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The impact of product life cycle on supply chain strategy

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Abstract

In order to compete in today's highly competitive marketplace supply chains must be engineered to match product characteristics and customer requirements. As products proceed through their life cycles these requirements dramatically change. Consequently supply chain strategies must be dynamically matched so as to maximise competitiveness. This paper demonstrates how an innovative UK lighting company re-engineered its supply chain to accommodate the impact of product life cycles. The key to their success is the ability to classify products and develop appropriate supply chain strategies. Careful matching of products to pipelines thereby enables maximisation of the appropriate order winner and market qualifier characteristics. The classification system used enables generic modelling of the methodology and hence potential for use in other market sectors.

Keywords: Case study; Product life cycles; Product classification; Supply chain management

1. Introduction

The need for tailored logistic channels in the product delivery process (PDP) is well recognised. Certainly "one size does not fit all" (Shewchuck, 1998) is in our experience a reasonable summary of both theory and practice. For example, in automotive spares supply chains at least three distinctive delivery channels are required. These are typified by the availability needs and holding cost requirements for (say) light bulbs, oil pumps, and bumpers (Towill, 2001). Each of the three resultant channels thus identified is then designed according to the optimal choice of location, mode and frequency of transport, inventory levels, and degree of postponement appropriate to that particular product. However an innovative manufacturer must do more than recognise the need for tailored logistics. Not only is the operating scenario likely to be more complex due to the wide range of both his customers and his suppliers forming an extensive interactive network, but also there is considerable interaction between the PDP and the new product introduction process (PIP).

The solution proposed herein is to design the PDP and PIP to be as seamless as possible so that products may flow as required by the customer throughout the life cycle. It should be noted that at the conceptual stage, the manufacturer does not know with any certainty what the life cycle pattern will be. Thus the manufacturer will need to engineer facilities which will cope with the

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demands of prototype manufacture, pre-production runs, and hopefully but not necessarily followed by a typical commodity product life cycle. This will include introduction, growth, maturity, saturation, and decline phases (Christopher, 1992). Yet the manufacturer may be managing the supply of thousands of such products simultaneously any one of which may be for a key customer. How is such complexity of operations to be underpinned by simple solutions?

We start by outlining the industrial background to the present paper. This includes a description of the difficulties encountered in conducting research in the present fast-changing business environment. This is followed by a description of how the industrial and academic research scenarios germane to the paper are integrated with considerable consequential benefit to both parties. The value stream integration concept due to Michael Porter (1985) shows how this has been achieved. This combines the identifiable strands of supply chain audit research, identification and evaluation of the particular lighting company, an industrial Case Study showing business processing re-engineering (BPR) effectiveness, and finally product classification research.

We then continue with a review of the need to engineer supply chains to match customer requirements. Specific reference is given to the development of focused supply chain "pipelines" to overcome averaging effects. We then describe the DWV^3 classifier (Christopher and Towill, 2000) used to segregate products according to pipeline requirements. This is followed by an in-depth review of a UK lighting company case study. Emphasis is placed on the development of four supply chain strategies, engineered so as to maximise competitiveness for four distinct clusters of products. Review of the key order winner (OW) and market qualifier (MQ) (Hill, 1985) characteristics for each cluster highlights the most appropriate supply chain strategy. The way in which these OW and MQ characteristics change during a product's life cycle is reviewed. This leads onto the tactical decision processes which may be used by the lighting company to switch and allocate products to pipelines as they proceed through their product life cycles.

2. Industrial background to the present paper

In assessing the impact of BPR programmes it is usually not possible to design a scientific experiment in which factors may be changed one at a time, and causal relationships established in a similar fashion to that observed under laboratory conditions. Indeed Burbidge (1984) has argued strongly that in production management it is often impossible to be certain of the *sign* of the impact made by a particular change, let alone its *magnitude*. The present situation is worsened because industry is under intense pressure, not only to change products and processes, but to do so with increasing frequency. Hence there is an inevitable tendency for companies to embark not just on one improvement programme at a time, but on a judgmental basis to execute a series of sequential and/or overlapping programmes. For research investigators this muddies the waters still further, not least because each programme may take many, many months to bring to a satisfactory conclusion (Berry et al., 1995).

Yet if industry is to obtain the full benefit of methodological change, results have to be interpreted in a generic form and related to an appropriate infrastructure. Otherwise the "transferability criterion" yardstick by which contributions to management theory should be judged will not be met (Micklethwait and Woolridge, 1996). As a minimum goal such transferability is certainly to be expected between businesses in the same sector. Preferably the "management theory" then becomes not only generic and identifiable but also transferable between market sectors. Thus, the phrase "lean production" (to which we shall return later) was coined to describe the process of minimum-waste manufacture in the automotive sector (Womack et al., 1990). Subsequently the concept has been found applicable to many other industries, including retailing, house building, and aero-engine manufacture (Womack and Jones, 1996). Nevertheless lean production must be selected and implemented with caution (Richards, 1996). It is not a universal panacea to be slavishly followed under all conditions, as our real-world Case Study will ably demonstrate.

