Uncertainty and contingency plans in ERP-controlled manufacturing environments

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Abstract

Purpose – This research aims to determine to what extent uncertainties affected manufacturing enterprises' delivery performance, to analyse the performance of their contingency plans in dealing with uncertainties and to explore what technical and organisational factors affected managers' decisions to implement an uncertainty-diagnosing model.

Design/methodology/approach – The methodology included a literature review, postal questionnaire survey and telephone interviews.

Findings – A total of 30 companies responded to the questionnaire, 56 per cent of which thought their systems worked well and 80 per cent reported that material shortages were responsible for tardy delivery performance. Tardy delivery was directly or indirectly caused by poor supplier delivery performance in the opinion of 92 per cent of respondents. Seven companies had developed an uncertainty-diagnosing model. Not all companies needed to adopt the model.

Research limitations/implications – Uncertainty and contingency plans were investigated in UK and Chinese organisations using MRP/MRPII/ERP systems. Therefore, the findings will be directly relevant to the organisations, but may be adapted to other similar organisations.

Practical implications – A detection method was proposed to determine the steps required for organisations to adopt the uncertainty-diagnosing model.

Originality/value – The paper provides some empirical data on uncertainty and the contingency plans used in ERP-controlled manufacturing environments in organisations in the UK and China. Data on uncertainty are scarce and this research gives further insights into the ways managers perceive and handle uncertainty.

Keywords Uncertainty management, Contingency planning, Inventory control, Manufacturing resource planning, United Kingdom, China

Paper type Research paper

1. Introduction

A great deal of effort has been expended in developing production planning and control systems. The very early work on simple paper-based systems developed in the 1920s has given way to more sophisticated systems as technology has advanced and become more widely available. In the 1960s materials requirements planning (MRP) was introduced by Oliver Wight and Joseph Orlicky. MRP aimed to provide the right materials to produce the right product in the right quantity so that, after manufacture, would result in the product being delivered at the right time.

MRP systems were designed to operate in stable and predictable batch manufacturing environments (Wijngaard and Wortmann, 1985). The MRP system calculates the planned order release (POR) schedule and this is used to execute purchasing or manufacturing operations. MRP is at the heart of manufacturing resource planning (MRPII) systems but with the addition of a feedback loop that considers used and available resource capacity. Enterprise resource planning (ERP)

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emerged in the 1990s and is a more advanced and sophisticated version of MRPII (Davenport, 2000). ERP systems integrate a number of business functions such as sales, marketing, accounting, purchasing, logistics and human resources. In production planning ERP uses the same principles and release logic as MRPII and therefore suffers from the same basic problems as MRP and MRPII (Koh, 2004). These problems are based on some assumptions and simplifications of reality, which affect the calculation of the POR schedule. For example, MRP assumes infinite capacity in developing POR schedules, assumes that both the planned purchasing and manufacturing lead times are constant and ignores the effect of uncertainty such as variation in lead-times due to late deliveries from suppliers or machine breakdowns. The feedback loop in MRPII does not operate in real time and therefore when uncertainty occurs, it is too late to plan for it. Thus, when dealing with uncertainty the POR schedule that is generated from ERP systems can result in orders being delivered late.

The effect of uncertainty on these systems has been noticed for some time and a great deal of research has been done to try and solve this problem. Koh *et al.* (2002) argued that uncertainty within ERP environments has not been studied systematically and that most researchers have attempted to find ways to cope with uncertainty rather than by diagnosing the significant underlying causes of those uncertainties. Koh and Saad (2002) have developed a business model to enable the underlying causes of uncertainty to be diagnosed within MRP/MRPII/ERP manufacturing environments. This model provides managers with a method to systematically analyse the uncertainties occurring within their organisation and determine the underlying causes of these uncertainties. Managers should then be able to adopt proper approaches or contingency plans to tackle these uncertainties. Thus, this work aimed to investigate the type of uncertainty that occurs, determine the extent to which uncertainties affected the manufacturing enterprises' delivery performance, identify the contingency plans used by managers to cope with these uncertainties and determine the performance of their contingency plans in dealing with uncertainties. This research also explored the technical and organisational factors that affected managers' decisions to implement an uncertainty-diagnosing model.

2. Literature review

MRP has been described as a system that consists of a set of logically-related procedures, decision rules, and records designed to translate a master production schedule (MPS) into time-phased net requirements, and the planned coverage of each requirement, for each component inventory item needed to implement this schedule (Orlicky cited in Chung and Snyder, 2000). In 1975, the MRP system was expanded to the standard MRPII system (Gray and Landvater, 1989) and is at the heart of MRPII systems (Parker, 1996). MRPII integrates information, manufacturing technology, plans and resources to improve the efficiency of a manufacturing enterprise. MRPII effectively plans all the resources of a manufacturing company. It is made up of a variety of functions, each linked together: business planning, sales and operations planning, production planning, MPS, MRP, capacity requirements planning, and the execution support systems for capacity and material. Output from these systems is integrated with financial reports such as the business plan, purchase commitment report, shipping budget, and inventory projections in monetary value. MRPII is a direct outgrowth and extension of closed-loop MRP.

ERP can be defined as an accounting-orientated information system for identifying and planning the enterprise-wide resources needed to take, make, ship, and account for customer orders. An ERP system differs from the typical MRPII system in technical requirements such as graphical user interface, relational database, use of fourth-generation language, and computer-aided software engineering tools in development, client/server architecture, and open-system portability (Cox and Blackstone, 1998). Chung and Snyder (2000) identified three distinct features of ERP in their architecture: the data dictionary, middleware and the repository. These three technological features are used to co-ordinate marketing, manufacturing, distribution, and human resources tasks within the firm.

