Planning for a "Sudden-Death" Inventory Loss Triggered by International Tax Competition

by

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Abstract

This study addresses a medical device company's need to relicense its products for export after declaring a new legal manufacturer. New license applications are approved at an unknown date with increasing probability within a finite time horizon. Approval results in the instantaneous obsolescence, or "sudden-death," of inventory bound for export. As a result, the company needs to re-align its supply chain strategy to avoid stock-outs or inventory obsolescence. This thesis develops a model that aids the organization in assessing the decisions and necessary information that can help navigate the transition. Potential responses include pushing inventory out of the system before obsolescence, or ramping down production in advance of the sudden-death event. Improved estimates of alternative distribution costs, shortage costs, salvage values, and production capacities will greatly aid the organization's ability to respond to the event scenario. Changing these factors suggest different optimal inventory policies. To illustrate this relationship, a dynamic programming model is derived based on a probability distributions for likely license approval times. The resulting model allows the organization to assess optimal inventory policies derived from various system assumptions. In the thesis, different product aggregations are used to assess inventory strategies for bulk-license application submission. Patterns are identified in the analysis of simulation runs, including the time period for starting alternative inventory ramp-up as well as ramp-down speed. The intent of the study is to provide an iterative method for experimenting with assumptions within the organization in order to drive a coordinated response to the sudden-death event. The method is intended to be useful to other organizations planning to transition in preparation for events occurring with increasing likelihood within finite time horizons.

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Acknowledgements

I have been fortunate to study with a few teachers and peers who have emphasized the need to think deeply and openly about problems. The need to properly assess the question at hand in this thesis, and not to see a situation though existing frameworks, was a regular theme in my weekly conversations with my thesis partner, Luis Mustafa. Luis' consistent encouragement to appreciate the wider situation made this project a generative and insightful journey from start to present. His emphasis overlapped with that of another mentor, Professor Jonathan Byrnes, who repeatedly encouraged students in his Case Studies in Supply Chain Management to "take a walk by the [Charles] river" in order to break through static thinking and bad patterns. My advisor on this project, Fredrik Eng Larsson, was also instrumental in keeping me on track, by focusing on method and assumptions rather than on a drive for a final solution. When a first failed attempt at a model was produced with overly complicated assumptions, he suggested starting instead from the most basic building blocks. This advice proved extremely generative. Melody Chang, who collaborated on this project, provided a great deal of enthusiasm and insight into the topics explored.

Most tasks and jobs are designed to reproduce an existing state of affairs, despite the reality that systems are always undergoing change, and that even basic objective progress requires thinking past established wisdom about what is "in scope." Once the larger picture is properly grasped, often the solution is simpler than first anticipated. Conversely, complications can multiply when one is trying to work retroactively out of a failed logic while taking associated faulty assumptions for granted. I am grateful for the sound wisdom of the mentors listed above, and many others not listed, who have emphasized the need to take time to question frameworks, and to think objectively about the wider picture. The method advocated in this thesis is that of constructive collaboration. I hope it conveys the same spirit which has been so beneficial during my studies at MIT.

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1 Introduction

This thesis addresses a problem in the medical device industry that will occur with increasing likelihood within a certain time horizon: all inventory in a system becoming obsolete. The moment this inventory becomes obsolete, an alternative almost identical set of inventory will need to be supplied. In order to plan for this event, the organization must approximate how decisions made over time will result in various outcomes. These choices attempt to avoid service interruptions by planning for alternative supplies and distribution channels while also striving to prevent exceeding production capacities and inventory loads. This thesis develops an iterative dynamic programming model to suggest optimal inventory policies as the sudden-death event approaches. Based on inputs that reflect system conditions, including alternative sourcing costs and capacity limits, the model recommends a period-by-period order policy. The model's responsiveness to different inputs can be used to determine the relative impact of various conditions on the ability of the system to implement the ramp-down of old inventory, or the ramp-up of alternative inventory.

The problem addressed in this thesis resulted from the attempt of the thesis partner to consolidate its subsidiary manufacturing companies into a new geographical jurisdiction in order to realize tax gains. The practice, broadly called tax competition, often results in reducing corporate tax rates to the single digits. The act itself is congruent with trends in the medical device industry, where the ability to strategically adapt to regulatory constraints is often a dominant basis for competitive gains. Medical device companies increasingly have become functional warehouses. This has been largely in response to shifts in the industry that have favored bulk deals with hospitals rather than tailored solutions for individual doctors. In this environment, mergers and acquisitions have also become a dominant competitive strategy. To allow for easy consolidation and dissociation of companies within a larger structure with minimal interruption to overall operations, systems are deliberately left largely autonomous.[1] Likewise, the tax consolidation procedure underlying this case is at first conceived with minimal disruption to overall system. In effect, it is set in motion with little more than a handshake. From the time of the agreement, a new tax rate can be secured immediately. However, what starts as a bureaucratic procedure will eventually result in concrete "sudden-death" logistical problems.

According to the thesis partner, the health ministries in certain countries, referred to as "restricted-markets," prohibit medical devices with old labels from being imported after licensing for new products is approved. Because license approval will result in the immediate obsolescence of all inventory destined for export to these markets, it matches the situation referred to in supply-chain literature as a "sudden-death" event (Cobbaert, 1996). In addition, in certain restricted-markets, new products cannot be manufactured for import until the new license is approved. This creates a serious challenge for maintaining a continuous supply to such markets. China, the market under examination in this paper, is just such a restricted-market, and represents a significant destination for the thesis partner's products. License approval is also a timely process, differing country-to-country and case-by-case.

The objective of the study is to provide an iterative method for experimenting with assumptions within the organization in order to drive a coordinated response to the sudden-death event. The method is intended to be useful to other organizations planning to transition in preparation for events occurring with increasing likelihood within finite time horizons.

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[1] This has an almost Kafkaesque impact on one of the company sites visited for the thesis. There, one employee admitted that the only way he could find the way to his cubicle was by following changes in the office's carpeting. The rest of the structure was left minimally decorated and furnished, reflecting the piecemeal way the organization adds and divests additional components.

1.1 Background

In 2009, the thesis company registered its medical device manufacturers in Switzerland and Ireland as consolidated legal entities. The company, through its subsidiary manufacturing arms, pays taxes both where the product is made, and where the company is registered. As a result of the re-registration, the company has been able to lock in a competitive rate for corporate tax obligations. The organization's challenge, as stated above, is to endure the state change from old to new licenses in restricted markets without interrupting its service and operations. Given these constraints, the company needs to decide whether to ramp down existing inventory as the moment of "sudden-death" approaches, and if so when and to what degree. It can also consider postponement practices, in which products are manufactured without labels until licenses are approved. However, postponement carries legal and operational challenges, as product components are often required to be produced with an already decided license variant in mind. In addition, inventory can be pushed into China before licensing approval.

The problem of information gaps within the company's supply chain is connected to the strategy that resulted in its present form of corporate organization. Fulfilling the objective for this project requires a model that can approximate the realities of the company's operations. The organization is unwieldy in both size and operational procedures, but it needs to perform a balanced delicate maneuver in order to complete the tax maneuver. This act could also be compared to making a Wal-Mart store function like an Apple Store for a limited period of time. Now, more than five years into the initiative, and with only two to go before the company's compliance is put at risk, only a handful of the thousands of SKUs carried have been submitted for licensing approvals.

One approach proposed by planners at the company is to simply increase production and push product into the Chinese market in advance of approval. They suggest that extra capacity could be secured in a similar way to promotional planning. This approach fails to appreciate the immensity of the change represented by the license approvals. This is not a typical promotional event. It could in fact represent the potential multiplication of inventory for every SKU in the organization's portfolio.