So how can generic research results be established against this background of a fast-changing industrial environment? In this paper, the origin of our success can be traced back to an identified need for change, as envisioned by the "product champion" in charge of the business. Herein this product champion had already implemented lean production to good effect, but regrettably found that the impact on the business was only that of playing "catch-up". To become a major international player required further successful innovation. In particular, triggered by an interest in the paper by Harrison (1997), the product champion adopted the principle of designing and implementing a concurrent family of cognate supply chains. Each supply chain was thereby matched to a specific market need. The outcome was achievement of the needed competitive edge with consequential substantial bottom-line impact. Furthermore, a detailed Case Study describing the industrial perspective was published which included coverage of the pragmatic approach adopted by the enterprise in the specific area of supply chain selection (Aitken, 2000).

3. Value chain integration of industrial and research scenarios

Meanwhile the Cardiff University Logistics Systems Dynamics Group was engaged on the Supply Chain 2001 Project. This had specific goals which included auditing current supply chain operations; proscribing the range of supply chain configurations likely to be required by industry in the 21st century; providing a methodology for matching pipelines to the marketplace; and finally offering up a route map which enabled a business to move from its present state to that needed in the future if a competitive edge were to be attained and maintained. The project has led to collaboration with a wide range of industrialists, academics, and consultants. The result has been a considerable extension of our database especially with respect to incorporation of additional market sectors. As a consequence a number of advances have already been recorded. These collaborative successes include proposals for marrying lean and agile paradigms (Christopher and Towill, 2000) bullwhip reduction (McCullen and Towill, 2001; Dejonckheere et al., 2002), VMI implementation (Disney et al., 2001), design of the agile enterprise (Aitken et al., 2002), supply chain audit (Lewis et al., 1998), and supply chain positioning (Waddington et al., 2002).

Three of these advances form an integral part of the Value Chain as conceptualised by Porter (1985). Our holistic version summarising the investigation is shown in Fig. 1. This clearly identifies the industry based BPR Programme flanked by research into pipeline classification systems and into development and application of a supply chain audit methodology, respectively. The first activity tests the codification system proposed in Christopher and Towill (2000) against others emanating from the literature. It is this system which is exploited as a generic model which encapsulates how the lighting company has moved to become closer to the marketplace by identifying and implementing their four focused pipelines. The second relevant activity concerns the supply chain audit methodology. This was initially developed in an integrated industry–academic mode for the automotive sector (Lewis et al., 1998).

However the audit methodology has since been extended and applied outside of the automotive sector (Naim et al., 2002). Structured interviews are a core component of the audit, since great care is taken to codify information into a common format. The lighting company participated in this audit. Of particular interest was their practical experience in identifying the need for, and implementation of, lean, agile and leagile supply as defined by Naylor et al. (1997). Also the audit showed that the lighting company demonstrated much good practice. Furthermore, a detailed Case Study was already written up (Aitken, 2000). It was therefore concluded that the lighting company would be an ideal test bed for the proposed use of the classification system as a generic model enabling transfer of best practice. So the lighting company became an active "player" in the 2001 Supply Chain project.

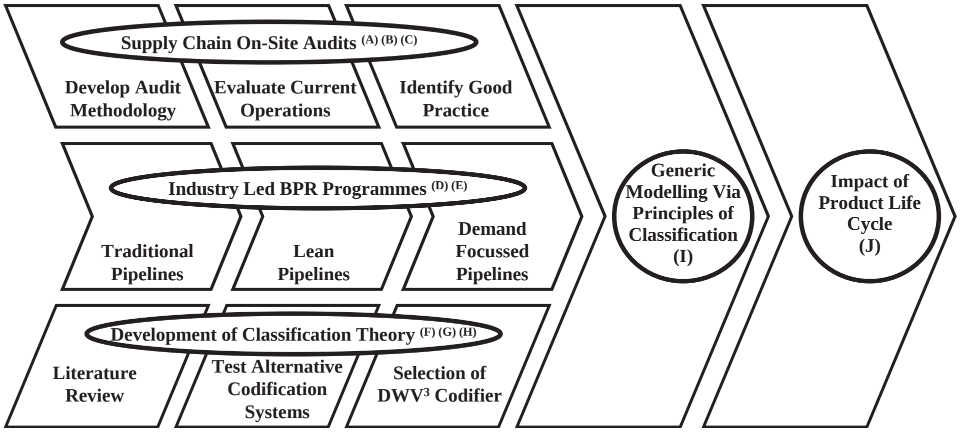

Fig. 1. Value chain integration of activities leading to generic modelling via principles of pipeline classification. Key references: (A) Lewis et al. (1998), (B) Towill et al. (2002), (C) Naim et al. (2002), (D) Aitken (2000), (E) Aitken et al. (2002), (F) Childerhouse and Towill (2000), (G) Christopher and Towill (2000), (H) Childerhouse (2002), (I) Childerhouse et al. (2002) and (J) Aitken et al. (2001).