It has been suggested that the claimed benefits of MRP (and MRPII and ERP systems) cannot be realised mainly because of the underlying assumptions used in MRP development (Steele *et al.*, 2005). The limitations in MRP's assumptions are listed as (Koh *et al.*, 2000):

- MRP systems use fixed lead-times to plan for material purchase and product manufacture. This ignores real life uncertainties of supply unavailability, variability of queue and variations in set-up and run times on the shop floor.
- As MRP was originally developed as a pure material planning system, the net requirement plans generated do not consider the availability of resource simultaneously, but identify resources required as a separate, subsequent activity.
- MRP systems work in a predefined routing in which the flow of materials has been fixed. Once some unplanned events have occurred, such as a machine breakdown or blockage from the initial route, MRP systems have no alternative routing to deal with it.
- MRP systems may be loaded with a pre-determined scrap rate. Any increase in this rate will automatically render the due date uncertain unless corrective measures are taken.

MRP systems do not consider supply uncertainties such as material shortages, labour shortages, faulty components and machine breakdowns, which would make the schedule receipt and schedule release differ from that planned.

These assumptions of MRP directly lead to its inability to cope with the uncertainty in a real manufacturing environment. Consequently, under-performance of MRP is unavoidable. MRP/MRPII/ERP is an "enabler" (planner) rather than "optimiser" (executor) (Mandal and Gunasekaran, 2003; Koh *et al.*, 2000). It can be executed under an ideal environment without any uncertainties. However, in the real world the planner has to apply some other techniques, such as rescheduling or subcontracting, to cope with the uncertainty.

Because of the assumptions and limitations of MRP/MRPII/ERP systems, the occurrence of uncertainty can cause a series of problems and the performance of these systems will be poor. Vollmann *et al.* (1992) categorised uncertainties into four types:

(1) Requirements shift from one period to another.

(2) Requirements are for more or less than planned.

(3) Orders not received when due from suppliers.

(4) Orders are received from suppliers for more or less than planned.

Koh *et al.* (2002) categorised uncertainty into input and process uncertainties. A variety of approaches or contingency plans have been suggested to cope with the unwanted effect of uncertainty. Yeung *et al.* (1998) has reviewed the types of approaches to cope with uncertainty. Most of these approaches or contingency plans can be categorised as either buffering or dampening.

2.1. Buffering

Cox and Blackstone (1998) defined buffering as a quantity of resource waiting for processing that is purposely maintained behind a work centre. Based on this definition, the buffering approaches can include for example holding safety stocks of finished product, holding safety stocks of raw materials or semi-finished components, safety capacity, etc. Based on the review from Koh *et al.* (2002), it was found that safety stock is deemed the most robust method in the buffering category (Miller, 1979; De Bodt *et al.*, 1982; Vargas and Metters, 1996; Krupp, 1997; Ho and Ireland, 1998; Kurtulus and Pentico, 1988; Guide and Srivastava, 2000).

Grasso and Taylor (1984) advocated the use of safety stock in dealing with material late delivery. New and Mapes (1984) indicated that application of mean yield rate and fixed buffer stocks is appropriate for continuous schedule, make-to-stock (MTS) environments. Wacker (1985) proposed that safety stock could be used robustly to buffer external supply, external demand and internal supply uncertainties for variations in timing and quantity. Yano and Carlson (1985) advocated the use of safety stock instead of using re-planning of MPS to maintain customer service, because the cost due to frequent re-planning exceeds the cost of safety stock required to maintain a stable schedule.

Vargas and Dear (1991) identified that safety stock should be used robustly to buffer external demand and internal supply uncertainties. Atwater and Chakravorty (1994) found that the use of safety capacity at non-constraints above the system's constraints capacity to be effective in buffering external supply uncertainty, late supply, internal supply uncertainty, machine breakdown, internal demand uncertainty and quality variation.

2.2. Dampening

Planning methodologies such as rescheduling and safety lead-time could not be categorised under buffering. To categorise this type of approaches, the term dampening has been coined (Koh *et al.*, 2002). Dampening approaches include MPS hedging (Miller, 1979), over-planning to deal with the uncertainty of quality variation (Murthy and Ma, 1991), planned horizon freezing (Sridharan and Berry, 1990; Sridharan and Laforge, 1994) and safety lead-time to cope with a variety of uncertainties. Hedging the MPS can protect against stock-outs or undesirable backlogs (Miller, 1979). Ho (1993) found that lot-sizing can be used to cope with a variety of uncertainties but Fildes and Kingsman (1997) argued that improving forecast accuracy regardless of the cost structure was much better than just using lot-sizing rules in dealing with uncertainty in customers' demand. Kurtulus and Pentico (1988) suggested the use of the expected value and the marginal lot-sizing rule to dampen process yield loss. Pandey and Hasin (1998) proposed the use of lead-time adjustment to dampen the difference between the planned scrap level and the actual scrap level. Sridharan and Berry (1990) found that in an uncertain demand environment the order-based freezing method can perform better. In addition, they also found that a longer frozen interval produces higher costs.

2.3. Combination of buffering and dampening

Some researchers propose the use of a combination of buffering and dampening approaches to deal with uncertainty. Whybark and Williams (1976) compared the performance of safety stock and safety lead-time for building a buffer inventory to protect demand against uncertainty in a single item MRP system. The simulation results showed that quantity uncertainty is best dealt with using the safety stock approach, while in the case of timing uncertainty; the safety lead-time approach is more appropriate.

Schmitt's (1984) research indicated that safety capacity could reduce actual lead times compared to other methods leading to improved service levels. Schmitt proposed the use of safety stock and net-change rescheduling respectively to buffer and dampen internal supply uncertainty. Buzacott and Shanthikumar (1994) found that frequent changes in the timing of orders favoured the use of safety stocks, but safety lead-time was preferable when it was possible to accurately forecast future requirements. Yano and Carlson (1987) concluded that fixed scheduling was more economical and frequent rescheduling should be performed with caution.

