ABSTRACT
Operations management (OM) theories have started to emerge in an attempt to unify different OM perspectives now typified by the lean and agile paradigms. These have taken the form of laws (Hopp and Spearman, 1995), conceptual models (Fisher, 1997) and theories (Schmenner & Swink, 1998; Vastaag, 2000) to mention more prominent examples. They all address the need to conceptualise these developments in order to provide practical means of explaining and predicting OM phenomena and means of achieving improved performance. This paper aims to contribute to this process by further exploring the underlying significance of variation, uncertainty, buffering mechanisms and trade-offs. The paper reviews evidence of best practice and prior research before reporting on a multi-case study. The theory of variation and uncertainty buffering is proposed as a means of unifying and extending existing theory at a more abstract level. The paper finally evaluates the utility and parsimony of this theoretical proposal, acknowledging the need for further work in developing its practical application.

Keywords: supply chain, trade-off, buffering

INTRODUCTION
OM and supply chain management are complex and dynamic fields of management and new developments naturally tend to be practitioner led. Such developments often go beyond, or conflict with existing theoretical understanding and the theory building process needs to be followed to make sense of the practitioner’s experience. This process typically commences with description followed by classification and correlation in the process of identifying key constructs and construct relationships (Bacharach, 1989). Such OM research areas include: focus manufacturing, just in time, supply chain management, total quality management, mass customization, postponement and agility.

Classification and correlation studies within and between these research areas tend to predominate the OM research agenda, commonly via hypothesis testing, but often in the absence of a clear underlying theoretical base. Ideally, hypothesis testing should be used to test or develop established theory, therefore, it is important for theory to lend itself to falsification, as well as being both useful and parsimonious (Whetten, 1989; Handfield and Melnyk, 1998; Voss et al., 2002). Such theory should be characterized by clear constructs and construct relationships that enable phenomena associated with OM practice to be logically explained and predicted.

This paper describes such a process, commencing with the identification of tentative constructs and construct relationships evident in good practice and formal research evidence. The following
research questions were devised to explore these relationships, utilizing the analytic induction approach to multi-case research.

- How and why does internal and external system variation and uncertainty impact a supply chain?
- How and why do different approaches limit such variation and uncertainty?
- How and why does the trade-off concept support the strategy development process?
- How and why should a company use investments in inventory and capacity to provide greater stability in the internal and external phases of a delivery system?
- Under what conditions does local (cost) rather than strategic considerations tend to lead decision-making?

Cases were selected to exhibit the range of phenomena and used to develop the constructs and identify construct relationships, utilising theoretical replication logic. Finally, the emerging propositions were mapped and related to existing research evidence before being develop in the form of a theoretical model.

THEORY DEVELOPMENTS IN OM

Before embarking on the case research, secondary research was used to clarify the underlying importance of the concepts of variation, uncertainty, buffering and performance trade-offs in the development of OM practice and theory. Theoretical developments are reviewed here to expose the underlying importance of these concepts in support of the subsequent theory development.

Scientific management (standardization)

The early part of the 20th century was marked by a revolution in manufacturing practice, particularly promoted by Fredric Taylor’s principles of scientific management (Taylor,1911). Taylor and others, such as Gilbreth and most notably Ford (1926), were practitioners who realised the potential of using scientific approaches in the systematic management of manufacturing.

*The development of a science ..., involves the establishment of many rules, laws and formulae which replace the judgement of the individual workman and which can be effectively used only after having been systematically recorded, indexed, etc. (Taylor, 1911: 37-38)*

The scientific approach resulted in breaking down the manufacturing process into its component parts to measure, analyse and develop best practice methods of working which were then used as a standard process to produce standard products.

*The change from rule-of-thumb management to scientific management involves, however, not only a study of what is the proper speed for doing the work and a remodelling of the tools and the implements in the shop, but also a complete change in the mental attitude of all of the men in the shop towards their work and towards their*
These scientific developments centred on centralized management and standardisation leading to significant reductions in unit cost, such that the cost of a product could commonly be halved whilst doubling a worker’s pay (Taylor, 1911). Such a transition in manufacturing practice is epitomised in the manufacture of the Model T Ford at the River Rouge Plant. Ford’s drive to standardise and exploit economies of scale resulted in him consolidating production in 1909 to supply just one wheelbase, one engine and one colour (Abernathy & Wayne, 1974). This cost minimization strategy was, however, short-lived as the customer demand for product variety forced Ford to adopt a growing product range in the light of the success of General Motors (Sloan, 1964) and others.