Avoiding such a scenario requires understanding the subtle aspects of the change brought about by a license application and approval. Until licenses are approved by the respective national authorities, the commodities in question do not change. They bear the names of their former parents, and can advance through the pipeline unabated even though their profits are accounted as belonging to their new masters. However, at the moment licenses are approved, the commodities cannot be imported. If they are bound for a restricted market, they effectively lose their value. However, if they are not yet labeled, or if they are already within the market's boarders, they do not experience "sudden-death." The key to the problem is to understand the probability of license approval occurring at vulnerable positions within the supply chain. By correctly assessing the likelihood of the license approval event occurring, these "at-risk-children" can be properly secured at "home bases," defined as either the point before a product is labeled for shipment, or the point after which it has entered a country for import. To solve the puzzle of where to arrange inventory during the license-approval period and when, an optimized inventory model is derived in this thesis for stocking inventory in distribution centers. The model balances the costs derived from having stock in these centers versus the expected cost of sudden-death events, while also modeling postponement and pushing solutions through a dynamic programming model.

In one undesirable scenario, the supply chain is caught off guard by license approvals without adequate stock within a country, and with insufficient manufacturing capacity to reproduce SKUs for export, resulting in damaging stock-out events. At present, the limited time available to meet compliance deadlines has caused the company to apply for approval licenses in bulk, increasing the danger of this scenario.

To "walk the tight-rope," an inventory model will likely combine ramping down normal inventory as a sudden-death event approaches, together with the use of postponement and warehousing solutions. The optimal solutions differ based on factors such as average sales volume and product value. In this thesis, a solution which aggregates SKUs of similar characteristics together to simulate a system wide solution is tested. This reflects the actual situation in which the company is applying for new licenses in bulk.

Grouping SKUs of certain characteristics into a first run may result in strategic advantages. This suggests organizations can experiment with the model to see that the deliberate grouping and staggering of product lines through a state change, if possible, can result in optimal solutions that allow for continuity of operations with minimal disruption. In this study, the organization had already run down the clock on the transition, requiring a policy that involves bulk transitions, with about two submission periods. Whatever the specific case, though, the emphasis in this approach is to clearly showcase 1) the importance of understanding the nature of the present supply chain policy, 2) the options available for undergoing the state change, 3) the likelihood of state changes occurring at specific moments of time, 4) that an organization must disaggregate its various product types to understand those which can be strategically grouped together for specific transition strategies. This approach is a necessary correction to the general trajectory of large organizations towards "one size fits all" supply chains solutions (Byrnes, 2005). It also attempts to adhere to Roberto Perez-Franco's framework for understanding supply chain strategy as the "logical bridge between the overall strategy of an organization and the operational practices of the supply chain," (2016).

1.2 The Global Context

The sudden-death problem was triggered by two contradictory moves in corporate strategy. The first can be described as a dispersed approach to company tax registration. Until around six years ago, many of the thesis partner's new acquisitions remained separate tax entities. This is in line with the flexible way in which new companies were acquired and divested from the organization. But more recently the trend has moved towards nominal corporate consolidation of these entities to leverage better tax deals. The previous practice facilitated legal registration of the companies and allowed separate entities to sell independent product classes. For instance, neurological products previously remained registered with one company, and bone replacement parts with another company. For the thesis partner, this was the case even when manufacturers were almost located across the street from one another, in the same Swiss canton. As separate legal entities, with distinct tax obligations, integration with the parent company was far from complete.

However, the rise of corporate "tax competition" has enabled companies to bargain directly with tax authorities for discounts in return for consolidating units into single entities. Although not the focus of the thesis, it is worth pointing out the relationship between tax regulations, company licensing policies, and inter-state economic competition. The competition between countries to serve increasingly mobile corporate constituencies has transformed what constitutes sovereignty, i.e. what constitutes the nation-state itself (Deutsch, 2015). As Deutsch states, "Countries still control their tax rates *de jure* and no other state has a say in their fiscal policy. However, due to the mobility of their tax base, de facto control over actual government revenues is weakened considerably."

The practice of "tax competition" is a relatively new phenomenon that since the 1980s has given multinational organizations tremendous power in realizing an interest beyond that of the nation state (Deutsch, 2015). Whereas in the 1980s, Deutsch notes, states such as the United States and Britain broke up the bargaining power of collective labor organizations, since then, owners of national debt and international companies have successfully been able to pressure states to effectively cave in to tax demands. For example, the Boeing Company paid no federal income tax between 2008 and 2012 despite being profitable in every one of these years, and creditors in financial markets have been able to demand nations restructure their public benefits to best serve the owners of their respective debts. Deutsch labels both practices as a form of "investment strikes." Tax competition itself was facilitated through extensive legislation in the US starting in the 1970s. It would not be unreasonable to see the procedure as designed to favor US and US-aligned corporate entities.

1.3 The Internal Situation

The partnering thesis company recently implemented a new conceptual model to re-engineer supply chain processes through the concept of "entitlement," in which different divisions in the company can obtain the right to secure inventory based on strategic objectives. The division of supply chain decisions into a partially "*de jure*" framework provides for two separate "material entitlements" for inventory, one a "base entitlement" computed from forecasting for demand with the use of cycle stock, pipeline inventory, and safety stock, and a non-base entitlement based on risk management planning, event planning, and "slow moving and obsolete" stock. Whether the model provides for greater supply chain coordination or balkanization remains unclear. The assessment of the thesis partner is that the entitlement model does not allow for the coordination necessary to effectively navigate this problem's state change. The entitlement model theoretically allows managers to pry open sections of inventory planning to avoid potential supply disruptions and inefficiencies. Overall, it implies a move towards basing inventory strategy on a more objective basis, or at least at a minimum, to make informal unspoken networks of control formal. Theoretical articulations of entitlement theory tend to have a both prescriptive and descriptive utility. Representative of the former, Robert Nozick, considered the founder of the concept, wrote that fairness in acquisition and transfer could produce a just society, an idea that he later largely repudiated (Nozick, 1975). In contrast Amartya Sen used the concept to map out a basket of entitlement-relations which in various economic situations could be used to ward off-famine Sen stated, "If, [the approach entitlements] appears odd and unusual, this can be because of the hold of the tradition of thinking in terms of what exists rather than in terms of who can command what" (Sen, 1981, 8). Sen's summation, that the entitlement approach is more useful for the articulation of the exercise of power by various agents, rather than as an objective means in itself to "optimize" a system itself applies in this case. Entitlement is a step towards a more responsive system that can quickly pivot around various scenarios. However, without a method to properly understand both the system and the scenarios themselves, entitlement approaches will simply produce a good deal of extra firepower without a sensible target. To their credit, members of the supply chain team were concerned that without further analysis, this approach may be inadequate.

In the following literature review section, I will review the primary scholarly works used to inform this thesis' methodology and model. Following this, I will describe the methodology and model created for the thesis partner, as well as associated assumptions and limitations to this solution. Next I will depict the resulting inventory strategies recommended through use of the model. And in the final two sections, I will discuss these results as well as conclude with an analysis of the applicability of the case to this and similar situations.

2 Literature Review

This thesis addresses a problem in the medical device industry that will occur with increasing likelihood within a certain time horizon: all inventory in a system becoming obsolete. An important feature of this objective is the creation of a model for producing inventory ramp up and ramp down strategies. This is done by incorporating the probability of obsolescence for product lines destined for restricted markets. Much of the literature on obsolescence argues that if obsolescence is an important part of inventory policy, objective and precise mathematical models need to be employed, rather than simply adding extra projected expenses into holding costs for economic order quantity (EOQ) equations (Song, 2004). As a cornerstone to this line of inquiry, work such as Barankin and Denny's investigated how a fairly standard inventory model could incorporate the risk of obsolescence by incorporating the probability for the occurrence into periodic calculations of potential salvage costs (1960). Inspired by Barankin's work, Pierskalla used the model to propose a discrete policy for calculating inventory levels when stock faced an increasing failure rate over time (1970). This failure rate was projected variously based on equally likely distributions, truncated Poisson distributions, discrete triangular distributions, and truncated geometric distributions. Pierskalla concluded that properly understood obsolescence distributions could strongly impact optimal inventory policies for all of the distributions studied, and for every period, up to near the convergence of the internal failure rate at zero at the final period, i.e. the time at which sudden-death obsolescence would have a 100% chance of occurring. Later work has investigated tools for using the above models to better optimize ordering responses. Israel David's investigation of military maps examines how high production costs as well as obsolescence due to changes in ground conditions require a sudden-death inventory model for a continuous-review policy (1997). This method provides a means to compute the start of the time interval when obsolescence is possible, and also prescribes an "order-to-the-end" point, when it is advisable to order for all foreseeable future demand.