2.4. Limitations of previous research

Research on coping with uncertainty has covered a wide area. However, there are still some problems encountered in coping with uncertainty. Despite the fact that there are so many buffering and dampening approaches or contingency plans, enterprises have no tool to identify the most important uncertainty in their organisations. It would be uneconomic and very difficult to adopt all the methods of coping with uncertainty simultaneously. This literature review shows that there is a lack of research on identifying the relatively important uncertainties, through which finite resources can be used to deal with them and this means that enterprises cannot achieve an optimal result when coping with uncertainty. Most of the previous research has usually focused on one of several kinds of uncertainty. Even with sufficient resources, without a comprehensive and/or holistic view on uncertainty it is impossible for an organisation to prepare for all types of uncertainty. When enterprises can find proper approaches to deal with uncertainty, the underlying causes of the uncertainty often remain unknown. Previous research had only examined the effects of uncertainty instead of identifying the underlying causes of uncertainty, which gives rise to significant effects on an enterprise's delivery performance.

2.5. Uncertainty-diagnosing business model

In order to tackle these limitations, Koh and Saad (2002) developed a business model for diagnosing the significant underlying causes of uncertainty that affect an enterprises' delivery performance. This business model was conceptualised from the construction of an Ishikawa diagram structuring causes and effects of uncertainty in MRP/MRPII/ERP environments. The ultimate performance measure used was finished products delivered late (FPDL) located at level zero. This business model consists of five separate strands, namely material shortages, labour shortage, machine capacity shortages, scrap/rework and finished products completed but not delivered and three levels. The link between each uncertainty at each level shows the cause-and-effect relationship. The underlying causes of uncertainty are located at level three and these are the potential reasons causing FPDL. The business model was verified through a questionnaire survey and validated via simulation studies. However, the business model needs an implementation guideline to enable full utilisation in an enterprise. The uncertainty-diagnosing business model (Koh and Saad, 2002) can be summarised as below.

FPDL is due to:

(1) *Material shortages*:
- poor supplier delivery performance (rejected by quality, delivered with shortages, late delivery, incorrect items supplied);
- inaccuracies of stock records (items missing in the BOM, insecure stores, poor transaction recording);
- application of incorrect stock control rules (unexpected demand pattern changes, demand/usage analysis not used to drive stock control rules); and
- unexpected/urgent changes to production schedule (customer changes delivery lead times, customer changes ordered quantity, customer changes product ordered, customer changes specified level of quality, customer changes design during/after planning, internal design changes during/after planning).

(2) *Labour shortages*:
- absenteeism (maternity, sickness, holiday);
- schedule/work-to-list not followed (schedule/work-to-list not produced, schedule/work-to-list not controlled, schedule/work-to-list produced but not available to labour);
- lack of skill availability (inherent shortage of skilled labour, unexpected demand for particular skill); and
- labour overload (MRP plan overload/ infinite scheduling of labour, unexpected/urgent changes to schedule – labour assignment).

(3) *Machine capacity shortages*:
- unplanned machine downtime (planned maintenance/repair time exceeded, planned set-up/changeover time exceeded, breakdown);
- machine overload (MRP plan overload/infinite scheduling of machine, unexpected/urgent changes to schedule/machine assignment); and
- idle machine waiting for resources (waiting for labour, waiting for tooling, waiting for material internally supplied from other work centre/department/site, waiting for material externally supplied from independent supplier/subcontractors).

(4) *Scrap/rework*:
- unacceptable product quality (labour error, defective raw material, machine error); and

- engineering design changes during/after production (customer changes design during/after production, internal design changes during/after production).

(5) *Finished product delivered late*:

- awaiting quality clearance (waiting for inspection from labour, waiting for inspection from mechanical/robotic device); and
- awaiting despatch (item on hold – financial, unavailability of transport, awaiting balance of order, seeking concession).

2.6. Aims and objectives

This work aimed to determine the factors that affect the adoption of the uncertainty-diagnosing business model in organisations using MRP/MRPII/ERP systems (herein referred to as ERP-controlled manufacturing environments) and establish a detection method to help its implementation in ERP-controlled manufacturing environments. Thus, the research objectives of this work were to:

- investigate the type of uncertainty that occurs;
- determine to what extent uncertainties affected manufacturing enterprises' delivery performance;
- determine the performance of manufacturing enterprises' contingency plans in dealing with uncertainties; and
- explore what technical and organisational factors affected managers' decisions to implement an uncertainty-diagnosing business model.

3. Research methodology

The methodology used to achieve the aims and objectives of this research included literature review, telephone interviews and postal questionnaire survey. The literature review established the theoretical basis of the study. The literature review examined the advantages and disadvantages of MRP/MRPII/ERP systems, previous research in dealing with uncertainty in ERP-controlled manufacturing environments, the development and application of approaches or contingency plans and business model, and the limitations of previous research. The telephone interviews were carried out with production and operations managers of manufacturing enterprises that use MRP/MRPII/ERP systems. The purpose of the interviews was to explore the use of MRP/MRPII/ERP systems in the organisations and to verify the responses from the questionnaire survey to eliminate obvious biases and errors.

