An exploratory study on uncertainty-reducing practices

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Abstract: Uncertainty-reducing practices such as labour overtime, safety production capacity, inventory levels, and their effect on performance have been analysed exclusively on simulation-based studies. To the best of our knowledge, this is the first paper that empirically explores this topic. The results should be of relevance for both practitioners and researchers.

Keywords: labour overtime, safety production capacity, inventory levels, uncertainty, manufacturing performance

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1. Introduction

Uncertainties with suppliers, manufacturing processes and customers' demands have been the subject of much research and study. There is a vast body of literature that has explored different alternatives to deal with such uncertainties. Variability-reducing practices such as safety inventory of materials, safety production capacity and labour overtime have been studied and recommended as ways with which companies can successfully cope with these uncertainties. Interestingly, a review of the literature reveals that these practices have been studied mainly through simulation studies.

This paper presents a study of uncertainty-reducing practices in 48 UK manufacturing companies in the electronics industry. Practices such as materials inventory, safety production capacity and labour overtime are studied with regards to their effect on other manufacturing performance measures. We feel that it is important that these approaches are tested in real-life manufacturing settings. We propose to explore whether the results obtained in simulated environments are also replicated in real life situations.

The remainder of the paper is structured as follows: section 2 reviews some of the literature of uncertainties throughout the supply chain. Section 3 discusses the literature review and states the research hypotheses. Section 4 describes the data and research methods. Section 5 analyses the information and tests the research hypotheses. Finally, section 6 offers some conclusions and suggestions for future research.

2. Uncertainties throughout the supply chain: a literature review

Uncertainties are part of the every day operations of any manufacturing plant. Even in industries where demand is stable and predictable, companies still have to deal with uncertainties inside their own facilities. Unstable labour force, machines and processes can also go out of control, etc. thus, companies have to respond to these uncertainties in one way or another if they are to meet their commitments with customers. In the following paragraphs, studies that have examined the effect of these uncertainties, and some practices used to deal with them are shown. In order to achieve brevity, we only show some papers that are representative of the literature.

2.1 Uncertainties with suppliers

Benton and Krajewski (1990) explore the impact that uncertainty in vendor’s quality and lead times has on some manufacturing measures. Their study shows that vendor's performance does have a significant impact on some of their customers' manufacturing performance measures. The authors recommend some strategies to dampen the effects of poor vendor performance, but at the same time encourage companies to rate/develop their suppliers in a close, co-operative partnership so the detrimental effects of poor vendor performance are avoided.
Handfield and Pannesi (1995) analyse the supply chain management factors which can lead to cycle-time reduction in make-to-order (MTO) markets. The results show that indeed, supplier performance is a significant antecedent of lead-time competitiveness.

Vastag and Montabon (2001) propose a model of “competitive advantage” and how it is affected by several practices, issues and manufacturing performance indicators. It is hypothesised that supplier performance (measured by the percentage of early, on-time and late purchase orders and average lateness of late orders) significantly affects the inventory levels and structure. Results reveal that the measures of supplier performance were all significantly related to the percentage of work in process (WIP) inventories. Supplier performance also was significantly related to raw materials inventory variation. Also, supplier delivery lateness (i.e. percentage of orders delivered late and average lateness of orders) proved to be significant in increasing the WIP levels. Increased lateness of late orders also contributed to the reduction of raw materials inventories. Ostensibly, supplier performance in terms of delivery reliability and average lateness has significant effects on both the inventory levels and its structure.

Milgate (2001) analyses “supply chain complexity” and how it affects some manufacturing performance indicators. Results show that the poorer the performance of the suppliers in terms of delivery reliability and quality of incoming materials, the poorer the performance of their customers. The “uncertainty” factor of supply chain complexity may be the most difficult for managers to accommodate and reduce. Thus, some sort of buffers in the form of extended lead time, or additional safety stocks may be required to cope with these uncertainties, the author concludes.

### 2.2 Uncertainties with manufacturing processes

Kurtulus and Pentico (1988) analyse three different material requirement planning (MRP) systems when there is scrap loss. Results show that in two of the three manufacturing processes structures, some rules that perform well under the low levels of inventory criteria do not do as well when it comes to meeting customer demands. The authors conclude that generally, in situations where there are process yield losses, a company has to spend on inventory costs in order to obtain high rates of MPS orders filled. However, as this study shows, this situation may be dependent on the bill of materials structure of the products.