4. Engineering supply chains to match customer requirements

Skinner (1974) identifies the need for focus in the manufacturing process so as to overcome conflicting objectives. He states that "*The focused factory approach offers the opportunity to stop compromising each element of the production system in the typical general-purpose, do-all plant, which satisfies no strategy, no market, and no task*." Fuller et al. (1993) expand this principle further when they explain the need to develop '*Distinct Logistical Businesses*'. This is primarily to avoid "*Averaging: A Diseconomy of Scales…Thus customers who needed specialised products quickly but unpredictably tended to be underserved, while customers for more commodity-like products were overcharged.*"

There is a great deal of commonality between the problems concerning the lack of focus in the supply chain and those of the associated manufacturing process. As pointed out both have frequently been incorrectly solely tailored towards efficiency (Skinner, 1974; Fisher, 1997). In itself this is not wrong but only if the overall strategy objective so dictates and definitely not otherwise. Skinner (1974) in a manufacturing context and Fisher (1997) in a supply chain context both stress the prime need to match market requirements and value stream objectives in order to best compete in today's highly competitive marketplaces. As a result cost or price in the market is only one of several possible order qualifying characteristics (Hill, 1985). For example, Christopher (1992) states the need to offer a service in combination with the product and typified by delivery, reliability, and after-sales support.

In adopting a scientific approach to this problem Johansson et al. (1993) segregate the value offered to customers into four constituent parts; cost, quality, service and lead time. Neither a supply chain nor a manufacturing process can optimise all four simultaneously and independently. Rather a trade-off has to be made based on market and customer requirements (Skinner, 1974; Fisher, 1997). This leads onto the need for focus because if multiple value streams with alternative market requirements are manufactured by a single factory then compromises must inevitably be made due to conflicting objectives. This parable holds equally true for supply chains. Hence the systematic progression is from focused manufacturing (Skinner, 1974) right through to focused logistics (Fuller et al., 1993) and hence on to focused supply chains (Childerhouse et al., 2002).

Broadening the need for focused logistics to focused supply chains means the development of market orientated channels that pass through several organisations each performing value adding activities (Fuller et al., 1993). Every organisation contains multiple supply chains, each focused on specific market requirements and ideally aligned with fellow supply chain members in a seamless manner (Towill, 1997). As with Skinner's '*factory within a factory*' (Skinner, 1974) it is also feasible to operate several supply chains through a single factory location, but emphasis must be placed on segregating the management and operation of each supply chain. Careful consideration must be given to which resources can be effectively shared so as to gain from economies of scale and which resources must be tailored for specific supply chain requirements so as to avoid averaging effects.

Fisher (1997) explains the need to match the appropriate supply chain management technique to product characteristics as shown in Fig. 2. The innovative/fashionable products require a responsive supply chain in order to cope with demand uncertainty and short product life cycles. The relatively predictable nature of demand for the functional products facilitates a more efficient supply chain. Fig. 2 illustrates only the two extreme types of product characteristics; in the real-world there is a wide spectrum of products with varying degrees of functional and fashionable characteristics. Furthermore, these characteristics are not frozen in time because as products mature through their product life cycles the customer requirements change drastically. Nevertheless the work of Fisher (1997) is a cornerstone of focused supply chain philosophy and is one important starting point of our approach.

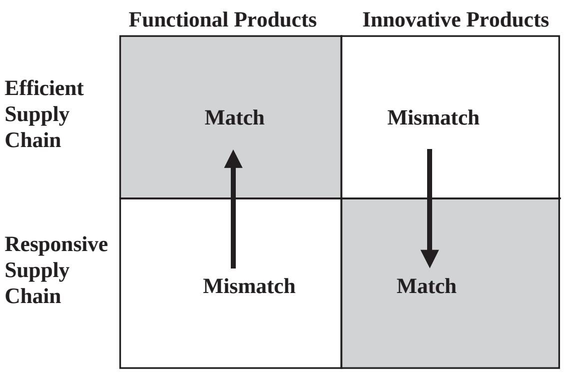

Fig. 2. Matching supply chains with product characteristics (*Source:* Fisher, 1997).

5. The codification system used as the basis of the generic model

From the left-hand side of Fig. 2 it is clear that during this research the challenge of establishing generic procedures transferable across businesses and/or market sectors inevitably presented itself. As Garrett Fitzgerald (a former Irish Prime Minister and economics expert) remarked on such problems "*I can see how it will work in practice, but I am still trying to figure out how it works in theory!*" (McRae, 2001). This statement is of critical importance because without a suitable model, establishing generic properties in production economics becomes extremely difficult. Fortunately the concurrent supply chain classification research had already homed in on a possible model on which the Case Study material could be tested. The latter source data was also considerably updated via further structured interviews with the product champion as exploited in Childerhouse (2002). The expected outcome from marrying the classification system and the updated Case Study is that the system is capable of realistic interpretation against the present product range: at the strategic level the system identifies how many concurrent supply chains are required: and at the tactical level how the present products are assigned to their best suited supply chains. It is the latter problem which is the specific focus of this paper which is an extended version of Aitken et al. (2001). Special emphasis is placed herein on the impact of the product life cycle in matching manufactured items to pipelines.