The questionnaire was developed based on the issues raised in the literature review and additional tacit knowledge on business model adoption and implementation. The questionnaire was designed to investigate to what extent ERP-controlled manufacturing enterprises suffered from uncertainties, managers' attitudes towards the existing approaches or contingency plans in their enterprises and what factors managers paid more attention to if they were to adopt the business model. The resulting data were analysed via the Statistical Package for Social Scientists (SPSS) software, mainly using frequency analysis. The questionnaire was sent to production and operations managers and directors in companies thought to be using MRP/MRPII/ERP systems for production planning. Although it was envisaged to target our sample to organisations that use these systems, a database that enables such search criteria or filter does not exist. Hence, the sample was chosen randomly through the search of some ERP vendors' web sites and personal contact. A random sample of companies in the UK and China were chosen from lists of medium and large manufacturing companies. The original intention was to make comparisons between these two countries, however, an insufficient number of responses were received from UK companies to make any serious comparisons worthwhile. The UK Department of Trade and Industry (DTI) definitions of medium (50-250 employees) and large (more than 250 employees) companies were used.

The questionnaire was designed in three parts. The first seven questions were designed to determine to what extent uncertainties affected the manufacturing enterprises' delivery performance and if these managers were satisfied with the performance of their MRP/MRPII/ERP system. Questions eight to ten explored the views of managers on the contingency plans being used in their organisations. Questions 11 to 15 aimed to explore what technical and organisational factors affected managers' decisions if they were to implement the business model and any other factors that may affect the business model implementation. The respondents were asked to rank the given factors (from 1 being the most important and so on) in their responses in order to determine the importance of these factors. A copy of the business model was given to each company to facilitate the explanation of such a tool for uncertainty diagnosing. The managers were asked to comment on the last 12 months performance data of the MRP/MRPII/ERP system used. Some difficulties were expected with this approach such as non-response for reasons of commercial confidentiality, lack of systematic analysis of the performance of the system used thus leading to rough estimates of performance, and lack of detailed knowledge about the business model. The non-response was minimised by telephoning the companies in advance to ascertain the name of the person to whom the questionnaire should be sent, to explain the aims of the research and to gain that person's commitment to respond to the questionnaire.

4. Results, analysis and discussions

The questionnaires were administered in the UK and China to production/operations managers in medium and large organisations (>50 employees). The questionnaires were completed via telephone interview and via mail. In the UK 56 medium and large manufacturing companies were contacted of which 19 were found to be using MRP/MRPII/ERP systems. However, only nine companies responded to the questionnaire giving a response rate of 16 per cent. In China, 91 questionnaires were sent out via mail, and 30 questionnaires were returned giving a response rate of approximately 33 per cent. All the companies were using MRP/MRPII/ERP systems and so the responses of a sample of 39 companies drawn form the UK and China were used in this study.

4.1. MRP/MRPII/ERP systems performance

The overall level of performance of MRP/MRPII/ERP systems of the respondents was examined. The aim of this question was to determine the respondents' perceptions of the performance of the MRP/MRPII/ERP systems in these companies. Figure 1 shows the respondents' perceptions of the performance of the MRP/MRPII/ERP systems in their companies.

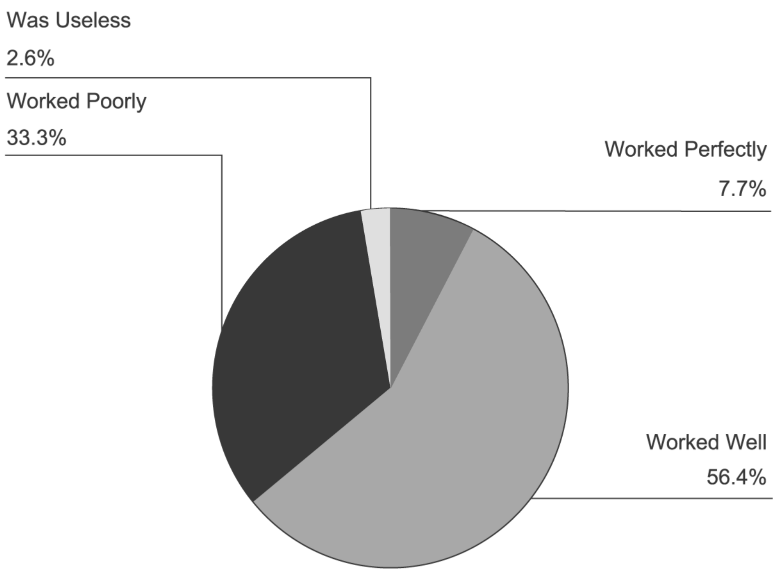
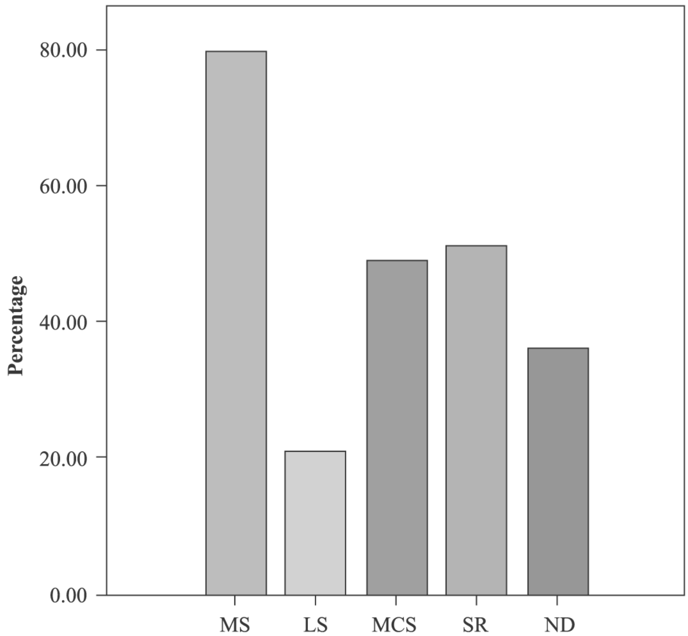


Figure 1.
Respondents" perceptions of performance of MRP/MRPII/ERP systems ($n = 39$)