Atwater and Chakravorty (1994) employ simulation to study the effects of protective capacity (PC) in two hypothetical production lines, one with protective capacity (WPC), and the other without protective capacity (WOPC). Results show that in the cases of low variability on both processing time and down time, generally the WPC line achieves a faster cycle time than the WOPC line at all levels of inventory. A similar situation is seen in the case of high processing time variability and low down time variability. Arguably, to be a true competitive edge, short lead times must be accompanied with high on-time delivery percentages. It is concluded that in the presence of variability in processing time and down time, the use of protective capacity can help companies achieve both shorter lead times and more reliable performance, thus enabling better on-time delivery, all of this while operating at lower levels of inventory.
Pandey and Hasin (1998) study the impact of scrap on process lead-time in batch-oriented, discrete-parts, intermittent-flow, make-to-stock manufacturing environments. Results based on simulation runs show that in the presence of scrap, the process layout configuration (in particular the position of the bottleneck work centre) can have a significant impact on the manufacturing lead-time. Another interesting result shows that the impact in terms of lost time on the bottleneck machine due to scrap produced in the preceding machine may depend on the time-instance at which the scrap-unit is produced. Nevertheless, scrap produced by a bottleneck machine, or its successor machines, will always have full impact on the machines succeeding them. Hence, the authors conclude that it is vital to control the rate of scrap generation, and encourage practitioners to understand better the complex nature of the interrelationships between the proportion of scrap produced, the manufacturing line layout and configuration, and the batch manufacturing lead-time.

Hurley and Whybark (1999) examine the performance of potential different alternatives to buffer against uncertainties regarding product mix and processing time. Two buffering approaches (WIP inventory and protective capacity) are used, along with a scenario in which the variability is reduced. Results indicate that as inventory is added, output rates, cycle time and utilisation increase (though nominally in the “push” environment). As protective capacity is added, output increases, cycle time decreases and utilisation decreases. As uncertainty is reduced, cycle time decreases, output increases and utilisation increases. The authors conclude that protective capacity should be considered as a serious alternative to WIP inventory for buffering against uncertainty.

Hung and Chang (1999) propose a new methodology for computing the standard deviation for cumulative good product output of a particular product type at a particular time. The authors review some approaches such as safety lead times, safety stocks of materials and protective capacity, which are generally recommended to lessen the effects of the different types of uncertainties. They conclude that in the presence of both flow time and yield rates uncertainties, safety stocks of inventory is the best option to cope with such uncertainties. It is concluded that by using this methodology, companies may be able to determine more accurately safety stocks levels, which should improve on-time delivery and customer service.

Doerr et al (2000) propose a model that jointly assigns workers and tasks to workstations to minimise the expected total cost of regular time and overtime production. Results show that planned overtime occurs in 92 % of the solutions, which indicates the usefulness of overtime when manufacturing to a quota on a synchronous line. Expectedly, total costs increase as worker variability increase. The authors conclude that planned overtime is frequently beneficial in terms of costs. They also comment that when worker times are highly variable, it may be relatively more efficient to pay for more overtime rather than hire more workers, which would introduce more variability.

2.3 Uncertainties with customers’ demands

South and Hixson (1988) argue that in addition to reducing work-in-process inventory, excess capacity may function as a substitute to safety stocks of finished goods to respond to fluctuations in demand and hence maintain a good service level.
They numerically compare the costs of having excess capacity versus the costs of having safety stocks of finished goods inventory. Based on their results and examples, the authors comment that companies should look more carefully at the trade-off between excess capacity and finished goods safety inventory. They say that when excess capacity exists, a reduction in finished goods inventory may be possible, and in some cases, the inventory reduction may be sufficient to offset the cost of the excess capacity.

Mapes (1993) analyses the relationships amongst three variables: levels of safety stock of materials, capacity utilisation and customer service levels. The results show that as production capacity approaches mean demand (i.e. reduced safety capacity), stockout risk increases and customer service level falls. Other results show that when safety stock is constant and average weekly demand and capacity are increased by the same amount, stockout risk and the number of backorders does not vary. The author comments that stock-out risk and partial backorder expectation are both functions of the excess capacity over average demand. The author says that the results clearly show that the effect of production capacity limitations is to increase significantly the amount of safety stock necessary to provide a given service level.

Grubbstrom and Molinder (1996) apply Laplace transform methodology in order to compute optimal safety stock values in a manufacturing environment with stochastic demand. The authors study the average setup, inventory holding and backlog costs in one and two-level assembly systems. Numerical solutions for the one-level system show that when the backlog cost parameter system is high, cumulative production increases faster than cumulative demand, resulting in an increase in safety stocks over time. On the other hand, in the case of a high inventory holding cost parameter, expectedly, the safety stock becomes negative. The authors note that in the two-level system, replenishment at the lower-level always must take place at the same time as some upper-level replenishment, and at that time both cumulative levels must coincide. It is concluded that safety production plans can be determined by using Laplace transform methodology in cases such as the ones examined in the study. The authors however propose to analyse this methodology under varied considerations and more general, real-life settings.