Cost optimisation models (sub-optimisation)

The scientific approach was born together with the acknowledged need to manage product variety. Consequently analytical models were developed to support the associated decision-making. The inventory model developed by Harris in 1918 is particularly notable (See Figure 1) as it attempted to optimise the cost trade-off associated with changing from one product to another. This was to be followed by similar models to optimise quality and transportation costs. A problem with the mathematical analysis of such models is the need to incorporate quantifiable parameters and minimise the control variables in optimising the conflicting trade-offs, as Baker and Kropp (1985:7) concluded.

A common element of decision-making deals with the problem of achieving a balance of trade-off between two conflicting tendencies. In the simplest cases there is one decision variable, and the problem is essentially deterministic. For example, in inventory control the choice of a replenishment order quantity (or lot size) affects both ordering costs and inventory carrying costs. Achieving a minimum total cost requires an optimal balance of these two conflicting tendencies. (Baker and Kropp, 1985: 7)

The resulting analysis of the operations function was well suited to cost optimisation but, as already illustrated, cost minimisation is not the only competitive dimensions that affected sales. The scientific approach encouraged the sub-division of the system and the use of cost measures to optimise the process. This worked to a point, but typically resulted in sub-optimisation as the factors considered were only locally driven, with each specialist area looking to minimize cost. This often results in different aspects of the delivery system pulling in different directions.

Performance trade-offs (focus and alignment)

In the 1960s (Skinner, 1966) became increasingly aware of the limitations of the traditional cost focus, but it was not until 1969 (Skinner, 1969) that his pioneering work on the role of performance trade-offs clarified the difficulty in satisfying conflicting performance objectives. The concept of manufacturing strategy is centred on the trade-off concept and the need to align a wide range of structural and infra-structural choices. Skinner’s thesis was:

...that manufacturing has too long been dominated by experts and specialists... as a result top executives tend to avoid involvement in manufacturing policy making, manufacturing engineers are ignorant of corporate strategy, and a function that could be a valuable asset and tool to corporate strategy becomes a liability instead. (Skinner, 1969: 136)

To illustrate his point he contrasted two businesses extremes; one supplying standard furniture at low costs, the other high-specification furniture with customised features. He then argued that there were rafts of operational decisions that need to be aligned, but with a mix of business competitive criteria there are a multitude of conflicting choices. Skinner’s work introduced the importance of the
concept of trade-offs in highlighting strategic choices rather than the sub-functional optimisation models previously associated with scientific management. To illustrate this point he used a mechanical engineering analogy.

For instance, no one today can design a 500-passenger plane that can land on a carrier and also break the sonic barrier. Much the same is true of manufacturing. The variable of cost, time, quality, technological constraints, and consumer satisfaction place limits on what management can do, force compromises, and demand an explicit recognition of a multitude of trade-offs and choices. (Skinner, 1969: 140)

He, therefore, argued that delivery systems need to be designed so the sub-functional trade-off choices are strategically aligned. To achieve this he advocated focused business units where each unit is aligned with one key manufacturing tasks (Skinner, 1974) which Hill (1985) interpreted as focusing on common order winning and qualifying criteria.

Quality (continuous improvement through variation reduction)

Whereas, western advances in OM stressed the development of the concept of strategic choice, Japanese developments from the 1950s were more closely associated with reducing the trade-off drivers at source. In 1950 Deming (1986) introduced the Japanese to statistical process control and the concept of continuous improvement through reducing variation, and developing stable and predictable processes. Central to his views (Deming, 1986: 3) was what he called the chain reaction which reverses the traditional trade-off view and argues that improved quality leads to improved productivity and lower cost. He also emphasised a systems view of the production system stressing the pivotal importance of the customer as well as the need to develop trusting long-term relationships with suppliers (Deming, 1986: 3-5). Deming consistently argued that management were responsible for common cause variation which he claimed accounted for 95 percent of cases.

The central problem of management in all its aspects, including planning procurement, manufacturing, research, sales, personnel, accounting and law, is to understand better the meaning of variation and to extract the information contained in variation. (Deming, 1986: 20)

Evidence from field research comparing Japanese quality and productivity levels corroborated the merits of the Japanese introduction of the above developments. Hayes (1981) put the Japanese success down to paying attention to manufacturing basics. Their emphasis being on reducing uncertainty by adopting policies that avoided crisis management and enabled lower inventories, often with spare capacity being held to enable the company to be responsive.