Some 56 per cent of respondents agreed that their MRP/MRPII/ERP systems worked well despite some under-performance. However, some 33 per cent of respondents found that these systems worked poorly. These results suggested that these systems could improve production planning but might not be satisfactory when they were used under ERP-controlled manufacturing environments with uncertainty. It was expected that a low per centage of respondents would find that the systems worked perfectly because the systems could not generate a usable POR schedule when the parameters in the system and the environment are fixed (Koh and Saad, 2004). Nonetheless, it was a surprise to find that 3 per cent of the respondents perceived that MRP/MRPII/ERP systems were useless. The manufacturing environments of these respondents may be very uncertain and dynamic. This could result in the role of MRP/MRPII/ERP systems for production planning being out of context since many systems users may not use the Production Planning and Material Management modules; or that the education and training for the use of the systems has not been carried out successfully, thus resulting in a lack of understanding of what these systems could offer (Loh and Koh, 2004).

4.2. The effect of uncertainty

To relate the effect of uncertainty on MRP/MRPII/ERP systems performance, the finished product delivery performance was measured. According to the business model (Koh and Saad, 2002) there are five causes of tardy delivery, namely, material shortages, labour shortages, machine capacity shortages, scrap/rework and finished products completed – not delivered. These causes are some types of uncertain events in manufacturing environments. To find the effect of these uncertainties on tardy delivery, we asked the respondents to tick which causes occurred most often and which resulted in tardy delivery. Figure 2 shows the proportion of respondents claiming occurrence of the causes.



Key:
Material Shortages = MS
Labour Shortages = LS
Machine Capacity Shortages = MCS
Scrap/Rework = SR
Finished Products Completed – not delivered = ND

Figure 2.
Frequency (in percentage) of causes of tardy delivery ($n = 39$)

It can be noted that material shortages were the most predominant cause of tardy delivery. This was supported by the findings in Koh *et al.* (2000). The material shortages results show MRP/MRPII/ERP systems underperformance in the context of not being able to generate a POR schedule that will ensure the right materials are available in the right quantity and at the right time. Scrap/rework and machine capacity shortages were found to cause tardy delivery approximately by half of the respondents. This is equally worrying, as these companies are not assigning machine capacity to order appropriately and hence resulted in orders being delivered late. This may be due to the lack of prioritisation in assigning orders to machine (capacity planning) given that this task cannot be done using MRP. Such a high claim of scrap/rework seems to imply that the planned scrap level in these systems needed revising, and quality control and management in supply and on the shop floor needed investigation.

Tardy delivery caused by finished product completed – not delivered reflects inefficient logistics planning. The product completion and delivery of the respondents appeared to be disintegrated thus resulting in tardy delivery even when the products had completed the production. The claim of labour shortages was found to be relatively low, but they cannot be disregarded because this uncertainty does result in tardy delivery and MRP cannot deal with labour capacity planning.

To examine the underlying causes of these uncertainties further, several underlying causes in the business model were brought to the attention of the respondents. These included poor supplier delivery performance, change in demand, machine breakdown, labour overload and quality problems. The respondents were asked to rate the number of times that the underlying causes affected tardy delivery using the scale provided. Koh (2004) simulated the worst-case scenario of high level of uncertainty in a real case company, which was modelled at a maximum of 5 per cent of the order being affected at any one time. To give further breadth in the difference of the uncertainty at higher levels, the minimum level of uncertainty was earmarked at 5 per cent and leading to a maximum of 15 per cent as it was regarded that any level above this would be equally bad. Table I summarises the results of the frequency analysis on these underlying causes.

Some 92.3 per cent of respondents claimed that tardy delivery was directly or indirectly caused by poor supplier delivery performance. Some 35.9 per cent of respondents experienced that more than 5 per cent of their orders were being affected. It was found that 12.8 per cent of the respondents reported a greater than 15 per cent frequency of poor supply. Although 56.4 per cent of the respondents were found to have less than 5 per cent of their orders being affected by poor supply, the high frequency of poor supply affecting tardy delivery suggested that poor supply chain management practices were being used by these respondents. It appeared that these enterprises could not control the effects of this kind of uncertainty.

It was identified that nearly 79.5 per cent of respondents thought that their under-performance on customer delivery was caused by change in demand. Some 30.8 per cent of respondents claimed that more than 5 per cent of their orders were being affected. Less than half of the respondents experienced a maximum of 5 per cent of their orders being affected by change in demand. This result showed that change in demand was another major underlying causes of uncertainty on tardy delivery, followed by poor supplier delivery performance. It appeared that these enterprises could not deal with change in demand effectively, thus resulting in its effect on tardy delivery.

Machine breakdown was also found to contribute to tardy delivery from some 79.5 per cent of enterprises, but it mainly affected to a maximum of 5 per cent of the orders at any one time. This finding was consistent with the previous finding in Koh (2004). That is, that the frequency of machine breakdown was relatively low in these

Frequency (%)	Poor supplier delivery performance		Change in demand		Machine breakdown		Labour overload		Quality problems	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
1-5	22	56.4	19	48.7	24	61.5	19	48.7	13	33.3
6-10	6	15.4	6	15.4	6	15.4	1	2.6	7	18.0
11-15	3	7.7	3	7.7	–	–	1	2.6	2	5.1
> 15	5	12.8	3	7.7	1	2.6	–	–	2	5.1
None	3	7.7	8	20.5	8	20.5	18	46.1	15	38.5
Totals	39	100.0	39	100.0	39	100.0	39	100.0	39	100.0

Table I. Frequency (in percentile) of underlying causes of tardy delivery ($n = 39$)

enterprises. However, its effect on tardy delivery cannot be ignored because it was found that machine breakdown induces a compound effect (Koh, 2004), which will significantly increase the percentage of tardy delivery and such an effect was found to be difficult to capture. This result explained why so little attention was paid to developing ways to deal with uncertainty that occurs less frequently.