Helo (2000) analyses how slack-capacity can be used to build agility into supply chains. The results show that capacity limitations constrain the ability of an echelon in the supply chain to process goods. The author says that cost-efficiency and fast delivery are trade-off performances that can not be maximised at the same time. He explains that in some very uncertain industries, buffering against variability (in demand, product mix and volume) by utilising inventories may be uneconomical. When technologies are changing rapidly, having old components, subassemblies or finished products may be very expensive. The author also notes that order variety may require various set-up changes that inevitably consume capacity. Due to this situation, in order to guarantee faster lead-times or to be prepared for a number of set-ups changes, a certain amount of slack-capacity may be required to hedge against this type of uncertainty. The author adds that big, separate production orders may cause problems in guaranteeing order-fulfilment. Thus, by using smaller sizes more frequently, the supply chain is more capable of reacting to changes faster. Hence, the author concludes that buffering against market changes by using flexible capacity (in terms of capital investment and labour) should be considered as a viable option, especially when demand is close to the final customer as value-addition is highest at that state.
2.4 Studies that analyse combined sources of uncertainty

Duenyas et al (1997) examine the use of production overtime as an alternative to cope with demand uncertainty and production rates uncertainty. Numerical examples to the mathematical solutions show that in some cases, when the fixed overtime costs increase considerably, it may be more sensible to try to increase the production quota (i.e. regular-time production) so the need to use overtime to deal with high demand lessens. A similar situation occurs when variable overtime costs increase considerably. However, if the backorder costs decrease substantially it may be sensible (cost wise) to reduce the regular production quota (hence failing to meet the demand), which in turn will decrease even further the need to use overtime. Expectedly, when the holding costs decrease drastically, this scenario makes it more attractive to carry inventory (by augmenting the regular production quota) from one period to another. As expected, when the mean demand is lowered, the regular-time production quota is also reduced (i.e. because less on-hand inventory is needed to meet demand), whereas reducing production capacity leads to a higher regular-time production quota (i.e. to take advantage of high production when it is possible). Interestingly, a reduction in the variability of the production capacity tends to reduce the optimal production quota and the total cost. Also, when demand variability is reduced, the total costs are also lowered, even though the production parameters do not change. Thus, the authors encourage manufacturing plants to embark on efforts to reduce both the production capacity and customers’ demand variability.

Koh et al (2000) aim at measuring uncertainties in MRP environments. Based on their literature review, the authors classify the different approaches to deal with uncertainties at the aggregate, intermediate and operational levels. The authors then proceed with a survey in which MRP users are asked to describe the practices they utilise to deal with a variety of uncertainties. The participants are classified into four groups (“good”, “poor”, laggards” and “improvers”) according to their uncertainty levels and customer delivery performance. It is found that in the group of “good” performers, overtime is used to deal with uncertainties such as rework, changes to master production schedule (MPS), customer order changes and design changes. The “poor” performers utilise overtime to respond to a number of uncertainties, including subassembly shortages, material shortages, labour shortages, machine breakdowns, rework, changes to MPS, customer order changes, supplier late deliveries and design changes. Part and finished goods safety inventory is used against labour shortages, machine breakdowns and customer order changes, while spare capacity is utilised to deal with machine breakdowns. Amongst the group of “laggard” companies, finished goods safety inventory is used to deal with machine breakdowns, rework and changes to MPS. Part safety inventory is employed against subassembly shortages, material shortages, machine breakdowns, rework, changes to MPS and customer order changes. The group of “improvers” use overtime when they face uncertainties such as labour shortages, machine breakdowns, rework, changes to MPS, customer order changes, late delivery from suppliers and design changes. The authors argue that overtime, subcontract, safety stocks for parts and multi-skill labour seem to be the prevalent approaches to deal with a variety of uncertainties in each of the four groups. They conclude that in general, overtime and/or multi-skill labour are the relatively most effective and most used approaches since both “good” and “improvers” groups that adopted those approaches obtain a good customer delivery performance.
3. Discussion of the literature and research hypotheses

Previous studies have examined the issue of uncertainties, and how they can affect and be dealt with. In particular, we have focused on representative studies that show how practices such as inventory of materials, safety production capacity and labour overtime can be used as a response to different types of uncertainties (e.g.; suppliers, manufacturing processes and customers’ demands). It is interesting to note that some alternatives may be more recommendable to others depending on the circumstances. Also, depending on the competitive priorities of a company, it may decide to respond or not to the uncertainties.