Tools, dies and production equipment were not overloaded. In fact, machines often operated at slower rates than they were designed for – and at less than the rate in US factories. This practice reduced the possibility of jams and breakdowns as well as the wear on machine parts and dies. (Hayes, 1981: 60)

Although trade-offs were often evident across companies in the US, when comparisons were made with Japanese companies the trade-off effect was largely negated. This was illustrated in the early 1980s by a survey of US and Japanese air-conditioning manufacturers (Garvin, 1983). This predictably showed that both productivity and quality improved where the product range was less varied and more stable in the US. However, the Japanese-US comparison illustrated how the Japanese quality and productivity performance was much higher even with much wider levels of product variety.
On balance, then, the Japanese advantage in production came less from revolutionary technology than from close attention to basic skills and to the reduction of unwanted variations in the manufacturing process. (Garvin, 1983: 72)

**Lean (eliminating wasteful variation to enable flow)**

The term lean manufacturing (Womack et al., 1990) and subsequently lean thinking (Womack and Jones, 1996) have their origins in the Japanese quality revolution and also the manufacturing practice commonly entitled just-in-time manufacturing which emerged from the Toyota Production System (TPS). The TPS dates back to the 1950s and the subsequent work of Taiichi Ohno (1988) and Shigeo Shingo (1989). Ohno, (Ohno, 1988) (originally published in 1978 in Japanese) recounts the concept of just-in-time, the importance of production flow and the direction of continuous improvement towards an ideal state.

*Just-in-time means that, in a flow process, the right parts needed in assembly, reaching the assembly line at the same time they are needed and only in the amount needed. A company establishing this approach throughout can approach zero inventories. From the standpoint of production management, this is an ideal state.* (Ohno, 1988: 4)

As long ago as 1947 Ohno started to experiment with shop floor layouts at the Koromo plant (1988: 11) and was able to arrange for one worker to operate three or four machines along the process route. Production levelling was a particular problem and the batching of production was creating artificial production cycles.

*We wanted to get away from having to produce everything around the end of the month.* (12).

The emphasis on waste reduction is clearly stated together with the world famous seven categories of waste (:19-20). He stresses the adoption of the kanban system to encourage flow but also emphasises that for it to work withdrawals should not fluctuate.

*The greater the fluctuations in quantity picked up, the more excess capacity is required by the earlier processes... Ideally, levelling should result in zero fluctuations in the final assembly line.* (36-37)

The counter-intuitive approach of small lots to enable the levelling, however, placed too heavy a demand on the die press section and resulted in the emphasis on set-up reduction.

*The TPS, however, requires level production and the smallest lots possible even though it seems contrary to conventional wisdom... As production levelling spread though the company in the 1950s, set-up times went to less than one hour and as little as 15 minutes. By the late 1960s, it was down to a mere 3 minutes’*

Shigeo Shingo (1989) (originally published in Japanese in 1981) provided more detail in his account of the system, discounting some of the misconceptions. He was a major contributor to the Toyota Production System that similarly emphasises the underlying importance of set-up time reduction.

*Anyone who carefully analyses the Toyota Production System will arrive at the following conclusion: Reduction in set-up times, achieved with the help of the SMED system (Single-Minute Exchange of Die) is essential. That is why we can say the SMED is a sine qua non of the Toyota Production System.* (Shingo, 1989: xxiii)

Shingo highlights the misconception that TPS aims to improve machine operating rates. Instead he emphasises the need to have sufficient capacity to operate under conditions of increased demand.
(Shingo, 1989: xxi). The emphasis was on operator efficiency often resulting in one operator running multiple machines, which are often awaiting his availability.

*The machine-output ratio at Toyota Motors is two or three times that of similar companies. Indeed, for the same level of production, Toyota has far more equipment than other companies and this is one of its strengths.* (Shingo, 1989: 72)

He emphasised the merit of holding excess machine capacity to cover variation in demand, and also the importance of equipment being available when requested. On the subject of load fluctuations, Shingo alludes to the role of capacity and inventory buffering and the need to adjust the kanban inventory levels accordingly. The emphasis, however, is on load leveling.