Some 53.9 per cent of respondents claimed that tardy delivery was directly or indirectly caused by labour overload. It was found that labour overload mainly affected less than 5 per cent of orders tardy delivery. Only 5.2 per cent of the respondents experienced larger than 5 per cent of their orders being affected by this underlying cause. This result suggested that labour overload does not occur very often and hence does not affect tardy delivery. It appeared that these enterprises may have adopted some suitable buffering or dampening techniques to tackle this underlying cause, e.g. multi-skilling labour or overtime, therefore had prevented or removed its effect on tardy delivery.

Nevertheless, quality problems were found to have a larger effect on tardy delivery. It was identified that nearly 61.5 per cent of respondents claimed that at least 1 per cent of their orders were being delayed due to quality problems. Some 28.2 per cent of the respondents found more than 5 per cent of their orders were being affected. This result indicated that quality problems play an equally balanced role on delivery; given that approximately half each of those respondents experienced the effects on tardy delivery.

The results clearly showed that some underlying causes occurred frequently, which had resulted in tardy delivery, but not all enterprises claimed that they had experienced the effects from all underlying causes. The underlying causes that were found to be the most significant on tardy delivery in the order of importance were:

- poor supplier delivery performance (1);
- change in demand (2);
- machine breakdown (2);
- quality problems (3); and
- labour overload (4).

Some of these underlying causes did not result in tardy delivery in the respondents' ERP-controlled manufacturing environments. Comparing with all underlying causes, 46.1 per cent of respondents did not experience tardy delivery caused by labour overload. This may be due to the use of effective and flexible workforce and capacity planning, hence eliminating labour overload, which could result in tardy delivery. Approximately 40 per cent of respondents also seemed to manage the quality problems effectively. A relatively small proportion of respondents experienced none of the poor supplier delivery performance, change in demand and machine breakdown.

During the analysis, some differences were found on the effect of uncertainty on tardy delivery in the enterprises in the two countries studied. The reasons for this were unclear and such international comparisons require considerably more data than we have at present.

4.3. Contingency plans

Attempts at coping with uncertainty include the use of safety stock, safety lead-time, hedging the MPS and freezing the planning horizon. Each of these approaches or a combination of them can be seen as a contingency plan aimed at coping with uncertainty. Nearly 77 per cent of respondents ($n = 39$) in this survey had adopted a contingency plan to deal with uncertainty. However, 51 per cent of respondents said that the contingency plan was helpful or very helpful and only 26 per cent said it only helped a little in coping with uncertainty.

We found that smaller enterprises coped better with uncertainty than larger ones. This was due to the ability of smaller enterprises to react quicker to the effects of uncertainty and retain a good customer delivery performance. Larger enterprises tend to be more complex and hence less agile in this respect. However, this agility is dependent on the levels of uncertainty and its knock-on and compound effects.

Analysis of variance (ANOVA) was used to determine if the enterprises' delivery performance was related to their managers' satisfaction with their contingency plan. The dependent variable used was tardy delivery, whilst the independent variables were set to be the underlying causes of tardy delivery. A 95 per cent confidence level was applied. The data used for ANOVA were the responses of the enterprises' degree of satisfaction with their contingency plan. No significant main effects and interactions between these causes were found. The results suggested no significant relation with the managers' satisfaction with their contingency plan. This showed that the types of contingency plan used to cope with these uncertainties were generally ineffective. This is worth further study because one would expect there to be a strong relationship between managers' satisfaction with the contingency plan and the enterprises' delivery performance. There could be two causes leading to this result. The data collected on the effect of uncertainty was mainly estimated by respondents and may be inaccurate. However, it seems more likely that managers' satisfaction with their contingency plan does not necessarily mean there is low uncertainty in their enterprises.

Nine respondents did not have a contingency plan. Four of these said that there were too many difficulties in implementing a contingency plan. Two of these respondents thought that the function of a contingency plan was too limited. Two respondents did not think a contingency plan was necessary, as there were very few uncertainties in their particular enterprises. Only one respondent had not tried to develop a contingency plan.

4.4. Use of an uncertainty-diagnosing model

Only seven companies out of the sample ($n = 39$) had developed a similar method to the uncertainty-diagnosing model of Koh and Saad (2002) in order to manage uncertainty. However, the performance of this model could be very different. The performance of this model could be affected by many factors and these factors could be categorised as technical and organisational factors. The technical factors could be divided into two aspects. First, the model itself should be effective and efficient. The other was the organisation, which will implement this model, should have enough technical resources and preparation. These factors could affect the planning and implementation procedures within the company. Furthermore, the organisational structure, culture and attitudes of employees towards this model could decide the final success of the model's implementation. However, these factors were often not treated properly and consequently under-performance or failure had occurred. These issues were explored in the questionnaire.

Table II clearly illustrates the order of importance of various technical and organisational factors in implementing the uncertainty-diagnosing model. That is, ease of customisation and ease of integration were seen by managers as the main technical factors involved in implementing an uncertainty-diagnosing model. These findings are very similar to ERP implementation environments where it has been suggested that heavy customisation is usually required and lack of integration between modules is the norm (Alshawi *et al.*, 2004). Hence, it can be inferred that enterprises need an agile model, which could assist problem solving rather than complicating the operations.

This result not only shows the order of importance of these technical factors, but also implies that some other issues need to be noted in implementing this model. The first three factors (ease of customisation, ease of integration, ease of use) were all about the model's function and capability, but the factors within organisations (ease of change in the operations and human issues) were ranked least important. The reason for this could be that the uncertainty-diagnosing model was a new tool, and managers had little or no knowledge about it. Consequently, they paid more attention on the technical factors involved in the model itself instead of those organisational issues involved within their own organisations. However, the participation of management is crucial in any organisational change (Long, 1987). Thus, it should be emphasised that to implement this uncertainty-diagnosing model, it would be necessary to make sure that managers had a clear and accurate understanding of the model. This was considered to be the most fundamental factor in order for managers to be able to participate in the adoption of such a model.