The review of the literature shows that the vast majority of studies has analysed the use of these practices with simulation-based approaches. Our aim is to advance the knowledge in this field by examining some of the relationships found in previous studies with information provided by real companies with respect to their use of uncertainty-reducing practices (i.e.; labour overtime, materials inventory and safety production capacity), and how they affect other measures of performance (e.g.; delivery reliability, manufacturing speed), and also to study whether the use of one practice affects the use of another one.

Thus, we proceed to propose various research hypotheses based on the reviewed evidence:

**Hypothesis 1:** uncertainty-reducing practices are positively related to delivery reliability rates.

**Hypothesis 2:** uncertainty-reducing practices are positively related to speed of manufacturing performance.

**Hypothesis 3:** volume flexibility performance is positively related to uncertainty-reducing practices.

**Hypothesis 4:** companies favour the use of some practices over other ones.

4. Research methods and data

A mail survey was sent in the summer of 2002 to a group of companies listed in the Kompass (2002) and FAME (2002) websites. The questionnaires were sent to 653 companies included in the category “electricity, electronics and nuclear” in the Kompass database and 923 companies in the FAME database classified under the US SIC code 36, which corresponds to the category “electronic and other electrical equipment and components, except computer equipment”. Responses from the recipients arrived over a period of several weeks after sending questionnaires. Various questionnaires were returned with incomplete answers. The respondents were contacted again in order to have the incomplete items answered. In some instances, respondents were not available or did not want to provide more information. Thus, it was decided to discard the questionnaires that did not have some of the main dependent variables fully answered from further analysis (on-time delivery measure, inventory turnover, safety production capacity, labour overtime and defective product return rates). This is consistent with the recommendations from Hair et al (1998). With regards to the rest of the variables, it was decided to adopt the
mean value of the whole sample in the case of missing values. In the final sample, only one variable presented one missing value (stock keeping units). Furthermore, as the FAME database includes companies from Ireland, and for homogeneity purposes, it was decided to exclude them from the study and use only UK companies.

Companies from the Kompass sample returned a total of 49 questionnaires. However, only 18 of these met the established criteria. 26 respondents indicated they are not manufacturers. One questionnaire was incomplete, another company indicated they are no longer manufacturers, two questionnaires were returned totally unanswered, and one company decided not to participate. Thus, the rate of usable questionnaires for the Kompass sample was 2.75 % (18/653).

Respondents from the FAME sample returned a total of 60 questionnaires. Nevertheless, only 30 of these met the required criteria. 12 companies indicated they are not manufacturers. 3 questionnaires were returned due to wrong addresses. 3 more were returned because people decided not to participate or were not available. 2 questionnaires were returned incomplete. 3 companies were from Ireland. 5 companies were no longer in manufacturing or had closed down operations. 2 more companies returned the questionnaires with no answers at all. Therefore, the rate of usable questionnaires for the FAME sample was 3.25 % (30/923). The total rate of usable questionnaires combining the Kompass and FAME populations was 3.04 % (48/1576). Thus, the final sample consisted of 48 UK companies that responded to the “electronic and other electrical equipment and components, except computer equipment” category.

As an exploratory study, and due to the limited number of subjects, we decided to use correlation analysis in order to test the four research hypotheses.

The following table shows the different variables included in this study:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>“Best value”</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTD</td>
<td>On-time delivery rates</td>
<td>High</td>
<td>Also referred to as “delivery reliability” in the study</td>
</tr>
<tr>
<td>ROM</td>
<td>Rate of manufacturing cycle performance</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>GPC</td>
<td>Good product with customers</td>
<td>High</td>
<td>GPC = 100 – average percentage of defective product return</td>
</tr>
<tr>
<td>DPWP</td>
<td>Defective product whole process</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>VF</td>
<td>Volume flexibility</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>INVTIT</td>
<td>Total inventory levels</td>
<td>High</td>
<td>INVTIT= 1/TIT</td>
</tr>
<tr>
<td>LO</td>
<td>Labour overtime</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC</td>
<td>Safety production capacity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Variables included in this study.
5. Results and discussion

The research hypotheses state that:

**H1:** uncertainty-reducing practices are positively related to delivery reliability rates.

**H2:** safety production capacity is positively related to speed of manufacturing performance.

**H3:** volume flexibility performance is positively related to uncertainty-reducing practices.

**H4:** companies favour the use of some practices over other ones.

The following table shows the correlation analysis between delivery reliability rates, rate of manufacturing performance cycle performance, and the three uncertainty-reducing practices:

