push to pull sub-systems. The semi-finished goods are stored between stage p and stage p+1. The storage with upper level sp(n) stands for nth product types. Rother and Shook (1998) defined it as a supermarket that is a buffer of ready-to-ship products strategically located; where shipping can pull the product. Each custom er-order requested one product-type only, with random arrival times and quantities O(n). When an order arrived, the finished goods stock will provide sufficient quantities or trigger a kanban to request upstream producing for fulfilling the customer requirement. If the safety stock upper level ss(n) of finished goods for each product type n is zero, then it is make-to-order (MTO) from the next stage of JP to final stage M, or make-to-stock (MTS) strategy while ss(n) is greater than zero.

Before using kanban in this hybrid production system, this research defined the kanban number k(n) for each stage. The numbers of kanban cards determine the WIP level in pull sub-system. Also, this model defined pitch time tp, it gave the final stage M an instruction to change production type every tp hours and so avoid frequent changeover loss of time.

There are two conflicting objectives that need to be fulfilled in this model; one is inventory cost (Ic) and the other is service-level (S). This research proposes that a hybrid
production system can be optimized by determining *JP* location that will satisfy both higher throughput and lower inventory cost. In this case, simulation can be used to create consensus by visualizing dynamic views of the scenario for a given candidate *JP* location. To obtain the optimum alternative scenario that has the highest degree of satisfaction for all of the relevant criteria, a multiple criteria decision-making method (MCDM) is applied. A hybrid Taguchi method and the techniques for order preference by similarity to ideal solution (TOPSIS) is used in this research.

The remainder of this paper is organized as follows. Section 2 reviews the literature and reported research. The problem statement and methodology is discussed in Section 3. In Section 4, the proposed case-study and empirical results are described. Section 5 contains the conclusions and discussion of future research opportunities.

2. Literature review

Numbers of researchers’ studied the possibility of integrating a push-control strategy and pull-control strategy, by developing specialized integration techniques (Benton and Shin, 1998; Xiong and Nyberg, 2000). A Markov decision process model was developed, by using both dynamic programming and simulation for several production strategies; including pure-push, pure-pull and hybrid push/pull control strategies (Hodgson and Wang, 1991). Olhager and Ostlund (1990) proposed that a possible transition point for hybrid push/pull systems can be at the custom order point, the bottleneck resource, or the product structure.

However, a real-world manufacturing process is far more complex than the presented research. It involves multi-products, random setups, random break-down, batch processes, and quality loss problems that cause the implementation of a pure pull-control strategy in such conditions a challenge. Hence, a hybrid push/pull control strategy is an option for a high-technology industry, *i.e.* a thin film transistor-liquid crystal display (TFT-LCD) production system.

Noticably, physical details of the manufacturing processes significantly affect the push/pull junction-point location. Hence, in some cases, a candidate *JP* location scenario that may consist of a set of conflict goals cannot be achieved simultaneously. The MCDM method, a technique for order preference by similarity to ideal solution (TOPSIS) is used to select a suitable option which much of the existing literature uses to solve manufacturing problems (Kuo et al., 2008; Yang and Hung, 2007). In addition, previous work using computer-based simulation tools was used to identify the impact of selected key parameters on performance and explore optimization (Sandanayake et al., 2008; Yang et al., 2007).
From the literature it is evident that a combination of push- and pull-strategies is straightforward to implement and may achieve better results than either a pure push or pure pull-strategy. However, there is little research directed to hybrid push/pull. Moreover, there are limited publications addressing random features of manufacturing parameters. Also, there is no previous study involving research of a standard procedure to find an appropriate JP workstation.

3. Proposed approach

This research proposes an approach to identify an optimal hybrid push/pull production system as shown in Figure 2.