The most important organisational factors were found to be senior management's attitude and return on this model. These were followed (in order) by the organisations' strategy, cost of the model, resources needed and the employees' attitudes to the new model. This was consistent with research in the change management literature that managers are the keys to change (Brown, 1994; Doherty and King, 1998; Al-Mashari, 2002). However, it was surprising that employees' attitude to the model was ranked last. It is well known that employees' resistance to change is seen as the most important factor in organisational change (Avison and Taylor, 1997; Axtell *et al.*, 1997; Hirschheim *et al.*, 1997; Bovey and Hede, 2001). This result could be explained by the notion that employees' attitudes were not given the necessary attention. In addition, the change likely to be caused by implementing the uncertainty-diagnosing model was regarded as a relatively trivial change in terms of organisational change and that change at this level does not require a great deal of attention to be paid to employees' attitudes (Huczynski and Buchanan, 2001). There may also have been some cultural

Technical factor	Mean rank	Organisational factor	Mean rank
Integration	2.87	Cost	3.56
Change in operations	3.33	Senior management's attitude	2.69
Customisation	2.21	Employees' attitude	4.72
Human issues	3.46	Return	2.69
Easy to use	3.13	Resource needed	4.41
		Organisation's strategy	3.33

Note: 1 being the most important

Table II.
Mean values of technical factors ($n = 39$)

influences since the bulk of the respondents were Chinese managers. However, the sample of companies was not large enough to make any cross-cultural comparisons.

5. Recommendation for implementation

Not all enterprises need to implement a new model to diagnose the causes of uncertainties, as their contingency plans may be sufficient to deal with them. Those organisations that do need to adopt the uncertainty-diagnosing business model need a guide to help them implement it, in order to ensure the model can function properly.

To resolve these problems, a detection method is proposed and developed. Figure 3 shows the proposed detection method. The concept of detection was derived from the signal detection theory (Green and Swets, 1966) which is defined as a way of making a choice over some countable set of options especially under uncertainty. Green and Swets founded the signal detection theory and since then it has been applied and adapted in many disciplines, including psychology, warfare, communication, decision-making and etc. It is adapted in this study because we need to filter the non-potential-users sample from the potential-users of the business models. This is a decision-making process that calls for the adaptation of the concept. It must also be noted that signal detection theory has never been adapted in the ERP-controlled research.

The main function of the detection method is to navigate the process of implementation of the uncertainty-diagnosing business model. The detection method involves three key stages or milestones, namely:

(1) enterprise feasibility evaluation;

(2) pre-requisites for implementation evaluation; and

(3) implementation steps.

Stage 1 will determine whether an enterprise should implement the uncertainty-diagnosing business model, or vice versa. Only if the enterprises have reasonably complex environments, underperformance of MRP/MRPII/ERP systems, and lack of a proper performance measurement tool, then they are more likely to maximise the benefits from the use of the business model. If not, it may be more feasible for the enterprise to find alternative methods. Provided that the enterprises have the above-mentioned characteristics, then we proceed to stage 2 in order to evaluate the pre-requisites for implementing the business model.

It has been identified from this study that both technical and organisational factors affect the implementation of the business model. Ranking of the most important technical and organisational factors has also been discussed. Stage 2 entails execution of a "health check" within the enterprise environment of the potential implementer of the business model. For example, the enterprise has to find out the current situations, problems and barriers within their environment and supply chain so that appropriate preparation, re-engineering and re-organisation could take place prior to implementing the business model.

After the pre-requisites are in place, then we proceed to stage 3, which is the stage where implementation of the business model will take place. Management and employee training will be carried out to ensure effective use of the business model. Cross functional group will be set-up to enable clear definition of roles and responsibility of users of MRP/MRPII/ERP systems within the enterprise and the

