

Postponement for Designing Mass-Customized Supply Chains: Categorization and Framework for Strategic Decision Making

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Abstract— The concept of mass-customization has been suggested as the mandatory capability in the 21st century market place where customer's individual need must be satisfied rather than the need of mass market. Postponement is a powerful methodology to achieve 'Cost-effective mass customization' when applied in the scope of supply chain. There have been a number of literatures that employed postponement or reviewed postponement in a complex manner but not much on providing a simple framework practitioners can easily apply for establishing the level of implementing postponement to their supply chains. In this paper the classification of the postponement in terms of level of implementation and the strategic decision framework for selecting the right postponement that considers realistic aspect of recent economy are presented.

Keywords— *Postponement, Supply Chain Management, Production/Logistics Strategy, Mass-Customization, Decision Framework*

1. Introduction

Markets are becoming more unstable, more demanding. In most industries the product life cycle is shortening, pressure of developing more product variety is getting heavier, and customer service competition is stronger than ever. To meet the need of individual customers, as opposed to mass market, mass customization has been proposed as one of the most effective solutions to the 21st century market place. Kahn [1] states that mass customization should get a lot of attention because it tries to combine an agile customization of products with lean production efficiency within the supply chain.

Postponement has emerged as a powerful methodology to achieve cost-effective mass customization, strongly illustrated by the success of Hewlett Packard [2]. Also other companies such as Benetton [3], Toyota [4], and Sun Micro System [5] have succeeded their own mass

customization plans that are attributed to the leverage of postponement strategies.

The postponement concept was established by Bucklin [6], which became the foundation for following researches. Researchers who focus on the manufacturing process level often call it "Delayed Product Differentiation" since their researches mostly deal with the delay of product differentiation point in the multi-product line. Products are likely to be differentiated as they go down the supply chain and approach to the point of departure. The logic is that by moving that point of departure closer to the point of purchase, benefits of consolidation can be applied which reduces the complexity of manufacturing, the uncertainty and the forecasting errors by delaying the production related decisions associated with a specific demand. In this viewpoint Ernst and Kamrad [7] defined postponement as "A value added process for a set of end products whereby the common processing requirements among them is maximized". The customized processing is postponed in the process, which gives scope for utilizing scale advantages without sacrificing the variety of products. Van Hoek [8] gives a supply chain oriented definition of postponement that is more suitable for the intention of this paper. It defines postponement as "An organizational concept whereby some of the activities in the supply chain are not performed until customer orders are received." Christopher [9] gives the motivation and indicates the advantages of using postponement. It says much of the flexibility is probably lost as the product is configured and packaged in specific forms early in the logistics process. It also strongly suggests that greatest flexibility is available when the product is generic.

It should be mentioned that inventory cost saving is the most noticeable among the advantages in many cases where the postponement is applied. Van hoek [10] points out that postponement is often more relevant when products are more sensitive to inventory than transport cost, that is, higher value products with large variety.

Inventory cost saving may hide unreasonable increase on transport cost.

Based on the literatures and practices in the industry, the major advantages of exploiting postponement are:

- Inventory savings: Inventory is more at generic level – fewer variants of SKU (Stock Keeping Unit) and less safety stock requirements.
- Less risk of salvaging and obsolescence: No finished product inventories – prevent loss of high value added inventory and obsolete finished products.
- Better forecasting: Forecasting more generic and consolidated products – forecasting gets easier and has fewer errors.
- Greater flexibility and variety: Final customization is postponed until the confirmation of exact customer need and order – gives the ability to match the customer need without wasting previously added values to the product.

Overall, we can see that postponement can be an effective mass-customization tool for a company. The remaining issue is choosing the most appropriate one for the given organization.

In order to help companies choose the right postponement for the nature of product and supply chain in the long term, there is a need to categorize what have been done so far so that the organization can choose at which level it will implement postponement since applying postponement may involve a big commitment and therefore the scope level has to be defined clearly. So far some of the key postponement review literatures have been comprehensive but somewhat too complicated or conceptual for providing basic understanding to practitioners. Another issue is that companies cannot pursue aggressive changes and investments due to the world-wide economic downturn but postponement may require a significant level of changes.