The classification system adopted herein was initially proposed by Christopher and Towill (2000) following an extensive literature survey plus their industrial experience in a range of industries. They have since shown that a variant of the model may be used to optimally fractionalise the relevant contributions of Developed Country in-sourcing to Third World out-sourcing of fashion garments (Christopher and Towill, 2002). A summary of the reasons for exploiting the DWV^3 model herein is shown in Table 1. There are clearly influences of both lean and of agile thinking in their original selection of the five key variables as follows:

*D*uration of life cycle,
time *W*indow for delivery,
*V*olume,
*V*ariety,
*V*ariability,

hence leading to the DWV^3 acronym.

It must be emphasised that application of classification systems in operations management is definitely an example of the Karl Popper maxim "there are many situations where it is far more preferable to be approximately right than exactly wrong" (Engebrecht, 2001). The reason is that DWV^3 is aimed at providing an uncluttered aid to strategic thinking by providing a rapid means whereby alternative pipeline concepts may be evaluated. To keep a handle on any classification system, the variables need to be kept to a minimum and the levels for each variable need to be as few as possible. If not, the alternatives to be considered by the analyst expand very quickly. For example if DWV^3 codification levels are selected to be binary for each variable there are already 32 supply chains theoretically needed to meet demand across the product range. No business could economically set up so many discrete pipelines. Nor, indeed, would it be wise to do so, since operations management overheads thereby escalate.

Hence in practice consolidation of items into a restricted number of pipelines follows detailed analysis of the product range (Fuller et al., 1993).

Table 1
Key reasons for the use of DWV^3 variables to classify demand chain types

Classification variables	Some key reasons for use to classify demand chain types
*D*uration of life cycle	• Short life cycles require rapid time to market. • Short life cycles require short end-to-end pipelines to enable demand to be continuously replenished during the life cycle. • Short life cycles require a demand chain to be able to 'fast track' product development, manufacturing and logistics to exploit ever decreasing windows of opportunity. • Replenishment lead times need to be matched to stage of the product life cycle, so to reduce lost sales and obsolescence risks.
Time *W*indow for delivery	• Rapid response is required to replenish fashion goods that are selling well at a particular point in time. • Competitive pressures are continually reducing acceptable response times, with many demand chains competing on the basis of very short windows for delivery of customised products.
*V*olume	• Products aimed at high volume mass markets allow for the lean-type production and make-to-forecast strategies to take advantage of economies of scale. • Lower volume markets benefit from flexibility both in production and the entire demand chain.
*V*ariety	• Greater variety results in a larger number of stock keeping units because the volume is split between alternatives. • Continuous appraisal of the proportional breakdown between variants must be conducted during the product life cycle because those variants popular at the introductory stage may be less popular in the decline stage.
*V*ariability	• Variability relates to both spikiness of demand and unpredictability, the former drastically affects capacity utilisation and resultant production techniques. The latter increases the risk of obsolescence and lost sales and can be addressed via information enrichment, consultative forecasting and lead time reduction.

Source: Adapted from Christopher and Towill (2000).

For example there might well be 32 theoretical contenders, but 6 of these may substantially cover 95% of the business. Expert judgement may further reduce these to (say) 4 pipelines. But the breakthrough is that there will be a logical (rather than an "ad hoc") progression to the selection of the supply chains really needed by the business. This is in contrast to a commonly met situation where new supply chains proliferate, but old ones are not closed down. The result is a complete mismatch of the pipelines needed to those actually available. It is yet another example of the phenomenon quoted by Morris and Brandon (1994) that new paradigms usually sit uneasily alongside traditional methods.

6. Matching supply and demand at the lighting manufacturer

The focused supply chain discussed here emanates from a BPR programme undertaken by a lighting manufacturer (Aitken, 2000). Briefly, in the pre-1996 scenario the company's organisation and management of its internal and external demand chains was based on a traditional functional approach. Manufacturing managed its material flow on a push principle driven by MRP and there was no differentiation between low and high volume products or between regular or irregular demand items. All products were treated the same way and moved along a single pipeline. Productivity was low as manufacturing orders ranged in size from 1 to 1000. Each production order was preceded, and followed by, costly changeovers and downtime. All seven forms of Ohno's (1988) classic wastes (or muda) were manifest in the internal demand chain and material conversion operations. Management of the external supply chain was on an arm's-length contractual basis as defined by Sako (1992). The supply base was inevitably broad as the strategy of the buying function of the company operated on the single principle of 'lowest price wins'. Buyers routinely moved the source of components to a new supplier if the price was lower. New vendors would be assessed on the basis of price and component quality alone. No obligation for repeat transactions was anticipated if the supplier did not remain the lowest priced bidder.