*In a kanban system, semi-processed parts waiting between processes may take the place of minimum inventory in providing a cushioning effect. Fluctuation beyond a certain magnitude, however, cannot be absorbed in this fashion, and level production becomes necessary...Obviously, thorough consideration should be given to levelling production so that such fluctuations can be prevented.* (Shingo, 1989: 187)

**Cumulative capabilities model**

The academic community was gaining a deeper understanding of the trade-off relationship and the evidence was now clearly supporting Deming’s contention that reducing variation and improving quality eliminated the trade-off driver at source.

*Cost and quality are traded off against each other if the attention is put on the cost; however, they both improve if the attention is put on quality.* (Nakane, 1986: 15)

Ferdows and De Meyer (1990) subsequently proposed a new theoretical model to help explain these findings that they used the 1988 survey data to test.

*To build cumulative and lasting manufacturing capability, management attention and resources should go first towards enhancing quality, then – while the efforts to expand quality are further expanded - attention should be paid to improve also the dependability of the production system, then – and while efforts on the previous two are further enhanced – production flexibility (or reaction speed) should be improved, and finally, while all these efforts are further enlarged, direct attention should be paid to cost efficiency.* (Ferdows and De Meyer, 1990: 168)

This model reversed the traditional focus on cost and raised further questions over the relevance of the trade-off concept as they appeared to be in conflict with each other.

**Agility, mass customization and postponement (managing demand uncertainty)**

The concept of agility emerged in the 1990s and stresses the need to respond to a dynamic market without incurring trade-off consequences. But, unlike flexibility the emphasis is not centred on the resource but the whole delivery system. This included product design, distribution and customer self-service, with a much more significant role for ‘human factors’. Sanchez & Nagi (2001) completed an extensive review of 73 papers in an attempt to classify the findings and concluded:

*Agile manufacturing systems are born as a solution to a society with an unpredictable and dynamic demand, and with a high degree of mass customisation in its products.*

(Sanchez and Nagi, 2001: 3596)

The term mass customisation has become closely associated with agility as it embraces the objective of gaining the market appeal of product customisation with the operations appeal of
standardisation. Such capability needs to be designed into the product and the increasingly world-wide delivery system from the start.

…to provide individually designed products and services to every customer through high process flexibility and integration. (Pine, 1993).

Thereby, resolving the trade-off between being responsive to special customer requirements whilst maintaining the manufacturing economies traditionally associated with standardized production. The need to reduce unnecessary product variation in satisfying customer requirements clearly is a prerequisite to the MC concept (Neal and Leonard, 1982).

Van Hoek (1998) uses empirical research to further clarify the role of postponement in reducing the impact of this uncertainty driven trade-off (1998:1).

Postponement is used to achieve customisation and efficiency within one operating system.

Van Hoek (1998) concludes that the interaction of customer data, operations and design enables postponement strategies to mass customise products, enhancing technical, process, product and market characteristics. This was notably demonstrated by Hewlett Packard’s printer manufacture and distribution (Feitzinger and Lee, 1997). Walker et al. (2000) investigate the construct of product customisation and postponement from a trade-off perspective, extending the work of Zinn and Bowersox (1988) in the development of alternative market-oriented supply chain strategies. They stress the trade-off implications of holding inventory versus lead-time and that of product customisation versus cost minimisation. They conclude by raising the question,

Does the use of both postponement and product customisation allow firms to overcome these classic trade-offs? (Walker et al., 2000: 132)

Conclusion
This review highlights how variation reduction has been central to developments in OM from scientific management to continuous improvement and the cumulative capability model. Similarly variation has been shown to drive the need for buffering and the choice of buffers is reflected in the performance trade-offs. Reduced variation, therefore, results in a reduced need for buffer investment in inventory and capacity. However, increasing product variety and demand volatility has raised the need to manage increased demand uncertainty as well as variation. In response, supply chain design has developed to incorporate concepts such as postponement and mass customization, which, in combination with capacity buffering support the agility paradigm. This emerging conceptual understanding is reflected in more specific theoretical statements, as outlined below.

RELATED OM LAWS, MODELS AND THEORIES
Three prominent theoretical contributions have been identified below because of their reference to the concepts of variation, uncertainty, buffering mechanisms and performance trade-offs. These will be used as a basis for subsequent evaluation of the proposed theory.