![Diagram showing the proposed approach]

**Figure 2. Proposed approach**

3.1 The control factors

An appropriate level of inventory at the right place is a powerful tool to buffer against surges in external demand as well as against internal process instability (Smith and Womack, 2004). Primary and secondary factors are: the upper limit of finished goods and semi-finished goods, respectively. The third factor is the level-scheduling frequency that establishes the production pitch interval. An appropriate production pitch time will drive a reduced changeover time caused by downstream demand and changes (Rother and Shook, 1998). The transportation batch-size significantly affects the WIP level. Therefore, the fourth factor is batch size.

3.2 The scenario design

The subsequent step is to define a range of scenarios that encompass most manufacturing variable elements. These include the longest changeover time, the longest batch process, greatest yield loss, and longest random breakdown time. These signal the workstation as a probable candidate for the JP location. Since pure push, pure pull, and constant work-in-process (CONWIP) are special cases of the hybrid push/pull strategy, those scenarios will be compared with multiple objectives using alternative control factors.
3.3 Simulation model

The simulation model is a proven tool in solving stochastic problems, and allows examination of the likely behavior of a proposed multistage system under selected conditions. Simulation is used to evaluate alternative scenarios of a candidate JP location. Those simulation results can enable management to compare the expected performance of the hybrid production system.

3.4 MCDM (multiple-criteria decision-making method)

The present paper proposes to solve the multi-response simulation-optimization problem by MCDM. It predicts the system performances for any combination of levels of control factors by using the main effects of the control factors according to the principles of a robust design method.

When all decision variables are restricted to only a few viable discrete values, and subject to the inclusion of sampling variability, the problem becomes a factorial design problem that is similar to Taguchi’s parameter-design (Yang and Chou, 2005). The main essence of hybrid Taguchi and TOPSIS is the notion of quality loss transformation. The idea of quality loss is applicable to the present study by transforming the performance measures into quality loss functions; as follows.

Let \( L_{ij} \) be the quality loss for the \( j \)th response at the \( i \)th scenario and let \( y_{ijk} \) be the simulation result for the \( j \)th response at the \( i \)th scenario, \( k \)th replication. \( N \) is the total number of replications and is equal to 20 for this research. The quality loss functions can then be defined as shown in equations (3) and (4) (Tong and Su 1997):

\[
L_{ij} = k_1 \frac{1}{N} \sum_{k=1}^{N} y_{ijk}^2,
\]

for the smaller-the-better response; and

\[
L_{ij} = k_2 \frac{1}{N} \sum_{k=1}^{N} \frac{1}{y_{ijk}^2},
\]

for the larger-the-better response.

In the proposed problem, the service-level is a ‘larger-the-better’ response and inventory cost is a ‘smaller-the-better’ response. The above loss functions were normalized to transform to a ‘larger-the-better’ type of measurement by equation (5).

\[
x_i = \frac{L_i - L_{ij}}{L_{i0} - L_{ij}},
\]

(5)
where $x_{ij}$ ($0 \leq x_{ij} \leq 1$) is the normalized loss function for the $i$th response at the $j$th scenario; $L_{\text{max}} = \max \{ L_1, L_2, \ldots, L_m \}$ and $L_{\text{min}} = m \in \{ L_1, L_2, \ldots, L_n \}$. The resulting $x_{ij}$ is a 'larger-the-better' type benefit function.

TOPSIS developed by Hwang and Yoon (1981) was based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. The terms used in the algorithm development are briefly defined as follows. Readers can refer to Yoon and Hwang’s paper (1995) for details.

3.5 Performance comparison

After these steps, each scenario will obtain the combination of optimum factors. Then, TOPSIS procedure to find the optimal performance will be one-more-proceeded. Finally, a robust combinatorial hybrid push/pull production system, evolved from pure push-control system, can be identified by using main effect analysis.

4. Empirical result

The proposed methodology is illustrated by the following case-study to validate the performance of the proposed methodology.

In this case-study, a TF T-LCD manufacturing company in Taiwan is investigated. The company’s business revenue was more than one billion US dollars in 2008. The company buys thin film transistors (TFT) plates, and applies a color filter (CF) process to scribe the product size. The operation comprises, inject liquid crystal, seal the panel, bevel to round edge, attach polarizer, and insert driving integrated circuit joints.