To overcome these problems the company embarked on a two phase, 4 year re-engineering programme (Aitken, 2000). The main aim of the re-engineering programme was to match customer requirements and PDP. To this end the company developed a pragmatic segmentation approach which mirrors Christopher and Towill's (2000) DWV^3 system for classification of supply chain variables. This resulted in the consequential partitioning of their product catalogue into four clusters. Table 2 illustrates each of these clusters in relation to their major characteristics. It very importantly also lists their respective key OW and MQ characteristics.

Once these four different types of product clusters had been identified the next step was to engineer appropriate supply chains for each. Cluster 1 consists of the low volume products.

Table 2
Key OW and MQ characteristics for the four clusters of lighting products

Product attributes	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Major characteristics	• Low volume	• High volume • Low variety	• High volume • High variety	• Short PLC • PLC = Infant stage
Key order winners	• Service level	• Cost	• Cost	• Design capacity
Key market qualifiers	• Cost • Quality • Lead time	• Quality • Service level • Lead time	• Quality • Lead time • Variant availability	• Quality • Cost • Design • Lead Time

This cluster is akin to automotive aftermarket products or "strangers" in the Lucas Group demand-frequency classification system ("runners", "repeaters", "strangers", "aliens") (Parnaby, 1993). It was decided that the existing MRP control mechanisms were the most appropriate for these particular types of products. Fig. 3 illustrates the internal supply chain for this cluster. Here the major OW for these products is service level. For such low volume products this has to be interpreted in terms of availability. Therefore we conclude that the application of a make-to-order approach via MRP control, with common raw material stocks and shared manufacturing resources maximises availability within acceptable lead time, cost, and quality parameters.

For Cluster 2, the high volume, low variant products are increasingly becoming commodity-like in nature and are particularly exposed to competition from low labour cost countries. The major OW here is cost. Since the UK lighting company cannot compete on the basis of cost alone, mainly because of higher wages, very short lead times are the only remaining competitive avenue. This is facilitated via a Lean supply channel (Womack and Jones, 1996) and coupled with a make-to-stock policy, so that deliveries to specific customer orders can be made in very short lead times (1 day if required). The resulting pipeline with the Kanban controls and 2-bin system operated across the supplier interface maximises efficiency for these products with relatively predictable demand patterns. This configuration is also illustrated in Fig. 3.

Despite the very short lead times offered for the commodity type products the UK lighting company, as with many UK organisations is in danger of being pushed out of the marketplace. To combat this pressure the lighting company and its associated supply chain increased customer service by offering multiple variants of relatively standard products. The items utilising this strategy make up Cluster 3. They are composed of high volume, high variant products. The OWs in this instance is cost followed very closely by availability of multiple variants. To achieve these twin

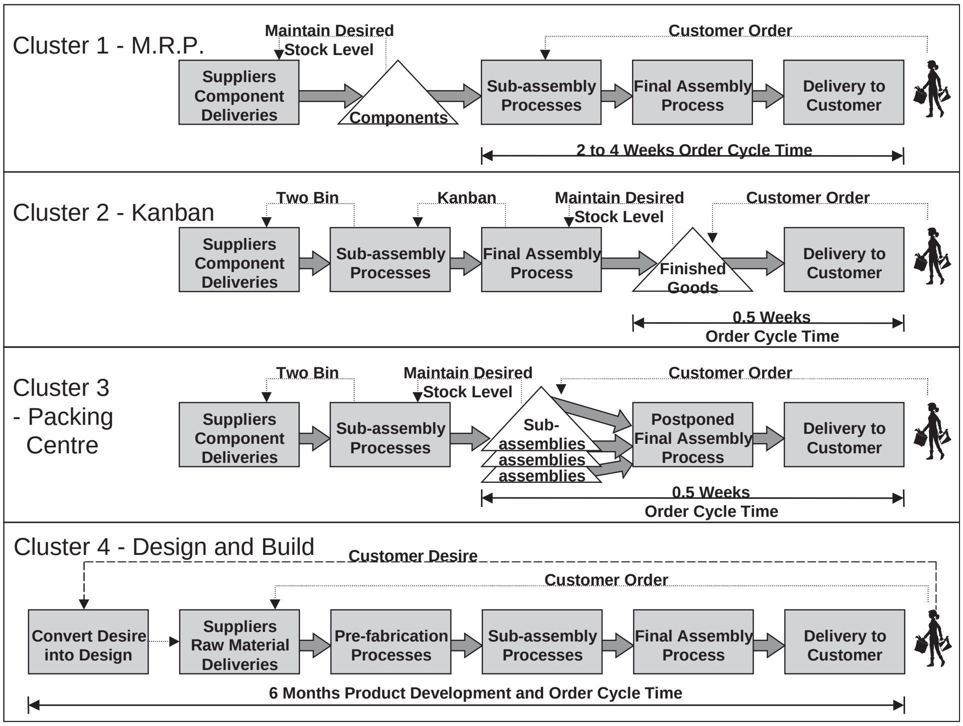

Fig. 3. Four internal supply chains designed to maximise OW and OQ objectives for each of the four product clusters.