Hopp & Spearman (1995; 2000: 295-300) very effectively deduced these laws which centre on variability and trade-off buffering.

- Law (Variability): Increasing variability always degrades the performance of a production system.
- Law (Variability Buffering): Variability in a production system will be buffered by some combination of Inventory, Capacity and Time
• **Corollary (Buffer Flexibility):** *Flexibility reduces the amount of variability buffering required in a production system.*

Fisher’s (1997) used empirical case research to clarify the trade-off relationship between different classes of product with efficiency and response in a supply chain (Fisher et al., 1997). Figure 2 highlights the need to align the design of the supply chain with the uncertain nature of the product, embracing the concepts of uncertainty, trade-offs and buffering (capacity, inventory and customer tolerance time).

- **Accept that uncertainty is inherent in innovative products**
- **Continue to reduce uncertainty (e.g. the use of common parts)**
- **Avoid uncertainty by cutting lead-times and increasing the supply chain flexibility so that it can produce ideally within the tolerance time of the customer.**
- **Where uncertainty has been reduced or avoided as much as possible, hedge against the remaining residual uncertainty with buffers of inventory or excess capacity.**

Schmenner and Swink (1998) proposed two theories to encompass various OM ‘laws’ they identified in relation to manufacturing plants. The first of these is the theory of Swift Even Flow (SEF) which is closely allied to lean manufacturing, emphasizing the relationship between variation and speed through a plant. This theory does not explicitly mention buffering but inventory and or time buffers are clearly implied. Hence reduced variation demands less buffering and, therefore, improves flow.

*The theory of SEF holds that the more swift and even the flow of materials through a process, the more productive that process is. Thus, productivity for any process – be it labour productivity, material productivity, or total factor productivity – rises with the speed by which materials flow through the process, and it falls with increases in the variability associated with the demand on the process or with the steps in the process itself.*

(Schmenner and Swink, 1998: 102)

Schmenner and Swink’s (1998) second theory, ‘the theory of Performance Frontiers (PF)’ was specifically derived to reconcile the apparent conflict between the concept of performance trade-offs and the cumulative capability model. The theory of performance frontiers is best conveyed through Figure 3, which identifies three operating states for a manufacturing plant.

*Plant A is underutilised and inefficient. Rationalising resources and resolving inefficiencies leads to position A1 at which the plant encounters its performance frontier. Operating policy changes improve the frontier and move the plant to position A2, where technological and asset constraints begin to significantly affect performance.* (:108)
This theory reconciles these apparently conflicting concepts by suggesting the improvements associated with cumulative capabilities (quality then dependability, then flexibility then cost) as in the case of JIT or TQC can move the operating frontier and close the gap with the asset frontier. As this gap closes the trade-off effect associated with the structural choices have greater significance. Vastag (2000) extended the scope of this theory arguing that the Japanese automotive experience suggested the operating rather than the asset frontiers of organisations was more important in achieving competitive advantage because the change in policy made this more difficult to replicate.

**Conclusion**

These theories, laws and models have much in common and clearly can be directly or indirectly related to the concepts of variation, uncertainty, buffering mechanisms and performance trade-offs at both the plant and supply chain level. The research that follows develops these concept definitions and relationships in search of a theoretical model that unifies these theories at a more abstract level.

**RESEARCH DESIGN**

The case-based research method was adopted, given the explanatory nature of the research aims and questions being posed (Yin, 1994). Six cases comprising nine delivery systems were chosen and administered in accordance with theoretical replication logic (Eisenhardt, 1989). The unit of analysis centred on one company but involved suppliers and customers where appropriate and feasible. Data was collected with a research protocol using multiple sources of evidence. The data collection method included plant observation, semi-structured interviews, archival records and documents, with due attention being given to triangulation and subsequent analysis (Miles and Huberman, 1994).

**CASE ANALYSIS**

An outline of three of the six cases is provided here to outline the nature of the analysis. The focus was on exploring the transitions in stability, the associated tactics adopted and the buffering mechanisms used. These construct definitions, below, are used in the subsequent case analysis.

**Key construct definitions**

The following constructs have been developed in line with the findings and prior definitions.

**Variation (demand and process):** The level of non-uniformity of demand or output from resources within a supply chain. This may result from external demand variation (e.g. mix and volume changes) or internal process variation (e.g. set-up time).