This paper aims to provide a simple categorization of postponement that can complement existing postponement review literatures and a decision framework for choosing an appropriate postponement strategy that considers the management decision to the changes that postponement might requires. First the categorization of postponement based on the level of implementation is presented in Section 2. Then a decision making framework that can help identifying the right postponement strategy is proposed in Section 3, followed by conclusion and future research in Section 4.

2. Categorization of Postponement: A Level-of-Implementation Approach

The following definition of postponement is the one that this paper proposes to build the basis for categorization of postponement based on the level of implementation:

“Postponing some degrees of customization in *product level, process level, or business function level* to minimize supply chain total cost while maximizing customer satisfaction”

2.1 Product-Level Postponement

There can be some companies that have too much restrictions or limitations for changing the structure of supply chain process so that the product is the most viable option for postponement. Or some products by nature provide more opportunities for customizations in the design phase that can be effective marketing tools. Product-level postponement this paper illustrates is the one that occurs in the product development/design phase by the engineers. But the interesting fact is that the customization is completed not by the manufacturer but by the customers. Within the general use of the product, *specific functionality of product is designed undetermined until the customers actually set it up*. This postponement approach is being used widely in semiconductor device manufacturing industry. So called ‘Programmable Logic Device’ is the best example of product-level postponement that is used in many areas such as wireless phones and network management system development. There are many semiconductor device literatures that apply product-level postponement ([11] – [15]). Also one of the well-known Operations Management literatures that demonstrate product-level postponement is Brown et al. [16]. In this paper, the company named Xilinx designed the chips so that its OEM customers get generic devices and program the final configuration using software. Not only Xilinx employed product-level postponement, they also applied postponement in their process flow design, which is illustrated in the next section.

2.2 Process-Level Postponement

In this approach, *certain processes of a business function are delayed until customer orders are received*. This is the most common postponement that we can witness in various industries and therefore a quite number of literatures are out there. But in terms of the focus area, they can be divided largely into two cases: 1) Some of the processes are postponed in *distribution/logistics* function; 2) Some of the processes are postponed in *manufacturing* function.

One of the key researches for the process-level postponement in distribution function is Zinn and Bowersox [17], which develop four different types of postponement: Labelling postponement, Packaging postponement, Assembly postponement, and Manufacturing postponement. Labelling postponement assumes the product is marked under different brand names. Products are moved in unlabeled to the warehouse and get labelled after customer orders by brand are confirmed, which removes the uncertainty regarding demand quantity fluctuation by each brand. Packaging postponement happens under the situation that products are sold in different sizes with the same content. Products are shipped to the warehouse in bulk and packaged upon the customer order according to its size. Bulk shipping reduces the transportation cost and fewer SKU results in inventory carrying cost saving. Assembly postponement can be applied to a product that consists of a base product and number of common parts which are based on customer unique configurations (ex: computer with different colors of case). Inventory consolidation reduces inventory cost and unassembled shipments of products, which would have better density ratios, result in lower freight class cost. Zinn and Bowersox mentioned another postponement called Manufacturing postponement which is a same concept as assembly postponement but different in the degree of warehouse assembly operations. Whereas assembly postponement performs a simple assembly of components from mostly single source, manufacturing postponement is warehouse-based job-shop operation of detailed parts that are from multiple sources, at the reception of customer orders. Subsequently there have been many literatures followed Zinn and Bowersox [17] such as Bowersox et al. [18], Twede et al. [19], Van Hoek and Van Dierdonck [20], Chiou et al. [21], Yang et al. [22], Trentin [23], and Wong et al. [24], where postponed processes are performed in warehouses or other intermediate stock locations.

For the cases of postponing certain processes in manufacturing function, Cochran and Kim [25] present an optimization model of the horizontally integrated push/pull hybrid production system (HIHPS) where the starting point of the processes to be postponed in the production line is determined by formulating an mixed-integer, non-linear optimization problem and employing a simulated annealing algorithm to conduct the optimization search. Then they use case study results to demonstrate the methodology and validate the model's predictions. Brown et al [16], which also mentioned in Product-level postponement, demonstrate how Xilinx postponed their back-end processes with an additional finished-product inventory location. The fact is that nowadays most semiconductor supply chains postpone their back-end processes from 'die bank' where fabricated wafers are stored as the point of process postponement. They use the

die demands, not the finished product demands to set the front-end production starts. Then produced generic wafers are pushed to the die bank. These dies are pulled to the packaging process by customer orders. There are other numerous cases that modify their manufacturing processes and product structures to postpone the customization processes such as Van Hoek [26], Yeh and Yang [27], Lin et al. [28], Tu et al. [29], Forza et al. [30], Skipworth and Harrison [31], Harrison and Skipworth [32], ElMaraghy and Mahmoudi [33], and Kisperska-Moron and Swierczek [34].