objectives the application of the principle of postponement was seen to be optimal (Lee and Billington, 1993; van Hoek, 1998; Pagh and Cooper, 1998). This was partially due to the nature of these lighting products in that they are (conveniently for postponement) assembled from three major sub-assemblies. Therefore the de-coupling point has been placed at the sub-assembly level as also illustrated in the pipeline set depicted in Fig. 3. In operating this pipeline, behind the de-coupling point Lean Production principles (Womack and Jones, 1996) are applied to maintain desired stock levels, as was the case for the Cluster 2 products. But downstream of the de-coupling point in the final packing centre specific customer orders are assembled and dispatched, therefore offering multiple variants cost effectively and with very short order cycle times. Thus for this particular pipeline a Leagile strategy (Naylor et al., 1997) was adopted so as to obtain the best from both worlds i.e. low price and quick delivery.

The final Cluster of products, group 4, was seen as leveraging potential new opportunities in the marketplace in line with the increased demand for customised products. Such products either have short life cycles or are in their introductory stages prior to possible commoditisation. Since we do not know which product sales will "take-off" the duration of the life cycle is very uncertain. A completely new approach to operating the supply chain is required in this instance and has been noted as Agile in nature (Aitken et al., 2002). Fig. 3 once more illustrates the internal demand chain exploited for this cluster of products. It has been specifically designed to offer customised products in short development lead times as effectively and efficiently as possible, therefore maximising the appropriate OW objectives. These four clusters define the requisite focused factory thus enabling appropriate and designated pipelines to be designed, implemented, and operated.

7. Dynamic appraisal of product routing based on stage of product life cycle

Phase 2 of the re-engineering was completed by the year 2000, at which time the necessary focus had been achieved in rationalising the lighting company's supply chains. The resultant four strategies had been implemented and competitive advantage gained in each pipeline via the removal of conflicting objectives previously masked by averaging effects. As stated earlier, consequential bottom-line enhancements were substantial. However, at this juncture it was noted that the product routing was not static i.e. frozen in time. In fact the marketplace OWs and MQs are dynamic for any specific product as it proceeds through its product life cycle. This has been previously noted by numerous authors including Porter (1985), Hill (2000), and Kotler (1994). Furthermore, as Hayes and Wheelwright (1979) and DuBois and Oliff (1992) have stated, the production and manufacturing processes must also dynamically adapt to best service these changing marketplace conditions. Hence Fig. 4 traces a lighting industry generic product life cycle together with its OW and MQs. Also shown is the most applicable supply chain strategy for the corresponding life cycle phase.

During the introduction stage of the product life cycle the lead time from concept through to availability and capability of design are key OWs, hence the design-and-build strategy is most applicable. Once the product has entered the market and if the demand subsequently increases, then the product enters its growth stage. During this time the service level in terms of availability of a product responding to an unpredictable demand is the key OW. As a result the product is transferred to the MRP push based supply chain. Once the product has reached its mature stage it is switched to the Kanban supply chain, so to best compete on the key OWs of cost. During the saturation stage low labour cost countries swarm into the marketplace, therefore the UK lighting company competes by offering multiple variants. In order to do so the packing centre strategy is exploited. Finally, as the demand for the product tails off and enters the decline stage of the product life cycle, it is transferred back into the MRP supply chain. This effectively maximises the service level within acceptable lead times for such a low volume product with highly unpredictable demand. Finally, once demand has significantly

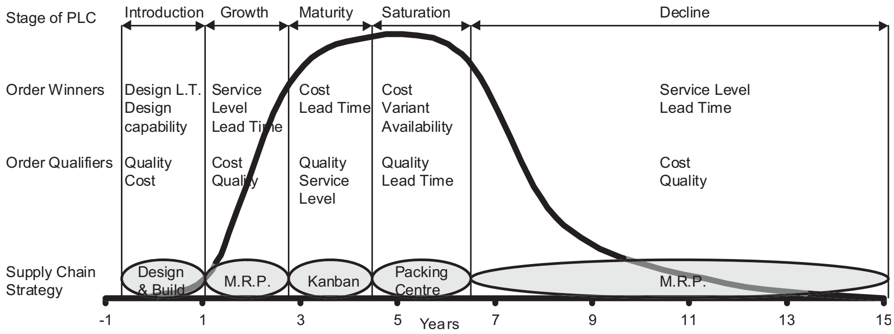

Fig. 4. Generic lighting product life cycle.

tailed off, the product is moved back to the design-and-build facility.

As an illustration of the change in operating scenarios following the design and implementation of the four focussed pipelines the MRP facility now handles 3500 active items, reduced from over 8000 items. The order cycle time for this pipeline has also been reduced by a factor of between three and four to one, depending on the particular product. In contrast the Kanban pipeline handles about 400 items. The design-and-build facility typically handles in the region of 1600 products during 1 year of activity.