The next stage is an anisotropic conductive film (ACF) process, followed by flexible print circuit (FPC) bonding, and then ultraviolet (UV) process to enhance FPC pull-strength resistance. The silicon process is to enhance the reliability of the product. The assembled process includes all the necessary parts, such as black lights, diffuser etc, to complete the final TFT-LCD module. The final inspection process ensures the product’s quality to the end-customer.

This research selected four types of products as experimental material. The data was collected from the historical data of the company’s manufacturing executive system (MES) database. The MES defines a lot size as 30 pieces; and therefore it was selected as the simulation entity unit. Since so me of operation data is confidential, some data has been modified to respect confidential proprietary information of the company in this study.
The present research use value stream mapping (VSM) to help recognize the improvement from a push-control system to a hybrid push/pull control system, by providing a representation of both current-state and future-state maps. The difference between the current-state and potential future-states is helpful in visualizing what conditions would work when some improvements are conducted (McKenzie and Jayanthi, 2007). In this article, all data for the VSM was collected from MES and used mean values to represent it. Figure 3 shows the current-state map in the Company.

![Current-state map]

**Figure 3. Current-state map**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Location</th>
<th>Characteristic description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$JP_1$</td>
<td>Clean</td>
<td>Clean is the last batch run workstation.</td>
</tr>
<tr>
<td>$JP_2$</td>
<td>Test#1</td>
<td>Stage Test#1 workstation that has yield loss 10%.</td>
</tr>
<tr>
<td>$JP_3$</td>
<td>Edge</td>
<td>Build supermarket for Polarizer workstation, because Polarizer process has the longest setup time character.</td>
</tr>
<tr>
<td>$JP_4$</td>
<td>Polarizer</td>
<td>Build supermarket for bottleneck workstation of COG.</td>
</tr>
<tr>
<td>$JP_5$</td>
<td>ACF</td>
<td>Build supermarket for FPC workstation, since machine of FPC is short MTBF and long MTTR.</td>
</tr>
<tr>
<td>$JP_6$</td>
<td>Test#2</td>
<td>Test#2 workstation has yield loss 5%</td>
</tr>
<tr>
<td>$JP_7$</td>
<td>Silicon</td>
<td>There are no MTBF, MTTR, and setup time from Module to Final inspection workstation</td>
</tr>
</tbody>
</table>

The box in the map represents the workstation; and each process has a data sheet below including cycle time, machine number, setup time, etc. It is evident that the Company’s manufacturing environment has the following features: random setup times for different product changeovers, random break-downs, a batch process, and yield losses at three test workstations. Such complex problems encourage the manufacturing manager to adopt large amounts of inventory to reduce the affects of uncertainty. Consequently,
this study assumes seven possible push/pull junction points as listed in Table 1.

4.1 The control factors

Since each scenario has the least number of treatments to account for more than four, three-level control factors. Therefore, an $L_9 (3^4)$ orthogonal array was used to collect the experimental data.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description (Unit)</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Finished product upper limit (lots)</td>
<td>0</td>
<td>288</td>
<td>576</td>
</tr>
<tr>
<td>B</td>
<td>Level scheduling frequency (min)</td>
<td>2</td>
<td>4 6</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Transportation of batch number (lots)</td>
<td>1</td>
<td>2 3</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Semi-finished products (lots)</td>
<td>192</td>
<td>384 576</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 shows that there are four, three-level control factors in the present study. The four factors are denoted as A, B, C, and D. Each factor has three levels. The first factor is the upper limit of finished goods. The mean service-level of finished goods is 192 lots per-day, with a day's stock having mean values of 0, 1.5, and 3. If the stock is zero, it represents the MTO from JP to customer demand. The second factor is the semi-finished products located at junction point, as the input buffer (supermarket). The third factor is pitch time of level-scheduling. The fourth factor is the transportation-batch between each stage.