2.3 Business Function-Level Postponement

This is a macro-level approach where strategically companies can *postpone entire business function based on the organization's unique need, process structure, and market situation*. Originally this concept was proposed by Bucklin [6] as the extension of shifting the risk of uncertainty from the retailers to the vendors – postponing the movement of differentiated products until customer orders arrive. This is the case where *business function-level postponement is used as a logistics strategy*. Zinn and Bowersox [17] also mention this approach as 'time postponement', where they suggest maintaining inventories only at a few central locations and waiting for the actual orders. Recently this approach has been leveraged in internet-based retailing business as 'drop-shipping' strategy. In this case internet retailers transfer the responsibility of managing physical inventories to their suppliers. Best example is Amazon.com - they coordinate the movement of products with their vendors and their logistics provider in order to implement the postponement of product movements. Papers such as Chen [35], Bailey and Rabinovich [36], Rabinovich [37], Yao et al. [38], and Xiao et al. [39] also discuss and illustrate this type of postponement strategy.

Another type of research in Business-level postponement is the research that suggests postponing business functions *as a supply chain strategy*. Pagh and Cooper [40] present this approach by using 'P/S Matrix' that identifies four types of generic supply chain postponement strategies. 'P/S' stands for Postponement/ Speculation strategies. Speculation strategy is the traditional production and distribution where product demand is predicted by forecasting and the distribution of finished products is implemented in advance of actual customer order. These Postponement/ Speculation strategies are applied to two main business functions of the supply chain: Manufacturing and Logistics. Based on the combinations of postponing/speculating those two business functions, they present the following four postponement strategies: the full speculation strategy, the full postponement strategy, the logistics postponement strategy, and the

manufacturing postponement strategy. Waller et al. [41] investigate the concept of market-oriented supply chain strategies, focusing on the relationship between postponement and inventory cost, lead time cost, and product customization. They demonstrate that postponement can be a meaningful and innovative approach for designing effective supply chains. Simchi-Levi et al. [42] present a more comprehensive framework for using postponement to determine the best supply chain structure. First they present a unified framework for identifying the right Make-To-Stock (MTS) / Make-To-Order (MTO) strategy. They then suggest approaches for determining the value of using postponement in supply chain design and for identifying optimal supply chain structures and inventory strategies. Also Frohlich et al. [43], Christopher and Towill [44], Lee [45], Towill and Christopher [46], Mills et al. [47], Christopher et al. [48], and Goldsby et al. [49] use postponement as a component of establishing supply chain strategies. Table 1 summarizes the categorization of postponement based on the level of focus:

Table 1. Categorization of postponement based on level of implementation

Level	Characteristic	Literatures
Product	Specific functionality of product is designed undetermined until the customers actually set it up	Santos et al. [11], Cancian et al. [12], Acernese et al. [13], Pozniac [14], Moise et al. [15], Brown et al. [16]
Process	Certain processes of a business function are delayed until customer orders are received	<u>In Logistics/Distribution:</u> Zinn and Bowersox [17], Bowersox et al. [18], Twede et al. [19], Van Hoek and Van Dierdonck [20], Chiou et al. [21], Yang et al. [22], Trentin [23], Wong et al. [24]
		<u>In Manufacturing:</u> Brown et al [16], Cochran and Kim [25], Van Hoek [26], Yeh and Yang [27], Lin et al. [28], Tu et al. [29], Forza et al. [30], Skipworth and Harrison [31], Harrison and Skipworth [32], ElMaraghy and Mahmoudi [33], Kisperska-Moron and Swierczek [34]