Substantial cost reductions have also been recorded following the matching of pipeline and products (25). These include 15% decrease in items still manufactured via the MRP pipeline, 30% decrease in the Kanban pipeline products, and a 20% decrease in those products passing through the Packing Centre. Design-and-build costs have, however, substantially increased. This is because of the large pool of expensive engineers and designers in the design-and-build centre compared with the low numbers required in the manufacture of high volume Kanban items. But the higher costs for providing a design-and-build service is now transparent and hence there is no cross-subsidisation of design-and-build products from high volume items. However, as we see from Table 2, cost is not the market winner for this product cluster. It is primarily design capability and customers are willing pay a (modest) premium for this core activity.

8. Routing a product through the "best" supply chain

Fig. 5 illustrates the major decisions which may be used by the lighting company to match stage of product life cycle and pipeline strategy. Once the initial request from a customer has been transformed into a working prototype and the most appropriate production process selected, the product is manufactured by the design-and-build supply chain. This is considered as the birth stage of the product life cycle. Satisfaction of the initial customer request is followed by marketing appraisal of the product in relation to its potential demand from additional customers. If no further demand if foreseeable, then the product is retained in the design-and-build facility. However, if sales to further customers are considered likely, then the production process is partially codified and the product is moved to the MRP facility, thereby entering the infancy stage of its life cycle. At this juncture the demand volume for the product is continuously appraised. When the sales increase significantly the product is moved to the Kanban facility, but if the demand drops off the product is moved back to the MRP supply chain.

Hence during a product's mature stage it is produced on a daily basis by the Kanban supply chain. But if consumer demand increases but is based on multiple variants for this product it is moved to the packing centre pipeline. Once the product reaches the later stages of its life cycle it is moved back to the MRP facility. During this time