4.2 The scenario design

For the case-study, the number of hybrid push/pull junction locations range from 1 to 7 (depicted in Table 1); since pure push, pure pull, and CONWIP are a special case of the hybrid push/pull strategy. To sum up, the experimental requirement for the case-study involves 10 scenarios to be solve by MCDM. These scenarios encompass most manufacturing variability elements, including changeovers, batch size, yield loss, and random breakdowns.

4.3 Simulation model

The system is modeled using the commercial simulation software, Arena 10.0 (2005). After observing the system output performance values, the first 30 days data was discarded as representing a warm-up period. One year data was selected as the steady-state simulation period. To simulate the random, real system in a discrete-event simulator, numbers of replications were required to obtain an appropriate confidence interval. The current-state simulation results identified that the service-level is 97.2% and inventory is 4312 lots. This includes 2864 lots of WIP and 1448 lots of finished goods.
4.4 MCDM

An L9(34) orthogonal array was used to collect the experimental data. Columns 1 to 4 were adopted to represent the four control factors. Therefore, the parameter design of each scenario will be obtained by using the same procedure.

4.5 Performance comparison

The next step is to compare those 10 scenario performances using the TOPSIS. The data for each response was obtained from the performance measure. The experiment design and TOPSIS result are summarized in Table 3.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Optimal factor of each scenarios</th>
<th>$S_l$</th>
<th>$I_e$</th>
<th>$x_{i1}$</th>
<th>$x_{i2}$</th>
<th>$v_{i1}$</th>
<th>$v_{i2}$</th>
<th>$S_i^+$</th>
<th>$S_i^-$</th>
<th>$C_i^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Push</td>
<td>2 2 1 0</td>
<td>98.9%</td>
<td>4688</td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.1838</td>
<td>0.2537</td>
<td>0.2249</td>
<td>0.1463</td>
<td>0.3941</td>
</tr>
<tr>
<td>CONWIP</td>
<td>3 3 2 0</td>
<td>90.6%</td>
<td>2416</td>
<td>0.8950</td>
<td>0.4532</td>
<td>0.1684</td>
<td>0.1307</td>
<td>0.1030</td>
<td>0.1796</td>
<td>0.6354</td>
</tr>
<tr>
<td>Pull</td>
<td>2 1 1 0</td>
<td>20.2%</td>
<td>533</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0375</td>
<td>0.0288</td>
<td>0.1463</td>
<td>0.2249</td>
<td>0.6059</td>
</tr>
<tr>
<td>$JP_1$</td>
<td>2 1 2 0</td>
<td>62.8%</td>
<td>2908</td>
<td>0.5412</td>
<td>0.5715</td>
<td>0.1167</td>
<td>0.1573</td>
<td>0.1450</td>
<td>0.1247</td>
<td>0.4624</td>
</tr>
<tr>
<td>$JP_2$</td>
<td>2 2 2 0</td>
<td>82.9%</td>
<td>3037</td>
<td>0.7976</td>
<td>0.6026</td>
<td>0.1542</td>
<td>0.1643</td>
<td>0.1387</td>
<td>0.1469</td>
<td>0.5144</td>
</tr>
<tr>
<td>$JP_3$</td>
<td>2 2 2 0</td>
<td>87.3%</td>
<td>2666</td>
<td>0.8530</td>
<td>0.5134</td>
<td>0.1623</td>
<td>0.1443</td>
<td>0.1174</td>
<td>0.1659</td>
<td>0.5856</td>
</tr>
<tr>
<td>$JP_4$</td>
<td>3 3 2 0</td>
<td>90.9%</td>
<td>2325</td>
<td>0.8989</td>
<td>0.4313</td>
<td>0.1690</td>
<td>0.1258</td>
<td>0.0981</td>
<td>0.1834</td>
<td>0.6515</td>
</tr>
<tr>
<td>$JP_5$</td>
<td>3 3 1 0</td>
<td>93.9%</td>
<td>2297</td>
<td>0.9366</td>
<td>0.4245</td>
<td>0.1745</td>
<td>0.1243</td>
<td>0.0959</td>
<td>0.1884</td>
<td>0.6627</td>
</tr>
<tr>
<td>$JP_6$</td>
<td>2 2 2 0</td>
<td>95.3%</td>
<td>3040</td>
<td>0.9553</td>
<td>0.6033</td>
<td>0.1772</td>
<td>0.1645</td>
<td>0.1358</td>
<td>0.1657</td>
<td>0.5496</td>
</tr>
<tr>
<td>$JP_7$</td>
<td>2 2 2 0</td>
<td>96.8%</td>
<td>3545</td>
<td>0.9734</td>
<td>0.7249</td>
<td>0.1799</td>
<td>0.1918</td>
<td>0.1630</td>
<td>0.1552</td>
<td>0.4877</td>
</tr>
</tbody>
</table>