Business Function	May postpone entire business function based on the organization's unique need, process structure, and market situation	<u>As Logistics Strategy:</u> Bucklin [6], Zinn and Bowersox [17], Chen [35], Bailey and Rabinovich [36], Rabinovich [37], Yao et al. [38], and Xiao et al. [39]
		<u>As Supply Chain Strategy:</u> Pagh and Cooper [40], Waller et al. [41], Simchi-Levi et al. [42], Frohlich et al. [43], Christopher and Towill [44], Lee [45], Towill and Christopher [46], Mills et al. [47], Christopher et al. [48], and Goldsby et al. [49]

3. A Decision-Making Framework for Postponement as a Supply Chain Strategy

When companies decide to leverage postponement to improve their supply chain performance in terms of cost reduction and customer service improvement, there are many factors to be considered and many approaches that can be taken for the decision making process. Generally speaking, the feasibility of product-level postponement is product-dependent and technology-dependent due to the requirement of capability for enabling customer set-up. Also there can be numerous ways to implement process-level postponement for many different types of products, processes, and organization types. Therefore, it is not easy to define how the decision framework of postponement employment should be constructed, even though there are some literatures that attempt to propose general frameworks such as Yang et al [50] and Yang et al. [51]. Compared to product-level and process-level, the case of supply chain strategy in business function-level postponement can generate more insights and implications in terms of decision making framework since no matter what industry a company is in the basic structure of business models share common elements of business functions such as supply, manufacturing/production, and logistics. In this paper, we concentrate on the postponement as a supply chain strategy and provide a decision making framework by extending the work of Pagh and Cooper [40]. First, a brief review of the framework in Pagh and Cooper [40] is given. Four types of strategic postponements in their work are:

1. The full speculation strategy: Combines manufacturing speculation (make to stock) and logistics speculation (decentralized inventories). This is the traditional supply chain model where full speculation of manufacturing and logistics operations are implemented by demand forecasts. Customer order point is at the end of supply chain downstream. The economies of scale yields low production cost and close location of inventory to customers can provide high customer service level. But a lot of capital will be tied up with unnecessary inventory and obsolete products may cause substantial loss.
2. The manufacturing postponement strategy: Combines manufacturing postponement (make to order) and logistics speculation (decentralized inventories). Some final manufacturing processes are postponed to the downstream of supply chain until the actual order is received while the distribution of semi-finished demand, not the actual demand. Thanks to the generic configuration of the product inventory, inventory cost can be reduced, the management of inventory can get easier because of decreased number of SKU, and there is a less possibility of obsolescence. In the other hand, due to the lack of economies of scale and the increased lead time due to the final manufacturing processes, product unit cost would increase and the fulfillment rate of customer orders may decrease.
3. The logistics postponement strategy: Combines manufacturing speculation (make to stock) and logistics postponement (centralized inventory with direct distribution). Manufacturing is controlled by demand forecasts and pushes finished products to the central warehouse. Then the inventory is managed centrally with the direct distribution to retailers or end customers. This strategy increases the visibility of inventory management and decreases the amount of inventory to provide customers with high in-stock availability. However, to perform the direct distribution substantial increase in the shipping cost may occur due to the faster, more frequent and small-sized shipment.
4. The full postponement strategy: Combines manufacturing postponement (make to order) and logistics postponement (centralized inventory with direct distribution). Actual customer orders trigger the latter part of manufacturing processes and the logistics processes, which reflects the highest degree of postponement among the four strategies mentioned in this section. Due to the lack of economies of scale manufacturing unit cost is expected to be relatively high. But inventory reduction will be extensive throughout the supply chain and thanks to the rapid development of third party logistics economies of scale in the logistics can be sustained fairly.

3.1 Decision for Structure Change

Most of industries have been dealing with a world-wide economic downturn for several years. When the economy was booming, many companies aggressively looked for opportunities of a significant level of changes in their organizations. Implementing postponement requires a high level of commitment in changes, especially if a company needs to re-shape its supply chain structure. Due to the financial difficulties and market uncertainties, it is reasonable to think that nowadays most companies will be reluctant to big changes that accompanies additional investment for fixed assets or changes with high risk. In the context of postponement, when companies need to change its logistics structure it may involve a high-risk reorganization or additional investment of their fixed assets. If a company is willing to change its production process structure, it may be necessary to change its product design (i.e. change to more modular structure) and calls for additional R&D investment. Also it may force the company to alter its parts supply network significantly, which may result in losing high-quality, long-term relationship suppliers. Therefore organizations must decide if they are willing to change its logistics structure or production process structure, before determining which postponement strategy to implement. Table 2 describes the feasible postponement strategies from Pagh and Cooper [40] based on the structure of logistics and production process.