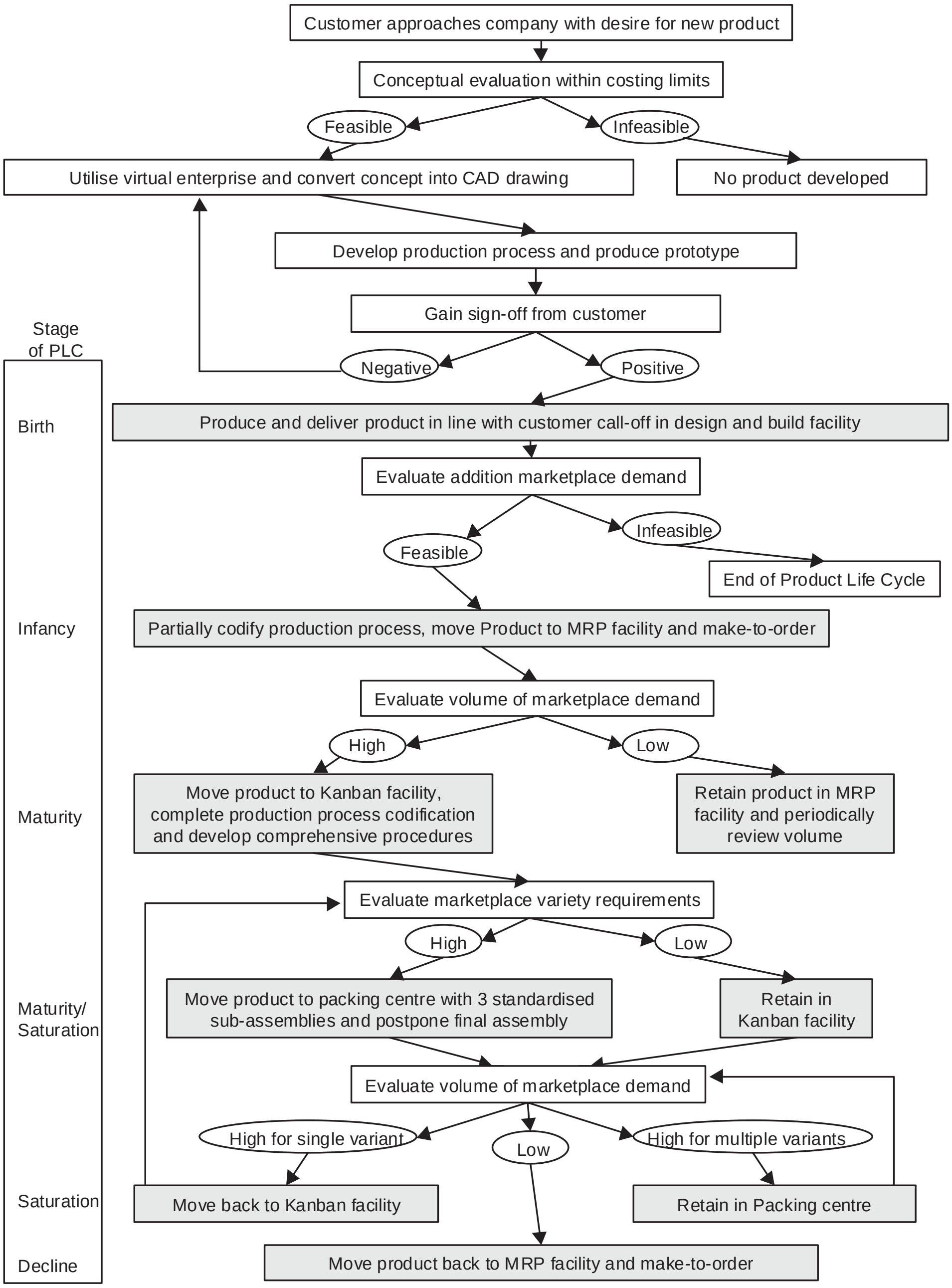

Fig. 5. Flow diagram of the decision processes used to match supply chain strategy and stage of product life cycle.

the demand for aftermarket or spares and repairs are produced and delivered to specific customer orders on a make-to-order basis. In the later stages of decline once the aftermarket demand has reduced the product is not discontinued, but instead it is moved back to the design-and-build facility. Thus the product is still retained as part of the portfolio; if customers require the product it is then built and dispatched from electronically stored designs.

The timescales for product routing changes can vary considerably. However it is felt useful to provide estimates for a typical generic lighting product in terms of the phases identified in Fig. 4. The initial, introductory stage starts at approximately minus 9 months prior to product launch, thus representing the time taken to move from an initial concept to a viable item in the marketplace. However within a year of the launch, the relative attractiveness of the product within the marketplace is clearly visible and the first change in routing is determined i.e. if viable move to MRP production ~ if not retain in design-and-build. The duration of the growth stage is somewhat more uncertain; if the sales volume climbs steeply the product is quickly moved to the Kanban facility. Alternatively, the status of the product is reviewed on a regular basis to check whether or not the volumes warrant transfer to daily production. Ideally the mature stage should be as long as possible, as this is when the initial investment in the product design is recouped. However by now the external competition is intensifying and the marketplace is soon subjected to third world low labour cost imports. Hence this product life cycle stage rarely lasts for more than 2 years before leading into a saturation situation. During the penultimate stage of the life cycle the provision of multiple variants only satisfies the customer for a limited period of time before the next generation of product is introduced. The final, decline stage can last between 5 and 15 years, as the obligation for providing spares and repairs, etc. can greatly increase the life cycle duration.

9. Conclusions

At a generic level there is no single supply chain strategy that is applicable to all product types. Rather we have found that supply chains should be engineered to match customer requirements. It has been shown that each stage of a product's life cycle has significant impact on strategy, especially in relation to supply chain management. As a product proceeds through its life cycle the demand characteristics change. There has to be a consequential requirement to change the supply chain strategy to maintain competitiveness. Hence the direct relevance of the focused supply chain in optimally matching product to pipeline. Analysis of the key OW and MQ characteristics during each stage of a product's life cycle facilitates the identification of supply chain engineering requirements. Therefore by monitoring a product as it proceeds through its product life it can be switched and matched to the most appropriate supply chain strategy for the next stage of its existence.

The UK lighting company analysed herein has provided compelling evidence of the need to match supply chain strategy with the stage of product life cycle. Furthermore the case study has provided a methodology for achieving this goal. However, there are two constraints which may inhibit universal application of the methodology. Firstly, the lighting company is large enough to be able to design and operate four alternative supply chain strategies. Secondly, the company is now able to match the competition during all stages of the product life cycle. In contrast most companies often specialise in just one or two of the life cycle stages which are most closely in line with their core competencies. If a company attempts to compete during all stages of a product life cycle but does not have the appropriate mix of supply chain strategies, averaging effects will occur to the detriment of the business for reasons given by Fuller et al. (1993).

It is always good to report an individual company successfully undertaking a major BPR Programme so as to align their pipelines with the marketplace, and particularly to observe consequential improvements to bottom-line performance. But this in itself does not make a contribution to Management Theory unless the "transferability criterion" is met (Micklethwait and Woolridge, 1996). This means that both the theory and the practice must be understood (McRae, 2001); one without the other does not take us very far forward. To enable ready transferability of delivery alignment strategies to other businesses within the same sector, and potential exploitation of the methodology into other sectors we propose using the DWV^3 classification system (Christopher, 1992).

By codifying these five product demand related variables (preferably on a binary scale) and subsequent aggregation and consolidation, a limited number of pipelines emerge as essential to satisfy any particular supply strategy. Finally, specific pipelines and particular products are not matched together for all points in time. Instead they require to be switched and delivered along different pipelines at the various stages in their product life cycles. The same DWV^3 Classification System may be used as an on-line monitor to trigger the necessary changes in product routings. Such continuous monitoring is desirable from the design-and-build phase right through to final decline in demand.

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