<table>
<thead>
<tr>
<th></th>
<th>INVITIT</th>
<th>OTD</th>
<th>ROM</th>
<th>GPC</th>
<th>DPWP</th>
<th>VF</th>
<th>LO</th>
<th>SC</th>
</tr>
</thead>
<tbody>
<tr>
<td>INVITIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTD</td>
<td>-0.070</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROM</td>
<td>-0.099</td>
<td>0.041</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPC</td>
<td>-0.023</td>
<td>0.160</td>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DPWP</td>
<td>0.097</td>
<td>-0.207</td>
<td>-0.240</td>
<td>-0.364</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF</td>
<td>-0.062</td>
<td>-0.065</td>
<td>0.524</td>
<td>-0.099</td>
<td>-0.146</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LO</td>
<td>-0.107</td>
<td>-0.147</td>
<td>0.240</td>
<td>-0.013</td>
<td>-0.005</td>
<td>0.296</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC</td>
<td>0.026</td>
<td>-0.034</td>
<td>0.123</td>
<td>-0.189</td>
<td>0.034</td>
<td>0.170</td>
<td>0.156</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Pearson correlation analysis.

n= 48

**BOLD**= significant at the .05 level

**BOLD ITALIC** = significant at the .01 level

The results show that contrary to theory and previous evidence, no one of the uncertainty-reducing variables is positively related to delivery reliability rates. Interestingly, the sign of the relationships between delivery reliability rates and each of the uncertainty-reducing variables, though not statistically significant, is negative, which also goes against our predictions. Thus, hypothesis 1 is rejected.

The relationship between safety production capacity and rate of manufacturing cycle performance is not statistically significant, though the coefficient has the sign that was predicted (positive). Based on this, hypothesis 2 is also rejected.
Volume flexibility is positively and significantly related to labour overtime, but not significantly related to materials inventory of production capacity. This means that companies in this sector, when faced with extra demand from customers, schedule labour overtime to respond favourably to this extra demand. This is consistent with previous study and theory. Thus, hypothesis 3 is accepted in the case of labour overtime.

The relationship amongst the three uncertainty-reducing practices (inventory levels, safety production capacity and labour overtime) is not significant. This might mean that companies do not necessarily employ one type of practice over another one. For instance, the correlation sign between labour overtime and safety production capacity, though not statistically significant, is positive. Interestingly, the correlation sign between inventory levels and safety production capacity is positive, while the correlation sign between labour turnover and inventory levels is negative. However, since all these results are not significant, hypothesis 4 is rejected.

6. Conclusions and suggestions for future research

Uncertainty-reducing practices have been the topic of much research. However, almost without exception, previous studies have employed simulation in order to examine the effect of these practices on manufacturing performance measures such as delivery reliability, manufacturing cycle performance, and volume flexibility performance. To the best of our knowledge, this is the first study that attempts at studying this topic with information from real manufacturing companies.

Four research hypotheses were proposed in order to study this topic. Only hypothesis 3 was accepted, in the specific case of volume flexibility and labour overtime. This tells us that, consistent with evidence and theory, companies employ extra resources in order to be flexible enough to respond favourably to extra demands in customers’ demands. Responding to customers’ demands and achieving low manufacturing costs might be a trade-off that can not be resolved. Helo (2000) notes that cost-efficiency and fast delivery are trade-off performances that can not be maximised at the same time. He adds that buffering against market changes by using flexible capacity (in terms of capital investment and labour) should be considered as a viable option, especially when demand is close to the final customer as value-addition is highest at that state. The results of our study seem to be consistent with these ideas.

This research has several limitations that give scope for future research. Both the sample size and the response rate are low, which make the results difficult to extrapolate. The survey was planned and designed considering the factors that result in good response rates. Unfortunately, this could not be achieved. We hope that future researchers who deal with this topic obtain a bigger and more representative sample.

The items that measure the uncertainty-reducing practices can also be improved. In particular, we think that the variable that measures inventory levels can be divided into finished goods inventory, work in process inventory, and raw materials inventory. The measure used in our study was an aggregate of these three inventory levels.
With more disaggregate measures, the relationships between inventory levels and other variables in our study could turn out to be confirmed.

In terms of the analysis of the information, we think that regression analysis could be a better alternative to analyse the relationships of uncertainty-reducing variables with manufacturing performance measures. It could be that with a bigger and more representative sample, regression analysis could confirm the hypotheses predicted in our study.

This research is an advance over previous studies. We hope future researchers will build upon the strengths and limitations of our study.

**Note: the items used in the survey, as well as statistical information about the variables in this paper are available upon request.**

**References**


• Kompass database (2002). www.kompass.com