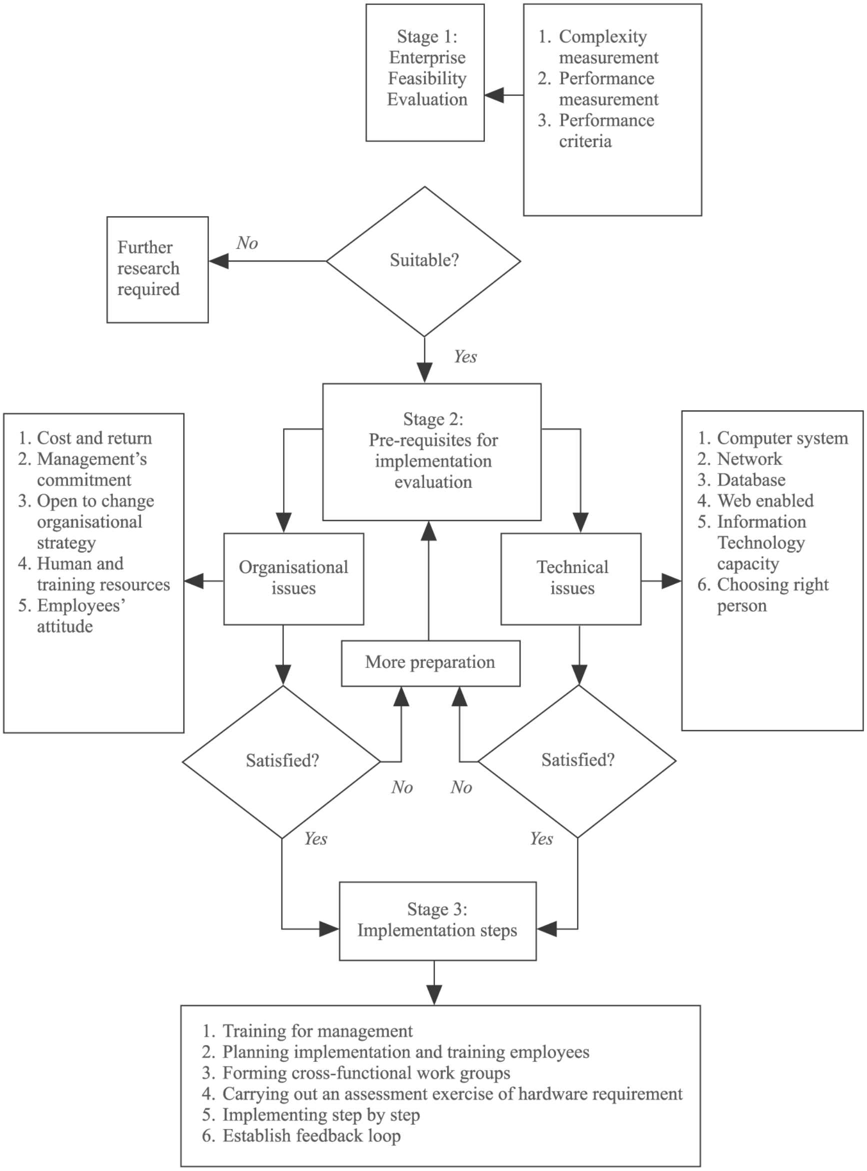


Figure 3.
Detection method

systematic mechanism to deal with uncertainty. At this stage, the users of the model will be able to diagnose the underlying causes of uncertainty that affect the performance of enterprises, and then appropriate contingency plans could be derived to deal with the uncertainty.

From the survey results it was concluded that this uncertainty-diagnosing model is more suitable to those enterprises with a complex manufacturing environment. Thus, in general, we would expect larger enterprises to have a more complex manufacturing environment and greater uncertainty than smaller ones. In addition, the more complex the end product, the more likely uncertainties will occur in its manufacture. Thus, it is suggested that the user with a more complex manufacturing environment is likely to obtain greater benefits, with a similar investment, from the adoption of an uncertainty-diagnosing model than an organisation with a relatively simple manufacturing environment.

6. Conclusions

Overall, it was found that managers involved in this research believed that MRP/MRPII/ERP systems could improve manufacturing management. However, these systems had some limitations particularly when dealing with uncertainties. All the enterprises that took part in this research reported the occurrence of uncertainties in their organisation and these uncertainties impacted negatively on delivery performance. Among the five types of uncertainty examined, material shortage was found to have the strongest impact on the performance of customer delivery. About 80 per cent of respondents suffered from this type of uncertainty. The other four uncertainties in order of their impact on customer delivery performance were machine capacity shortage, scrap/rework, FPDL, and labour shortages. It was concluded from this that most enterprises could not achieve full customer satisfaction from their MRP/MRPII/ERP systems and that it was necessary to take some remedial action to improve the performance of these systems.

Most respondents had recognised the effects of uncertainty and acted to deal with them using contingency plans. Nearly 77 per cent of respondents reported the adaptation of contingency plans to deal with uncertainty. One-third of these respondents reported that their contingency plans were very helpful. This result was better than we had expected but there were still problems with these plans and the impact they had on the delivery performance of the enterprise. The effectiveness of these contingency plans appeared to depend on various technical issues and organisational issues. Managers ranked the technical issues higher than the organisational issues despite the wealth of research in the literature that suggests that organisational and change management issues also have a major impact on the ability of an organisation to implement complex systems.

Most respondents had not adopted a kind of uncertainty-diagnosing method or model. This finding implied that uncertainty has not been coped with systematically in these enterprises. This research proposed the use of an uncertainty-diagnosing business model, which will enable these enterprises to cope with uncertainty. Since these enterprises do not have significant prior know-how in such kind of model, this research developed a deduction method, which will navigate the process of implementation of the business model. The detection method was derived based on the adaptation of the signal detection theory, and will help managers "walk through" the process of implementation in three main stages or milestones, namely the enterprise feasibility evaluation, the pre-requisites for implementation evaluation, and the implementation steps. It was envisaged that ERP-controlled enterprises that are complex, under-performed and do not have an effective performance measurement system, will benefit most from the use of the business model.

The results of this study also showed that managers consider technical factors related to the model itself to be more important than organisational factors when implementing such an uncertainty-diagnosing model in ERP-controlled manufacturing environments. This is quite reasonable and understandable since managers with a technical background, e.g. IT or engineering, were likely to be involved in implementing such a model. In addition, managers considered senior management's attitude towards the model and the return from implementing such an uncertainty-diagnosing model to be the most important organisational issues. The employees' attitude was unexpectedly ranked last behind the cost and resource needed to implement such a model. This was explained by the small degree of change being undertaken which would have little impact on employees and the lack of attention paid to employees' attitudes in these types of organisations.

The limitations of this research were that the data on the impact of uncertainty on these organisations' delivery performance were managers' estimates rather than objective measures of the performance of the MRP/MRPII/ERP systems used. It must be noted that enterprises do not collect data on uncertainty and hence it is not possible to obtain objective data of uncertainty. However, the telephone interviews did attempt to eliminate obvious biases and errors as much as possible. This research suggested that there might be some differences between Chinese and UK companies in their approach to these types of system and the way that an uncertainty-diagnosing model might be implemented in these organisations. Similarly, some differences on the impact of uncertainty on these companies in the two countries studied were also found. This was a tantalising result but the data were insufficient to draw any significant conclusions. Further work in this area is needed with a much larger set of data.

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