Table 2. Feasible strategies based on the structure of business functions (Based on Pagh and Cooper 1998)

Business Function	Structure Type	Feasible Strategies
Logistics	Centralized	Full Postponement, Logistics Postponement
	Decentralized	Full Speculation, Manufacturing Postponement
Production	Make-to-Stock	Full Speculation, Logistics Postponement
	Make-to-Order	Full Postponement, Manufacturing Postponement

3.2 Investigating the fit of Candidate Strategies

Once the feasible strategies are identified, we have to examine the fit of those candidates to the company based on company's products, markets, and process characteristics and select the best supply chain strategy.

Pagh and Cooper [40] propose a comprehensive tool called 'profile analysis' to analyze various factors that can determine the fit of a particular supply chain strategy among their four strategies. They divide important determinants into three categories of product, market and demand, and manufacturing & logistics. The 'product' category breaks down further into life cycle, product characteristics, and value of the product. Under these categories they use twelve determinants to see which strategy among those four fits the most to the company under consideration. Figure 1 shows the profile analysis from Pagh and Cooper [40]. By leveraging their profile analysis, we can identify one of the four strategies that can be the basis of further investigation.

3.3 Development of Focused Strategies

Among the four strategies in Pagh and Cooper [40], 'Logistics Postponement' and 'Full Postponement' strategies potentially possess more tailored options that can meet each company's needs more effectively. For 'Logistics Postponement' strategy, we may extend the extreme centralized logistics strategy into a hybrid-type one that places a few more strategic inventory stock locations between the company and the customers [17]. Or we can have several differentiated semi-finished products where different levels of form postponement are applied at the central location and customize movement of inventories to different types of customers [52]. For 'Full Postponement' strategy, Pagh and Cooper originally placed the decoupling point, where a particular product is linked to a specific customer order [53], in the last stage of the manufacturing process. But the decoupling point can be

placed at various positions in the supply chain ([50], [54]), which enables companies to have more detailed and diversified strategies for their various products and markets.

By going even further, Kim and Kim [55] customize the strategizing process of postponement for semiconductor supply chains based on the products, processes, and the business models of organizations. Kim et al. [56] extend the postponement concept by incorporating more than one point as the decoupling point in the supply chain. Figure 2 shows an example of positioning decoupling points that can generate customized strategies for different products and processes for a certain type of business model in semiconductor industry from Kim and Kim [55]. Figure 3 illustrates the strategies for semiconductor supply chains based on the positioning of decoupling points from Kim et al. [56].

Stock Point Process Product	WB		DB	FW
	WFF	WFB	A&T	
Structured ASIC		▲		
GA		▲		
PLD			▲	
FPGA			▲	
ASSP			▲	
Standard IC			▲	

Figure 2. Strategically placing decoupling point for different products in semiconductor supply chains (Kim and Kim, 2012)

Some important P/S-decision determinants			Generic P/S-strategies			
			The full speculation strategy	The manufacturing postponement strategy	The logistics postponement strategy	The full postponement strategy
P r o d u c t	Life cycle	Stage	Introduction	Growth	Maturation	Mat./Decline
		Volume	Low/Med.	Med./High	Med./High	Low/Med.
		Cost/service strategy	Service	←→	←→	Cost
	Product characteristics	Product type	Standard	←→	←→	Customized
		Product range	Narrow	←→	←→	Wide
	Value	Value profile	Initial stages	←→	←→	Final stages
		Monetary density	Low	Low	High	High
Market and demand	Relative delivery time	Short	←→	←→	Long	
	Delivery frequency	High	←→	←→	Med./Low	
	Uncertainty of demand	Low	←→	←→	High	
Manufacturing & logistics	Economies of scale	Large	Small	Large	Small	
	Special capabilities	Yes	No	Yes	No	