The scale of the thesis company's operations implies that a periodic review policy, in which inventory is re-ordered at specific periods of time is a more feasible solution, unlike a continuous review policy, in which inventory is continuously reviewed and reordered when dipping beneath a certain level. However, for the sake of understanding performance based on a continuous review basis, an optimization model for continuous review was created in the course of this study as well.

Other models account for a more complex understanding of the likelihood of obsolescence. Song and Zipkin's work derives probability distributions from a confluence of interacting sub-models, including possibilities that demand drop-offs can contribute to obsolescence, in addition to technological obsolescence (1996). They incorporate these various factors through sub-models based on Markov chains. Their model assumes that there is no way to dispose of excess stock, which makes the problem of obsolescence more essential to a business operation. The conclusion of their paper is in contrast to an earlier work that investigated "sudden-death" obsolescence for spare aircraft components (Brown, 1964). It argues that starting state conditions often do not have a substantial impact on optimized inventory decisions. The difference was partly a result in scope and focus. In Song's work, fast product life cycles and highly diverse customer behavior in the technology sector requires a model more attuned to multiple variables that shift period to period. Song's study used Bayesian updating procedures together with calculations of sudden-obsolescence as well as Markov processes.

Recent work has looked more closely at integrating obsolescence into forecasting systems such as Teunter's work (2011). This report argues that SAP systems commonly use the Croston method for calculating intermittent demand, and that such a method is not capable of satisfactorily accounting for the obsolescence of slow-moving objects. Such a system does not update when there are successive period with zero demand. Instead, a method is proposed which updates demand probability rather than demand intervals, and does so every period. While in this thesis, fast-moving SKUs were a priority due to the value represented to the overall system, it is important to note that a large majority of the company's items are just the sort of slow moving objects that Teunter examines. As a result, Teunter's methodology can be used in tandem to the method illustrated here.

Others argue that many of the obsolescence models proposed thus far are unrealistic in most operational settings (Cobbaert, 1996), and propose that obsolescence can indeed be incorporated into simple carrying cost equations. Approaching the issue from a pragmatic standpoint, Cobbaert's report investigated an engineering firm that specialized in machinery for wire drawing mills. It concluded that mathematical models for "sudden-death" obsolescence were overly complex given the 30,000 SKUs in inventory. An alternative EOQ model was proposed instead for the problem, based on three scenarios. The first assumed a constant obsolescence risk, with no possible shortages, i.e. stock-out events. The second included variable obsolescence risk, also with no possible shortages. And the third included variable obsolescence risk, with shortages allowed. Cobbaert's model is essentially a standard EOQ model, but with expense for obsolete items based on expected cost—derived from a probability distribution—added to the holding cost. The approach is "myopic" in that obsolescence is only assessed in terms of the next order cycle. As such, as opposed to the approach in the study, Cobbaert does not examine the impact of decisions made in one period on all future periods. Cobbaert justifies this approach because he states it is nearly impossible to understand with any certainty the time in which sudden-death obsolescence will occur.

This approach, which is designed to optimize overall efficiency, is not so relevant to the state-change problem addressed here. Rather than understanding the model as a tool with which to provide members of an organization with new insight, Cobbaert's approach simply is an attempt to better implement an existing solution. As stated, even assumptions about sudden-death projects should be seen as inputs into an iterative process of team and knowledge consolidation rather than simply a one-time fix that would either provide a good solution or an ill-conceived one. Cobbaert's model assumes that the system already works properly but simply needs to more properly calculate risk. While many executives and even supply chain academics may see such an approach as a realistic way to engage with systems, experts such as Byrnes argue it is precisely this sort of assumption that supply chain thinking must interrupt (2005). In addition, Cobbaert argues that a dynamic programming solutions, such as the one provided in this study, are not practical for systems involving hundreds of SKUs at the time. However, this fails to appreciate an argument made above—that it is precisely through various groupings of SKUs through an iterative dynamic programming approach that key insight can be produced into potential strategic synergies.

Overall the literature illustrates that understanding the actual properties of a supply chain, including quantity, value, and variability in demand, are all vital in deriving a proper model for assessing "sudden-death obsolescence." Looking ahead, Teunter's methodology for incorporating obsolescence factors into SAP forecasting systems will provide helpful insight into scaling the final model for implementation by the actual organizations. In addition, the scenario studied here closely approximates the "sudden-death obsolescence" situations studied by many of the scholars above. Similar to the situation on which David and Greenshtein's 1997 work was based, the thesis partner's service levels must be kept extremely high, and salvage prices are likely minimal due to a complex regulatory environment.

The literature consulted for this study points to the unique applicability of studies on "sudden-death problems," once restricted to wartime issues, to many contemporary intuitional challenges. Strategic supply chain analysis was not viewed as a primary factor with which to achieve organization transformation in 1996 when Cobbaert dismissed a more mathematical and scientific approach to his study's sudden-death problem as "not-practical." Today there is an increasing need to restructure organizations at an international level to reflect emerging risks and opportunities while keeping operational disruptions to a minimum. The model presented here represents an extended application of such analysis—restricted in the past to a small variety of items—to the needs of large organizations undergoing complex operational changes incorporating thousands of components.

3 Methodology

In order to derive an approach for solving the problem of preparing for the sudden-death loss of all inventory within a certain time-horizon with increasing probability, the products most relevant to the organization must be properly segmented and aggregated. The thesis partner distributes 24,000 medical device SKUs, of which 3,001 are relevant to the China market assessed in this study. These include everything from low cost screws to high value surgical components. The company must maintain a very high service level to its clients given the life-critical nature of its products. As a result, the company carries an extensive inventory of SKUs, the majority of which are demanded less than once every three years, as well as products that are issued thousands of times per month. The top 600 fast-moving SKUs represent approximately 90% of the company's product value in the market overall and over 98% of its units in the market, as shown in figure 3-1. These are the items placed in scope for this study as a result of the high value that they represent to the operation.

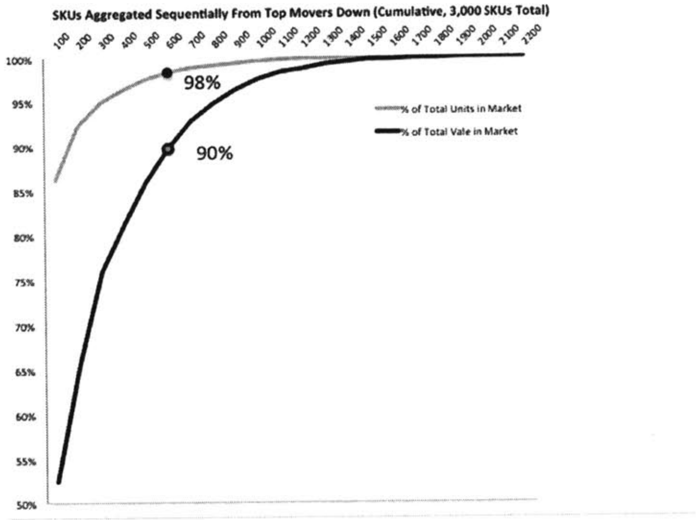

Figure 3-1 SKUs in scope as percentage of total value and units sold by the company in China

Products from manufacturers are consolidated into three distribution centers in Europe and then are transported to local hubs in destination countries. For this study, normal inventory levels representing distribution points outside of destination markets were assessed, together with the potential to create alternative sources of inventory to mitigate the impact of a sudden-death event. This alternative inventory could consist of postponed inventory at the point of manufacture, or inventory pushed into local markets.