**Uncertainty:** The level of unpredictability of the associated variation. This may be in relation to demand variation (e.g. forecast uncertainty) or process variation (e.g. equipment failure).

![Performance Frontiers](source: Schmenner and Swink, 1998:108)
Buffering mechanisms: Three generic forms of buffering are used to manage the impact of variation and uncertainty on a delivery system; that of forward load, inventory and capacity.

- **Forward load**: Actual or anticipated work waiting before the delivery system that is normally measured in time. This can take the form of an order backlog associated with a variable extension to the lead time. However, where the lead time is a fixed commitment the inclusion of an additional time buffer against variation induced backlogs is common. The alternative to using time in this way is to buffer through investment in inventory and/or capacity, the choice of which will similarly primarily depend on the order winning and qualifying criteria.

- **Inventory**: In contrast to forward load, inventory compresses customer response time by committing capacity in advance of demand. This may be held at an intermediate or a finished stock level.

- **Capacity**: Providing capacity to manage variation directly can be achieved through proactive or reactive means. A proactive capacity buffer would include annualised hours or under capacity scheduling where unused capacity can be otherwise exploited. Reactive capacity, as in overtime requests, tends to be more uncertain and expensive and, therefore, used as a last resort.

Case 1 - Knitwear apparel supply

Stevensons is a garment dying business that was originally vertically integrated within the Coats Viyella Group (CVG) providing the capability to postpone the colour choice in garment manufacture. This involved producing the garments preseason in a pre-dyed state and subsequently dyeing and finishing the garments across two factories within a 4-6 week lead time. The reported transitions in stability of concern here began in 2001 when the Group dissolved and much of the work moved offshore considerably extending the colour choice lead times. This was due to both the remote supply and the adoption of yarn dyeing as opposed to garment dyeing. Stevensons downsized and developed its capability to both garment dye and finish in one, compressing the lead time from 4-6 weeks to just 2 weeks. This fast response dyeing and finishing capability was combined with offshore garment manufacture to help reconcile the cost versus response demands of the market. This option was, however, more expensive and the tension between fast response and low cost resulted in a series of short term commitments to this fast response capability.

Case 2 - Japanese automotive supply

Auto Mouldings Company (AMC) is located 3 miles from the assembly line of its main customer, an automotive manufacturer. AMC produces moulds and assembles door panels for the interior trim of two models produced on separate assembly lines. AMC manufactures and delivers these products directly to 40 different points on the two assembly lines that normally run 2 shifts 5 days per week. The case study describes the delivery system and developments, but particularly centres on the transition associated with AMC redesigning its door panel assembly cells to reduce the intermediate inventory by moving from synchronous delivery to synchronous manufacture. However, the removal of this decoupling inventory inadvertently exposed AMC to increases in demand variation subsequently imposed on the assembly line. This resulted from the automotive manufacturer adopting annualised hours as a capacity buffer in place of finished stock and so exposed the assembly line and AMC to increased demand variation.

Case 3 - Grocery retail supply
RFB is based in Wales and was purpose built as a dedicated plant producing fresh ready-meals for a major grocery retailer. The plant now supplies a second customer with frozen ready-meals, a rapidly growing pub food chain, which represents 20% of the plant volume. The grocery retailer’s product range is around 100 SKUs and the pub chain range involves about 25 SKUs. The lower value pub chain products do not demand the same quality of raw material or processing, however, the ability to hold buffer stocks of this frozen range provides the opportunity to smooth some of the seasonal capacity demands particularly associated with the fresh product range.

The transition in RFB (fresh) concerned the improved stability of order transmission from the retail stores as the instability in daily ordering experienced by RFB did not reflect the inherent stable demand. This demand variation and uncertainty induced RFB to introduce capacity (annualized hours) inventory and forward load buffers all with waste implications. Subsequent agreement to set the order level weekly enabled these buffers to be reduced and at the same time reduce wastage and stock outs for the retailer. In the case of RFB (frozen) the transition similarly concerned the elimination of artificially created demand variation induced by the unstable ordering of the distribution company. The variation and uncertainty in the daily ordering encouraged the use of forward load as a time buffer and this in turn exacerbated the demand uncertainty. The replenishment times and inventory levels were reduced by providing visibility of actual demand and adopting a form of vendor managed inventory.

**CROSS CASE ANALYSIS AND EMERGING PROPOSITIONS**

Analysis of the individual case delivery systems was followed by cross case analysis that was used to develop both the construct definitions and construct relationships in the form of propositions.