Figure 1. Profile Analysis for evaluation of strategic fit (Pagh and Cooper, 1998)

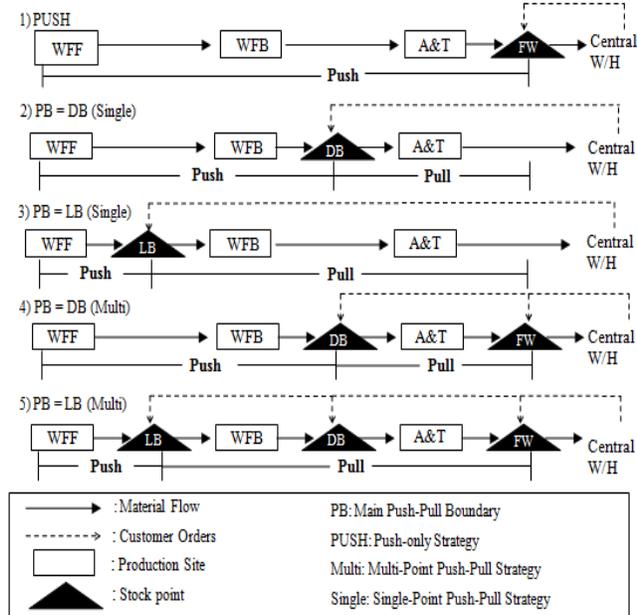


Figure 3. Diversified strategies for semiconductor supply chains based on the decoupling point locations (Kim et al., 2012)

In Figure 2 & 3, DP stands for the decoupling point and LB (Lot Bank), WB (Wafer Bank), DB (Die Bank), and FW (Finished-goods Warehouse) are the names of candidate stock points in a semiconductor supply chain. Also in Figure 3, WFF (Wafer Fab Front-end), WFB (Wafer Fab Back-end), and A&T (Assembly and Testing) are the names of major process stages in a semiconductor supply chain.

3.4 The Decision Making Framework for Postponement as a Supply Chain Strategy

By combining the elements presented from Section 3.1 to 3.3, Figure 4 presents the proposed decision making framework to implement postponement as a supply chain strategy. The description of Figure 4 is followed below:

1. Review the current logistics and production structure.
2. Make a management decision on the willingness of structural changes for logistics, production or both.
3. Based on the decision made, identify candidate strategies.
 - A. If only logistics structure change is feasible, the candidate strategies are the ones under the production structure the company currently uses in Table 2. For example, if a company is using make-to-stock production and willing to change its logistics structure, 'Full Speculation' and 'Logistics Postponement' can be the candidates.

- B. If only production structure change is feasible, the candidate strategies are the ones under the logistics structure the company currently uses in Table 2. For example, if a company has decentralized logistics and willing to change its production structure, 'Full Speculation' and 'Manufacturing Postponement' can be the candidates.

- C. If both changes are feasible, then all four strategies are the candidates.
- D. If no changes are allowed, identify the one based on the current logistics and production structure. Then use the profile analysis to see if the current strategy is a good fit for the organization. If not, re-consider the changes in logistics or production. If it is a good fit, the company may continue the current strategy.

4. Apply the profile analysis to the candidate strategies chosen and select the one that fits best to the company.
5. If 'Full Postponement' is selected, investigate feasible decoupling points and implement focused postponement strategies based on the optimal decoupling points for the products, processes, and the business models of the organization.
6. If 'Logistics Postponement' is chosen, consider the possibility of placing intermediate central inventory locations in addition to the centralized logistics structure and implement focused postponement strategies for different types of demand and customers.

4. Conclusion and Future Research

Postponement has been well documented and deployed as an effective tool for mass-customizing various supply chains in industries. This research aims to present a different perspective in postponement literature reviews and attempts to reflect the current economic trend of overall downturns in most industries into a decision making framework for implementing postponement.

First, the categorization of postponement literatures based on the level of implementation is presented, in order to complement existing reviews of postponement so that we can provide practitioners with better understanding of postponement without complex relationships among the factors suggested in many literatures. Second, a decision making framework for constituting a supply chain strategy by postponement is presented by extending the work of Pagh and Cooper [40].