3.1 General Approach

To assess potential decision levers, there is a need to first clarify when a state change in a distribution channel is likely to occur. In the thesis partner's case, this is triggered by the approval of variant licenses by governmental authorities. This act shifts the status of normal inventory on hand to unusable instantaneously. Approval times by state authorities occur with various levels of regularity. Historical data in this scenario can serve as the basis for forecasting future behavior. A mode, minimum and maximum figure can be derived on the basis of existing data and application experience, in this case based on an estimated mode of 360 days, a minimum of 180 days, and a maximum of 365 days. This approximate method was deemed the best method in this scenario because of difficulties in receiving historical records from the organization. This situation likely pertains to other organizations as well. Ideally, legal or regulatory departments would grasp the importance of cooperating with a supply chain team to facilitate event-transitions, whether they be a merger, divestiture, or legal re-organization. However, this often is difficult given established divisions of labor and prerogatives. As a result, a maximum, minimum, and mode estimate for an event timeline can be an easy to obtain substitute for a more scientific range of dates. From this information, it is possible to establish a probability distribution function over the full range of time in scope. A triangular distribution is closely pegged to reported figures. It results in a nearly fixed line slope between minimum, mode, and maximum estimates. The beta distribution models these inputs according to a k-factor which represents the variance of the distribution. In this paper and the associated model, a beta distribution with a k-factor of four and ten respectively are used to test probability distributions for the event timeline. The k-factor of four depicts a more gradual distribution of approval times, resulting in an expected value for approval time of 270 days. The k-factor of ten derives an expected approval time of 315 days, with a far steeper increase as the date approaches.

The cumulative probability distributions using a triangular distribution function and beta distribution, as well as beta distributions with the two k-factors are displayed in figure 3-2 (left). The y-axis represents the probability that sudden-death occurs by the day marked on the x-axis. The top of the graph, 1.0, represents a 100% probability that sudden death has occurred.

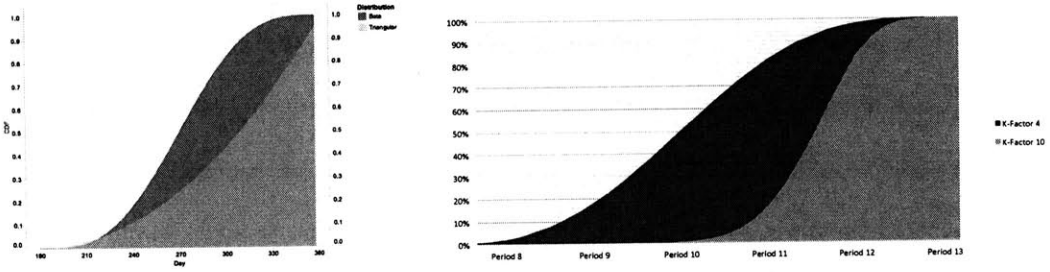

Figure 3-2 Left: Sudden-death cumulative distribution function represented by beta and triangular distributions Right: Beta distribution with K-factor of 4 and 10

An inventory model can be constructed starting with an initial period and advancing to the period in which obsolescence must occur with 100 percent certainty. This final period is derived from company estimates for maximum time to the sudden-death event described above. In order to best match the monthly periodic order policy reported in the data supplied by the organization, each period is set to last 30 days. This can be adjusted based on the order policy of whatever operation is under investigation. In general, the most relevant periods will be those during which there is a likelihood of sudden-death occurring, and periods before this range should reflect a normal and static inventory strategy. The notable exception however is when capacity constraints force a build-up of alternative inventory in advance of the sudden-death range.

Conditional probabilities are used to assess the expected costs incurred during given period. This involves adding the approximate stocking, shortage, holding, and profits expected given the inventory level set for that period. This total is multiplied by the conditional expectation that sudden-death *has not* occurred during the start of the period.

The probability of a sudden-death event occurring during the start of a period is the cumulative possibility that such an event will have occurred at any point during the previous period. This may seem counterintuitive; however, it is a necessary aggregation. Shortening the duration of the periods would produce a more accurate approximation of the effect of an event occurring at a given point at time within the period. However, doing so would likely come at the expense of realistically representing the inventory policy of the operation in question. A similar procedure is used to calculate the expected costs accrued in the event that a sudden-death event occurs during the start of the period. This involves adding the shortage penalty, profit, replacement inventory cost, and salvage costs for lost inventory. In the case addressed in this study, shortage penalties can be understood practically as the emergency cost for shipping items to customers. This is because it is assumed due to the life-critical nature of these items that stock-outs are not permissible. In one of the main scenarios tested in this thesis, this penalty is set to approximate the expense of air-shipping items to customers. In the other case it is taken to be a factor of 1.5 times the cost of the item to begin with. It is assumed that none of the "normal" inventory can be used to fulfill demand during a sudden-death event. In this case, inventory must either be derived from an "alternative" inventory supply, set period-by-period, or be supplied through an emergency shipment.

After these sudden-death event costs are combined, these costs are multiplied by the conditional probability that a sudden-death event *has* occurred during the start of the period given that such a sudden-death event has not occurred during a previous period. This probability is the inverse of the cumulative possibility that such an event will have occurred at any point during the previous period.

The expected costs of both the event and non-event scenario for the period are then combined. Then, in order to determine the expected optimized cost for decisions for this and all future periods, this total is added to subsequent period totals, with the subsequent period totals first being multiplied by the cumulative probability that there had not yet been a sudden-death event following the immediate period in question. As this probability decreases with the approach of the final period, earlier periods will be weighted more heavily in terms of likely impact on expected total costs than later periods. A dynamic optimization program is then run to establish optimal or near-optimal levels for normal and alternative inventory levels period by period. This procedure helps establish key patterns in the system that illustrate when to ramp down certain types of inventory, when it is advisable to set up alternative inventory supplies, as well as the sensitivity for key factors in changing overall performance such as penalty cost and the characteristics of the SKU or SKU aggregate in question.

As stated above, "alternative inventory" can be understood either as inventory stored in alternative distribution channels such as foreign warehouses, or alternative operational strategies for sourcing product to market, such as postponement. The setting of associated expenses for each procedure will greatly affect the feasibility of the strategy. Breaking points based on this expense are established to determine what alternative costs justify the establishment of alternative inventory in specific periods. In expectation that this case may explore the advisability of establishing warehouses in China in preparation of the sudden-death event, an additional dynamic programming model was prepared with integral switches for incorporating various set-up costs for the warehouses and operational costs. However, these estimated expenses, at least as currently understood, were insignificant in terms of the overall volume of inventory in question for the operation, and hence did not greatly impact optimization decisions.

3.2 Model Formulation

The variable t can represent the period of time starting from time 0. In the specific case covered in this thesis, time 0 represents the day in which a license application was submitted. In the model period M represents the first period in which obsolescence can occur and T represents the number of total periods in the finite time horizon until sudden-death. Hence $T \leq M$ (Pierskalla, 1969). In this case, M was period 13, starting at day 360, and T was period 7 starting at day 180. X represents a random time to obsolescence measured from time 0. As a result, we can say that for all $t > 0$, $G(t)$ is equal to the probability that $X \leq t$, so that $G(t)$ is the cumulative probability that sudden-death obsolescence has occurred by time t. Correspondingly, $\overline{G}(t)=1-G(t)$, the cumulative probability that sudden-death has not occurred by this period. $\bar{G}(\tau|t)= \bar{G}(t+\tau)/\bar{G}(t)$ (David et al., 1997). In order to derive expected non-sudden-death costs in a period, the cumulative expenses are multiplied by $\bar{G}(\tau|t)$. This is for calculating the expected expense in a scenario in which sudden-death does not occur within a period, given a certain inventory decision. And because of the 30 day periods used in the specific thesis case, this translates into the probability that sudden death has not occurred at the end of the 30-day period given that it had not yet occurred during its start. To calculate the expected costs of a sudden death situation occurring during the period, associated costs for then event are multiplied by $G(t+\tau)/\bar{G}(t)$. The expenses of these two scenarios are then added to arrive at the expected cost for the period, given that sudden death has not occurred in previous periods. Costs for each period can be calculated by assuming an expected demand μ.[2] The larger problem is to optimize inventory decisions for all subsequent periods in the model. x can be referred to as the initial inventory before a stocking decision is made for a period. The model works by finding a value $y \geq x$ for all periods up until period T that minimizes total expenses. The expense function $L_1(y)$ is calculated based on an inventory decision for normal inventory (y_1) and for alternative inventory (y_2) such that for non-sudden death scenarios:

$$L_1 (y_1, y_2)=h[(\mu/2)+(y_1-\mu) +y_2]+p(\sigma^*g(k))-r(\mu-\sigma^*g(k))$$

in which g(k) is the unit loss function for expected units short based on a standard normal distribution as well as the level of inventory available (y_1 during a normal period, and y_2 in the case that sudden-death occurs during the period). Multiplying this function by σ, the standard deviation in demand yields the