Note: $(w_1, w_2) = (0.5, 0.5)$

Finally, the steps rank the alternatives according to Table 6 equal-weighted results, as follows: $JP_1 > JP_6 > CONWIP > Pull > JP_3 > JP_7 > JP_5 > JP_4 > JP_2 > Push$

It is shown that the ‘best’ junction point location is always $JP5$. The location of $JP5$ is the longest MTTR workstation. Also, system variability of a downstream workstation is trivial, such that a pull-control strategy can be easily implemented. The second rank junction point is $JP4$. It is significant that to move $JP$ backward makes the service-level better and inventory cost performance lower.

4.6 VSM: Future-state

Acting upon areas identified from the value stream mapping of the existing state that need improvement, several changes were proposed (see Figures 4).

The results of the future-state map show that the cycle-time from the first stage to the supermarket is 7.3 days and less than 0.5 days from FPC to final workstation. This can be achieved by controlling the supermarket and stock upper-limit of 192 for each product type; and a total of 576 lots by implementing MTS, respectively. The
supermarket before the $JP$ is established is 192 lots for each product type. To establish a continuous flow, the average WIP in supermarket is 434 lots - represented by 54.3 hours cycle time. Comparison of results, between the current-state map and the proposed future-state map, is summarized in Table 6.

![Figure 4. Future-state map](image)

Table 4 shows that the performance measures of inventory cost and service-level of the future-state significantly outperform the current-state map. A decision-maker may not accept the compromised solution, because the service-level is 3.4% lower. Then a backward $JP$ location to $JP6$ or $JP7$ can achieve a higher service-level of 95.3% and 96.8%, respectively. In this instance, performance will be sacrificed at the expense of inventory cost.

<table>
<thead>
<tr>
<th>Comparing items</th>
<th>Current-state</th>
<th>Future-state</th>
<th>Improvement ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput rate (%)</td>
<td>97.2</td>
<td>93.9</td>
<td>-3.40%</td>
</tr>
<tr>
<td>Inventory cost (lot)</td>
<td>4312</td>
<td>2297</td>
<td>46.73%</td>
</tr>
<tr>
<td>Cycle Time (day)</td>
<td>14.92</td>
<td>10.00</td>
<td>32.97%</td>
</tr>
</tbody>
</table>

5. Conclusions and future research

The objective of this research was to address a variety of irregular dynamic junction point location models. The underlying purpose was to achieve benefits from both a higher service-level and lower inventory cost. The study also proposed an effective procedure, based on a MCDM approach, to solve appropriate junction point location problems from alternative candidate scenarios.

By analyzing the results, a number of design conclusions can be identified. First,
implementing a pull-control sub-system can result in lower system inventory costs. Second, an upstream push-control sub-system design will continuously maintain the supply of semi-products. Third, in normal conditions, a junction point can be located in a stage where the downstream process variability is minor. Fourth, implementing MTS in a pull sub-system achieves a better performance than MTO. Finally, the proposed analysis procedure can be simply extended to problems that have complex production variability.

Future research direction includes extending the model to include detail factors encompassing design problems, possibly encompassing supplier considerations. Detailed reflection, on post-implementation, could reveal insightful lessons for real-world improvements.

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