This paper proposes a framework of leveraging postponement at the strategic level in a supply chain. Developing a postponement decision framework at the process level or product level would constitute a

meaningful extension of this paper. For process level framework, it may be necessary to create a portfolio of frameworks with respect to various industries whereas a

portfolio based on various product types would be necessary for process level framework.

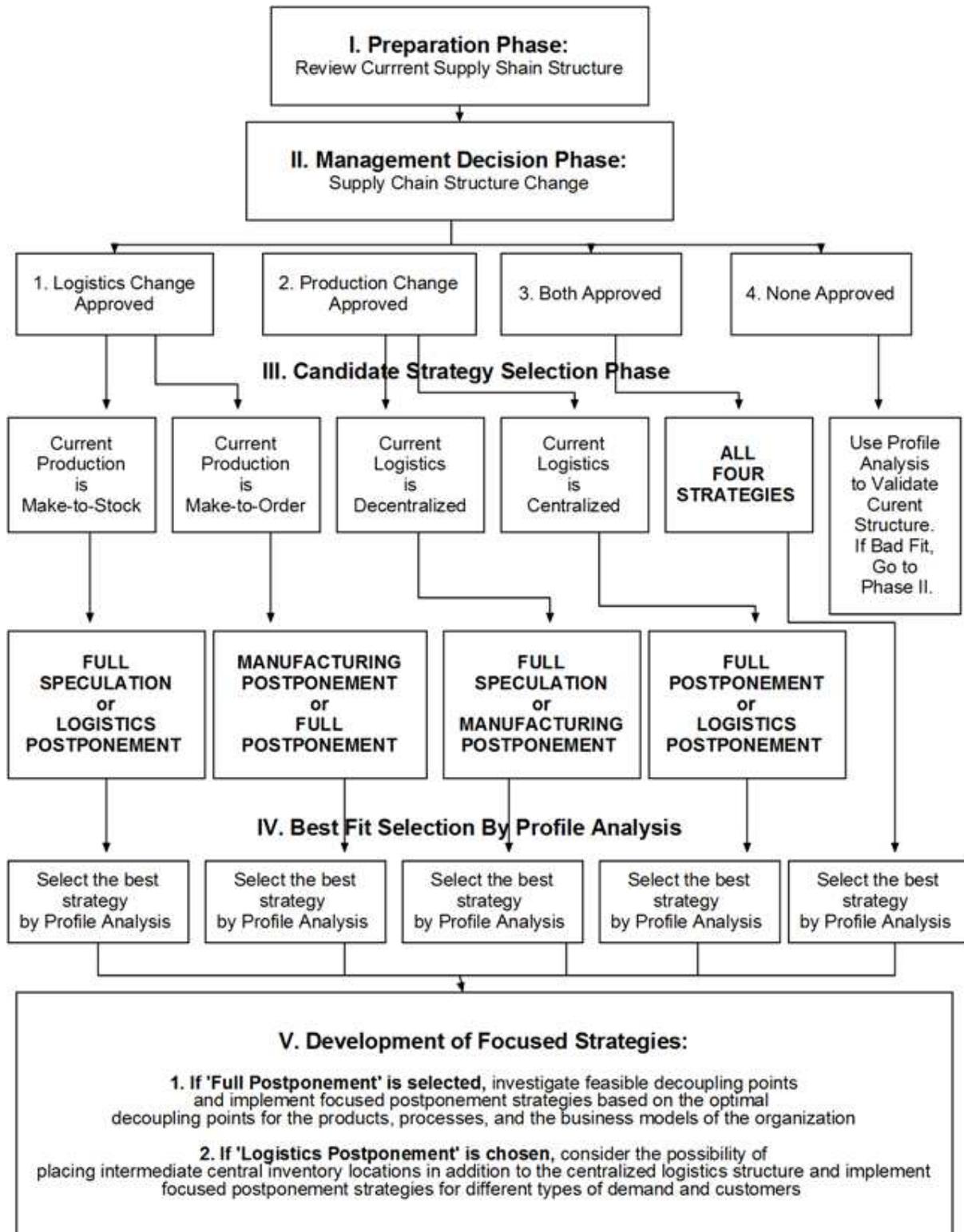


Figure 4. The Decision Making Framework for Postponement as a Supply Chain Strategy

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