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[2] In Pierskalla (1969), a specific demand was multiplied by its derivative in order to calculate expected expenses per period. However, for the purpose of creating the dynamic programming model used in this method, expected (μ) demand was deemed a suitable approximation of likely outcomes as the derivative model would not have been practical to calculate with the non-linear programming tool.

expected units that are short. c_1 and c_2 are the costs for normal and alternative inventory respectively and x_1 and x_2 are inventory levels remaining after a period for normal and alternative inventory respectively. p is the item short cost, and r represents the revenue generated by sale of the item, and h represents a standard holding cost. In a period in which sudden-death occurs, expenses are represented by:

$L_2(y_1, y_2)= h(y_2/2)+p(\sigma*g(k))-r(\mu-\sigma*g(k))-y_1*s_v$

s_v represents a salvage value. Holding costs are calculated by assuming that inventory is removed from a distribution center at a constant rate throughout the period. Item purchase costs are attributed each period separate of the conditional events of sudden-death or normalcy, as they must be covered each way, and are calculated as $c_1(y_1-x_1)+c_2(y_2-x_2)$. Excess alternative inventory in a sudden-death event is salvaged at the normal cost of inventory, reflecting its ability to re-enter the supply chain in future periods. Normal inventory is delivered immediately for use in the same period. Delivery times for alternative inventory are tested as either instantaneous (same period), next period, or through a mid-period assessment based on average orders from the present period and the previous period.

3.3 Model Assumptions

I have stated thus far that the model described in this paper is intended to facilitate an iterative approach for organizations attempting to manage sudden-death scenarios, and hence is not intended to produce ready-made solutions to problems, but rather attempts to enhance transparency and understanding of the system in question. However, if the limitations of the model used are not properly understood, then these intended aims, even if properly understood, will be compromised. As a result, assumptions about the problem at hand and the intended results that informed the construction of the model are described below.

Firstly, a major assumption underlying this approach was informed by my conversations with employees of the partner organization. Many of them described that internally there was a relatively abstract depiction of the supply chain system and upcoming sudden-death scenario, the result of a lack of overall system integration. Detailed knowledge about inventory policies, procedures for handling licensing approval scenarios, and the basis of SKU cost parameters were clearly not universally understood within the organization. And this suggested to me that clarifying these factors would be an essential task of this project. Core concerns raised by the partner were the need to avoid service interruptions while not overtaxing the operational system with excessive demands on manufacturing processes and inventory loads.

It was also assumed that the key to navigating the event transition described in this scenario hinged on the ability to accurately model aggregated as well as disaggregated inventory behavior as well as to represent existing inventory policies. As opposed to the end-to-end, product by product customer by customer method for analyzing supply chain systems promoted by scholars such as Jonathan Byrnes (2010), I assumed that this organization's supply chain, due to a series of institutional constraints, operated largely because of, rather than despite of, an aggregated "one-size-fits-all" approach to inventory and distribution. However, even within this aggregated system, there is a basis for qualitative insights to be derived by disaggregating the system into different product profiles. Segmentation of products hence became a major part of this study. Several SKU portfolios were explored through the creation of composite "model SKUs," and the behavior of these aggregates to various system parameters were compared. In this case, the thesis partner planned to initiate bulk license applications because of the approaching deadline for tax compliance. This suggested that a large percentage of the SKUs in question in the study would be subject for approval at the same time. Likewise, it was assumed that decisions about alternative distribution channels should be considered primarily through an aggregation of large groups of products. It does not make sense to establish a warehouse for one item. However, this should not limit the potential applicability of the model simply to assessing alternative warehousing strategy. As stated above, the alternative inventory level represents any alternative supply chain flow, and costs can be adjusted accordingly. It possibly could serve to represent a stock of postponed inventory prepared for expedited shipping to market. And if this were the case, individual product factors would be well justified to inform a specific rather than aggregated inventory decision. As a result, the performance of individual

SKUs was explored. However, there is limited information about the estimated costs or feasibility of such alternative options at present. This limited the accuracy of the simulations run for this thesis.

There is also the possibility that informational opacity within the organization was less pervasive than imagined. If there were the ability to more accurately determine the parameters in this case, including country license behavior and costs factors, then this would suggest that a research based study would be preferable to designing a model that fulfills the objective of facilitating a scientific appreciation of the system. And if this were the case, it would suggest that a study focus on improved research into existing conditions, such as warehousing expenses and repackaging strategies.

An additional assumption underlying the study was the difficulty of repackaging or salvaging goods that had become obsolete. While theoretically the products in question could be used in non-restricted markets, they must be repackaged and be cleared of legal restrictions. However, another area of research could be into the diverse maneuvers possible for re-export and re-import practices.

Of key importance to this case is the lack of information available as of yet about how the organization would fulfill internal demand after a license approval. Based on existing distribution strategies, in which distribution centers remain primarily located in Europe, it would be impossible to meet demand following a license approval, as product would have to be manufactured, then shipped to distribution centers, and then shipped to China. As a result, alternative distribution was assumed to be a necessary component of the solution, and cost parameters for this solution were estimated accordingly. If internal warehouse distribution or other alternative inventory options were not possibilities, the model could take this into account by setting the alternative stocking cost factor to a very high level. As a result, the model would simply focus on the behavior of conventional inventory level by ramping down as the likelihood of the sudden-death event increases.

Two additional potential limitations exist in the present model. The first concerns the specific construction of the probability model for the sudden-death event explored in this scenario. The second concerns the holistic logic of the model overall.

As mentioned, it was difficult to obtain the historical license application submission and approval dates from the organization's legal department. Instead, the organization reported a maximum and mode figure, both reported to be 365 days. After questioning if this truly could be the case, the liaison on the project suggested that 360 days be used as the mode for approval time instead, and that 365 days should be listed as the maximum. This proposal was used to construct the probability model for the study. However, the similarity of these figures suggests that the dynamics behind approval time need to be further investigated. For instance, currently the model derives an 18% probability that the eleventh period, starting at day 300, will arrive without a sudden-death event having already occurred. However, if the mean and the maximum approval time truly are both 365 days, then it is quite probable that most sudden-death events may occur only after the twelfth period, when 330 days have passed. The clarification of this question hence will have a substantial impact on the validity of the model results.

Lastly, despite the repeated emphasis thus far that this paper attempts to serve the "zero-sum" strategic terms of a heterogeneous organization undergoing a state change, this model in the end was constructed based on cost assumptions. In this case, a zero-sum scenario reflects the need to comply with tax requirements without interrupting an existing and hard to maneuver operational structure. The dynamic program application here though optimizes for a single best cost output derived from decisions made during 13 periods. This process contains an implicit logic of efficiency and quantitative improvement in contrast to the desired result of the exercise—qualitative analysis. After each run, an optimized total expense figure is derived. In reality, this figure is simply an abstraction. It is through analysis of the relative impact of the various parameters on this output that the model's value can be realized. In order to use the tool properly, iterative runs of the simulation are necessary in order to manually identify trends and break points. This suggests that going ahead, it may be necessary to incorporate additional "flags" that could alert the user to dynamics driving the optimized results. The analysis of the results derived from the model, as well as the inputs into the model, are the essential tasks. It is more difficult to "universalize" this procedure. It is, by necessity, tied to the specific case analyzed here. I hope that the process illustrated below can still provide some insight into the distillation of analogous problems.