*Cross case analysis*

As illustrated in the case summaries the selected cases exhibited a range of transitions in variation and uncertainty that involved a mix of buffer choices with implications on the delivery system performance associated with strategic priorities (See Table 1).
Table 1 Summary cross case comparison

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**Propositions**
Through the cross case analysis nine generic proposition were identified and Figure 4 presents the propositions in a relationship diagram. These propositions were supported by the case evidence and refined in the light of prior research. The propositions underpin the emergent theory and provide the basis for testable hypotheses.

**EMERGENT THEORY**
The following theoretical model has been developed in line with these empirically derived propositions. This has been summarized here as ‘the theory of variation and uncertainty buffering’ (VUB).

- The theory of variation and uncertainty buffering (VUB) holds that variation and uncertainty within a supply chain, whether this arises through external demand or internal processes, drives the need for buffering and the buffering choices determine the performance trade-off. It follows that there are three fundamental buffer choices and three generic strategies that may be used to reduce or manage the buffer requirements in line with strategic priorities (see Figure 5).
Theoretical model

Three generic strategies are related to the trade-off concept in this theoretical model (Figure 5) and represent means of reducing and aligning buffer choices in support of strategic priorities.

- Identify strategically limiting operations trade-off(s)

The strategic implications of the variation and uncertainty driven buffers is reflected in the performance trade-offs which are central to this model and the research evidence highlighted the lack of sufficient management awareness of such trade-off implications. This model, therefore, starts by focusing on the strategically limiting trade-off choices (eg price versus availability), which in turn relates to operations performance and buffer choice. For example, Stevensons garment dyeing route provides a means of addressing the delivery speed versus cost trade-off.
off conflict. These choices are strategic because they impact the order winning and qualifying criteria which will differ between products and markets. As reflected in the propositions these strategic trade-offs are directly related to the level of variation and uncertainty, which can be reduced or managed through three generic strategies. The trade-off focus enables the impact of these generic strategies to be assessed in relation to supply chain priorities.

I. Reduce the underlying variation and uncertainty
As variation and uncertainty degrade performance, means of reducing the underlying variation encompasses the concept of continuous improvement which reduces the need for buffering. Sources of variation and uncertainty may be classified as demand or process and it was found to be important to expose and challenge assumptions associated with these causes. This was evident in both AMC and RFB where the need for order variability needed to be challenged.

II. Separate or postpone the different levels of variation and uncertainty
Separating or postponing different levels of variation and uncertainty within the product range or across the supply chain limits the need for buffering which may also be restricted to exploit the natural hierarchy of risk associated with investment in buffering mechanisms. In the case of postponement this will often involve product and/or process design, as in the case of Stevensons. However, this also applies to separating out conflicting order winning criteria as advocated in focused manufacturing.

III. Buffer the variation and uncertainty
Variation and uncertainty degrades supply chain performance, but the choice of buffering mechanism enables the trade-off balance to be aligned with supply chain priorities. The most appropriate strategic balance will depend on the specific market and operations priorities. There are three prime buffering mechanisms: forward load, inventory and capacity (proactive and reactive). The need to align such choice was clearly evident in all the cases.

These generic strategies are not mutually exclusive, but commonly apply in combination, as evident in the case and cross-case analysis. The combination of these generic strategies, therefore, needs to be uniquely aligned with the supply chain concerned.

DISCUSSION
This theoretical model is a natural extension of Hopp and Spearman’s (2000) law of variability buffering but also encompasses Fisher’s (1997) use of the concept of uncertainty which is particularly relevant when dealing with demand uncertainty and the implications of replenishment time on forecast accuracy. The definition of the three buffering mechanisms is consistent with this earlier work although the concept of a capacity buffer has been sub-classified as proactive or reactive to distinguish ad hoc means from preplanned capacity buffering, as in the case of annualized hours.

A more significant development is in the identification of three generic strategies to reduce and manage buffering needs and choices.

- Reduce the underlying variation and uncertainty.
- Separate or postpone the different levels of variation and uncertainty.
- Use the buffering mechanisms to buffer the residual variation and uncertainty.