3.4 Parameters for Running the Model

In subsequent runs of the model, salvage prices for inventory lost to sudden-death were set at 10% and 50% respectively.[3] In addition, penalties for items short, i.e. not able to meet demand, were calculated according to a high figure and a low figure. Because it is assumed that there is a need for constant supply of inventory to market, given the life-critical nature of many of the SKUs stocked, this rate is in effect the dollar amount needed to expedite a postponed product from the site of manufacture to the Chines market. For its high estimate, this cost was generally set at three times the cost of the initial stock unit, or the cost of a stock unit plus $200, reflecting an international express shipment to China. For its low value, the amount was calculated at 1.5 times the value of the SKU, however in extreme cases this parameter was altered. Often a penalty of only 1.5 times the SKU value resulted in an outcome in which item shortage no longer was a major factor, offset by the combined impact of high salvage prices and high alternative inventory stocking costs.

In order to simplify the number of simulations run, each SKU run was divided into a "challenging scenario" with high penalties for items short and low salvage costs, and an "optimistic scenario" with lower penalties for items short and high salvage costs. The model however tends to assign a higher weight

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[3] These figures themselves need to be subject of greater inquiry by the company. They were derived however to reflect the difficulty in reintegrating products already approved for export to one country into a supply chain for another, a process which requires the input of regulatory and legal affairs. Based on the current operations of the company, a situation that requires as little unorthodox maneuvering as possible appears most likely to receive the support of management. To reflect the operational burden associated with reintegration, a low salvage value of 10% is set. To reflect the potential gains to the system should there be a focus on innovative repackaging solutions, a value of 50% is projected as well.

to the penalty parameter than salvage costs. As a result, the disparate outcome of simulations for the same SKU tended to primarily reflect the associated penalty parameter. In addition to these parameters, all inputs were constrained by a total production demand per period limit set at 1.5 standard deviations above the mean. Inventory levels were also prevented from exceeding twice this level. In future runs, it will likely be useful to adjust this constraint according to specific productive capabilities.

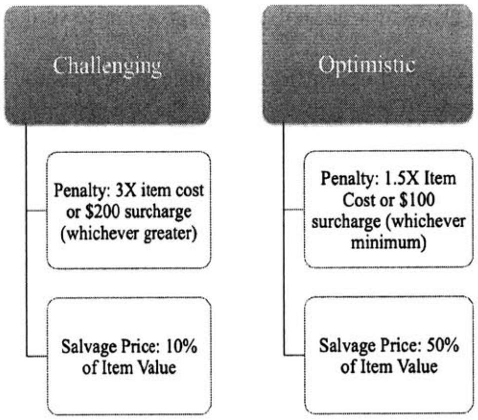

Figure 3-3 Parameters for the two inventory scenarios tested, grouped into a "challenging" and "optimistic" scenario

Figure 3-2 shows a chart of the parameters run for SKU aggregates as well as for individual SKUs. Mean, standard deviations and item costs were all determined by aggregating data sent by the organization. Penalties and salvage prices were set separately. Revenue was set at 1.5 times the cost reported by the company in order to compute expected profits from satisfied demand. The categories first are ascribed "challenging scenario" values. And then when they repeat in the chart below they are ascribed "optimistic scenario" parameters.

In the event of a sudden-death event, all alternative inventory will need to have already been placed in the distribution center for use. This assumes that it will take several weeks to produce new product with new labels, and another several weeks to ship such products from the distribution centers in Europe to the Chinese market. Based on the time critical window to replace such inventory, inventory costs for replacement were set at 150% of normal costs. As stated, a secondary model was constructed to assess whether fixed cost investments in alternative inventory methods are justified. For this model, a switch was set for the establishment of additional warehouse capacity in the Chinese market, estimated to require $20,000 of startup costs, as well as $20,000 monthly operational costs, based on standard estimates for warehouse space rents and labor costs in China.[4]

The key to navigating the event transition described in this scenario hinges on the ability to accurately model aggregated as well as disaggregated inventory behavior as well as existing inventory policies. Correspondingly, demand data from the China market was aggregated into "model SKUs" according to characteristics which seemed likely to induce different inventory behavior. These model SKUs comprise the categories in the chart above, including SKUs representing the top and bottom 50% of products by volume, a model SKU representing all 600 SKUs within scope, as well as the 50% most expensive SKUs and the 50% least expensive SKUs on a per item basis. In order to form these aggregate "model SKUs," total monthly demand for SKUs in each category were derived. From this data, standard deviations were derived from the variance within each category from month to month. Cost parameters were calculated as an average of the cost for SKUs in a category. Through this method, rough "model SKUs" were created, composed of a theoretical homogenous bundle of SKUs with a standard deviation, cost, and quantity representative of the group overall.

In addition to SKU cost parameters, simulation runs tested the impact of changes in the variance of license approval behavior, as well as various lead-times for stocking alternative inventory in the system,

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[4] A preliminary continuous order policy model was established as well, using a dynamic programming operation starting with the first period in which obsolescence may occur, and optimizing the estimated time period covered by order per period, balancing between ordering costs, holding costs, and costs from lost inventory in the event of a stock-out. This model operated more as a supplemental part of this study, as the thesis company's focus primarily is on a periodic order policy for hundreds of products items.

as stated in the model formulation section 3-2. Together this resulted in two parameters for SKU conditions as described in figure 3-3, three alternative inventory lead time scenarios, and two k-factors to test the impact of variance in approval behavior. Altogether this results in 12 scenarios with which to test every SKU (figure 3-4).

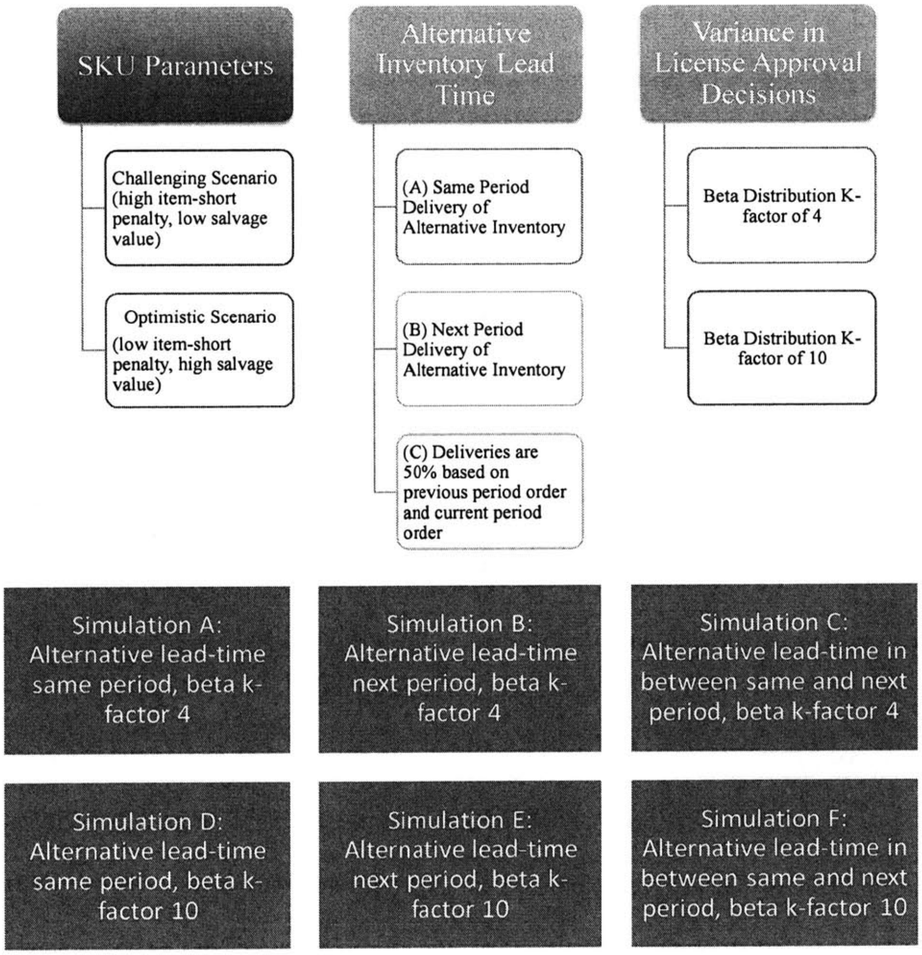


Figure 3-4 Simulation test parameters (12 iterations per SKUs as SKUs are already divided between the challenging and optimistic scenarios)

Running the model for these SKUs suggests potential decisions strategies. As the likelihood of obsolescence increases, in this case affected by license approvals, it becomes increasingly "costly" to hold on to "old" inventory given the risk. As a result, alternative actions to existing inventory policies are assessed vis-à-vis the output of the dynamic programming optimization. These include the speed for ramping down the model, as well as dates for pushing inventory into alternative distribution channels. Costs hence reflect the estimated profits and expenses derived from inventory in the system before the sudden-death event, as well as expenses occurred form the obsolescence. Costs are not calculated for decisions made after a sudden-death event because the system at this point will return to a normal optimized state, regardless of previous inventory decisions.

3.5 Method of Analysis

After the model is run for all SKUs, they are analyzed in terms of the results for aggregate SKUs and individual SKUs, and then analyzed for sensitivity to key parameters. Certain representative simulation results are analyzed to demonstrate more specific behavior, such as the impact of constraints such as item short penalties and variance in licensing decisions. Together, this information can provide the organization with a portrait of potential inventory responses to the upcoming sudden-death event. The outputs are also intended to convey the key factors driving such responses.

3.6 Accuracy of the Model

If this model implies to users that after running a simulation that the solution is at hand, then it has not done its job. Several company representatives expressed the importance of not working within silos in order to better address the coming operational state change. The model elaborated in this thesis needs to be seen primarily as a tool to illustrate the importance of assessing decision levers in the system. Parameters such as "salvage costs," for instance can easily be adjusted, and in doing so produce vastly different suggested outcomes. But the feasibility of relabeling products, including the extra time necessary to attain the buy-in of regulatory affairs hence becomes a key pressure point in assessing the validity of such alternatives. Until this process is squarely evaluated, the actual "cost" of salvaging an obsolete item is for all effective purposes a cost-prohibitive endeavor. The need to create new channels for communication and cooperation between regulatory affairs and quality control, and supply chain and operations, is imperative to the present challenge. Collaborative input on the parameters needed for the model can theoretically serve this ends.

4 Results

Key insights from the simulation runs are described below for aggregate runs, individual runs, and overall behavior. In addition, the complete period-by-period inventory policies for all runs are displayed in Appendix Table 3.

4.1 Aggregate SKU Results

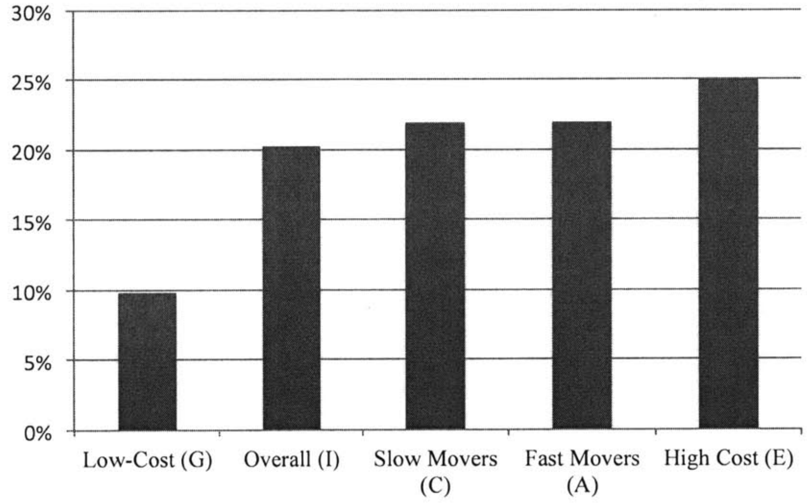


Figure 4-1 Increase in profit for inventory policies after aggregate SKUs were run through programming optimization

Aggregate SKUs demonstrated substantial increases in profitability after they were run through the dynamic programming model compared to estimated profits with a business-as-usual response (see figure

4-1 and table 4-1). Overall, low cost SKUs showed the lowest overall improvement because of the trade-off of investing in alternative inventory with a smaller return on overall investment. Even though the average cost of these items was relatively low ($46), the item short penalty derived for the "challenging" scenario depicted in figure 4-1 and table 4-1 was significant ($246), a situation which is likely to occur in the medical-device industry in which stockouts for even low-cost items would represent a significant threat to the operation of medical facilities. As a result, there is a need to push this inventory earlier, resulting in less overall cost savings. In the optimistic scenario, in which the item-shortage penalty is only $46, it no longer is necessary to push inventory to this early date (figure 4-2). Aggregate improvements unsurprisingly showed less variability than the results of individual SKUs.

Table 4-1 Estimated profits before and after dynamic programming runs for aggregate SKUs

	Non-Optimized	Optimized	Increase
Low-Cost (G)	$ 5,627,649	$ 6,179,177	10%
Overall (I)	$ 17,730,118	$ 21,317,708	20%
Slow Movers (C)	$ 607,335	$ 740,359	22%
Fast Movers (A)	$ 12,632,425	$ 15,402,775	22%
High Cost (E)	$ 17,730,118	$ 21,317,708	25%

In Figure 4-2, the aggregate SKUs are shown to result in a substantial breakdown between launching alternative inventory in periods seven or twelve. A far higher percentage of SKUs in the optimistic scenario resulted in a later push, due to the more favorable item-shortage costs in these situations. In optimistic scenarios, there also was a far higher number of cases in which no alternative inventory ramp-up occurred at all.

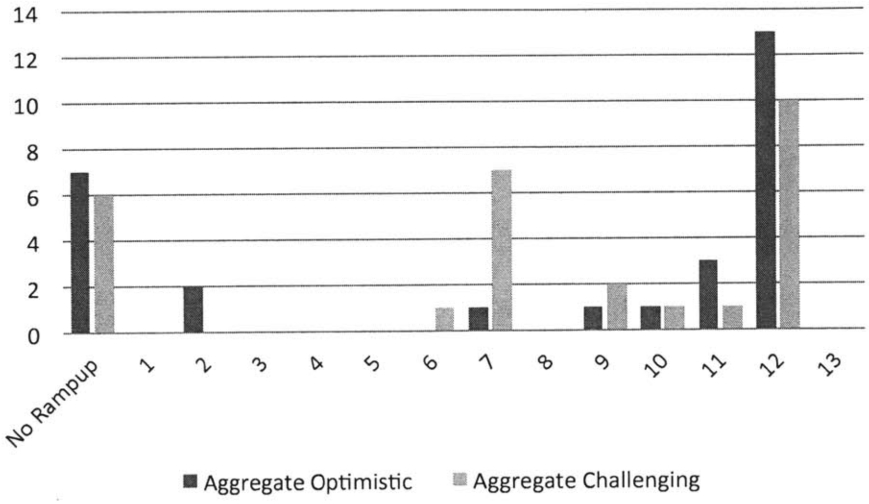


Figure 4-2 Period inventory ramp-up for aggregate SKUs (number of runs)

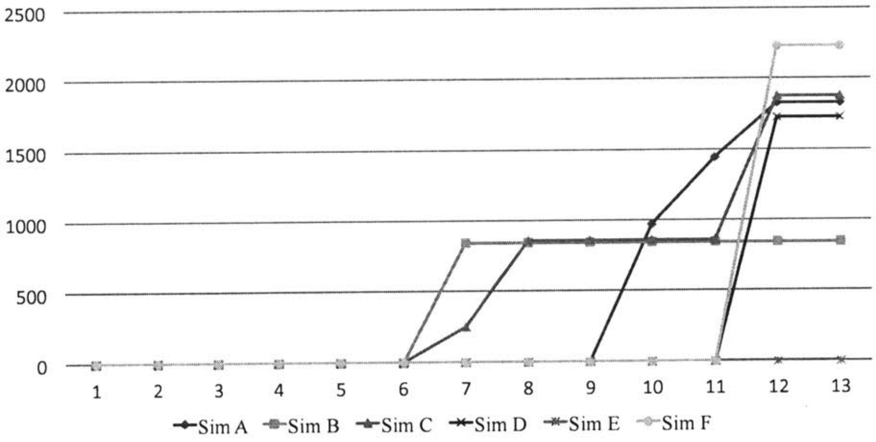


Figure 4-3 Slow-Mover Aggregate SKU (C) inventory policy results (see table 3-4 for simulation breakdowns)

In the case of slow moving SKUs (figure 4-3), there was overall an earlier ramp-up when lead-time for alternative inventory took one period, with levels remaining relatively low. When lead-time took between the present period and the period in question, ramp-up could be pushed back a bit to a later period, but then rose to a far higher level.