The theory proposes that these generic strategies reflect strategic options that are utilized to meet specific case requirements. Therefore, supporting the argument that strategies need to be uniquely aligned with the supply chain concerned.
developed to meet the business need and not adopted prescriptively. However, it may be useful to use these generic strategies to generalize how such approaches are commonly viewed (see Table 2), but this is only illustrative.

**Table 2 Relating OM approaches with the proposed generic strategies**

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<tr>
<th>OM approaches</th>
<th>Reduce variation</th>
<th>Reduce demand uncertainty</th>
<th>Separate</th>
<th>Buffer</th>
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This model notably avoids the use of the concept of flexibility due to its complex nature. Hopp and Spearman (2000, p 300) succinctly relate flexibility to variability and buffering: *Flexibility reduces the amount of variability buffering required in a production system.* This interpretation of flexibility highlights the complexity, in that it encompasses but doesn’t distinguish between variation, uncertainty and the different buffering mechanisms. Previous popular sub-classifications (e.g. range and response in relation to product, volume, mix and delivery (Slack and Lewis, 2001: 42) distinguish between demand and process variation but do not effectively distinguish between reducing the variation and managing it. Consequently, being more mix flexible can mean reducing variation at source (as in setup time reduction) or increasing the buffer (as in capacity buffering through annualised hours).

**EVALUATION OF THEORY**

The objective of this research was to develop a theoretical perspective at a higher level of abstraction to those already cited. Bacharach (1989) and Handfield and Melnyk (1998) identify the primary criteria upon which any theory should be evaluated as: utility, parsimony and falsability. It is, therefore, proposed to use these criteria as a basis for evaluation.

**Parsimony**

Hand field and Melnyk (1998) claim the power of theory is inversely proportional to the number of variables that it contains and this can effectively be done through comparison. Therefore, for this purpose let me use the two theories proposed by Schmenner and Swink (1998). That is the theory of swift even flow (SEF) and the theory of performance frontiers (PF) outlined earlier.

In the case of SEF the theory stresses variability and speed, but does not emphasise a direct relationship between the two. In the case of VUB variability is directly related to buffering requirements and, therefore, the speed of flow where the buffer is in the form of forward load or inventory. In a similar way variation and buffering can be directly linked to the creation of non-value adding activities, such as inspection, storage and counting, that SEF associates with speed but does not link directly to variation. It is, therefore, proposed that the VUB theory operates at a more operational and abstract level.
In the case of PF there are two frontiers to performance, but as with VUB the emphasis is on utilizing existing assets in shifting the operating frontier. Although JIT and TQM principles are cited as typical means of achieving this, the underlying concepts of variation and uncertainty are not directly related to this. PF does not conceptually define the nature of the shift in the operating frontier or the trade-off choices and there is no direct reference to buffering mechanisms. The suggested interpretation made by Vastaag (2000) was allied to the example of the Japanese automotive industry, where the associated drive to improve is akin to reduced variation and uncertainty (process and demand) including resource aggregation (flexibility). VUB theory is largely consistent with the PF conceptual model but may be used to explain the cause and effect relationship at a more abstract level. VUB can be considered to move the operating frontier towards the asset frontier by reducing or managing the impact of variation and uncertainty. This may be achieved directly or by separating/postponing the impact and strategically locating buffers in support of strategic priorities.

The above interpretation of VUB, if valid, can be seen to largely encompass these two theories at a more abstract and parsimonious level and with the use of more operationalised constructs enhance utility and flexibility.

**Utility and falsability**
The utility of the model has not been formally tested but proposals have already been made to utilize conflict resolution tools in combination with an earlier version of this model (Stratton & Warburton, 2006). As discussed earlier it is important for theory to be testable and for that the propositions need to be defined as variables. Several hypotheses have already been devised from the above propositions that are inherently testable.

**CONCLUSION**
The proposed Theory of Variation and Uncertainty Buffering appears to be consistent with empirical evidence and OM practice. The initial evaluation also suggests it provides a useful means of encompassing existing theories, models and laws at a more abstract level. The concept of trade-offs and buffering mechanisms together with the three generic strategies provide means of interpreting OM management approaches as well as clarifying the relationship between them. These generic strategies encompass the lean and agile paradigms and clarify the need to both reduce and manage variation and uncertainty imposed on the delivery system. Operations and supply chain strategy, therefore, is considered to encompass all three generic strategies in a process that resolves performance trade-offs at source and strategically aligns the residual variation and uncertainty via the buffering mechanisms.

**REFERENCES**