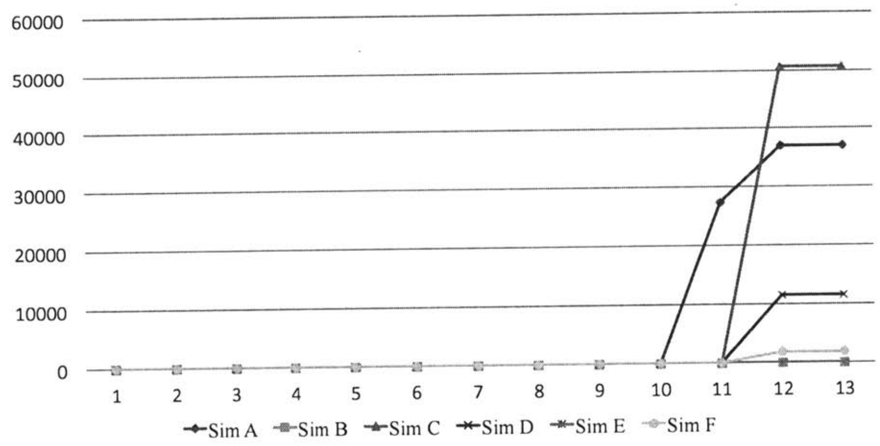


Figure 4-4 Low-Cost Aggregate SKU (G) inventory policy results

For low-cost SKY's (figure 4-4), no alternative inventory was justifed in situations with medium to long range lead times. However, significant inventory buildup was still justified in these scenarios if the sudden-death event had not yet ocurred by period 12. A less degree of build-up ocurred in cases in which variance in the event-probability distribution exists.

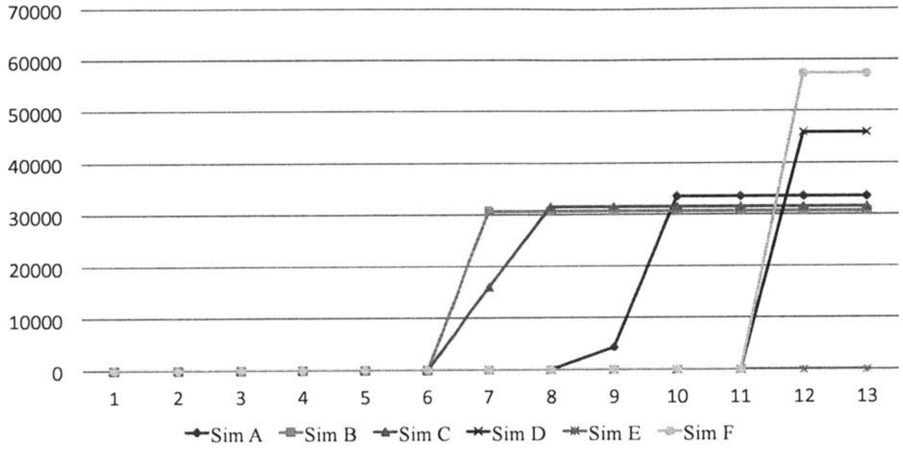


Figure 4-5 Overall Aggregate SKU (I) inventory policy results

The overall aggregate simulations were intended to provide a glimpse of performance in the system overall, and to represent a hypothetical system wide bulk-transition (figure 4-5). These simulation outputs were highly dependent on the specific parameters being assessed. With alternative inventory sourced only in the following period (simulation B), inventory pushes were still justified in period seven, and then stayed at a constant level. However, in the same situation, with a higher variance in event-probability (scenario E), no inventory push was justified at all.

4.2 Individual SKU Results

Table 4-2 Selected estimated profits before and after dynamic programming runs for aggregate SKU

	Non-Optimized	Optimized	Increase
SKU (S) Fast Mover, Mid-Value	-$4,496	$ 2,090	N/A
SKU (Q) Fast Mover, Mid-Value	$ 167,060	$ 219,462	31%
SKU (K) Fast Mover, Low-Value	$ 1,843	$ 131,163	7018%
SKU (Y) Slow Mover, High-Value	$ 467	$ 1,132	142%

Overall individual SKUs showed a far higher variability in profit improvement when using the optimization model, compared to a business-as-normal policy. Factors contributing to the immense variability in results included capacity constraints, which often applied in the case of fast-movers with high standard deviations, limiting the ability of alternative inventory to reach optimum levels. The improvement in performance for the individual SKUs overall was far higher than for the model aggregate SKUs (tables 4-1, 4-2) also reflecting the ability of the model to properly accommodate the criteria of specific item dynamics, and the limiting effect of grouping these items together.

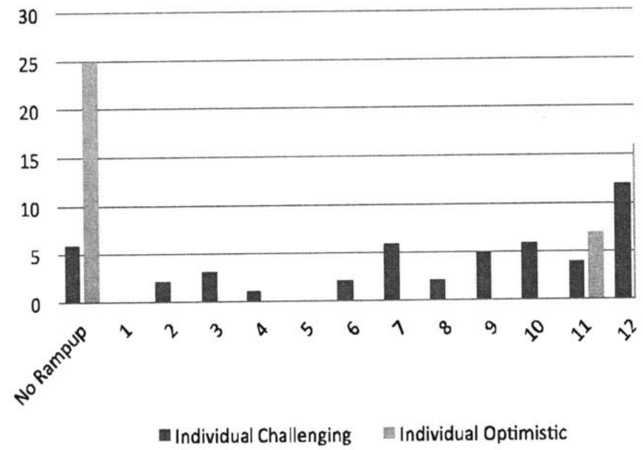


Figure 4-6 Period ramp-up for individual SKUs (number of runs)

There were a large number of SKUs which showed no ramp-up when an optimistic scenario was tested. This was particularly the case when a high k-factor for the beta distribution was tested. Ramp-up for the challenging scenario was relatively evenly distributed, though it had the greatest likelihood of occurring, if at all, in periods 12, 7, and 10. Optimistic runs were almost exclusively grouped in the latter periods of 11 and 12 (figure 4-6).

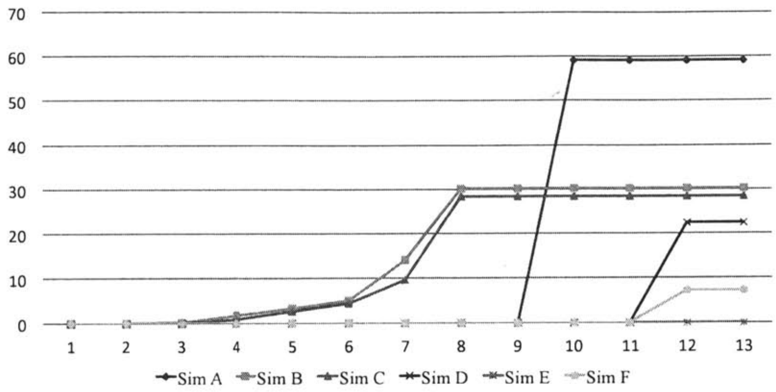


Figure 4-7 Mid-Mover Mid-Value SKU (S) inventory policy results

Figure 4-7 shows an example of the diverse range of outcomes present within the individual SKU runs. For this model, when a low variance scenario with same period delivery is tested (simulation A) a high ramp-up occurs in period 9. However, for all other scenarios, ramp up is far lower. When variance in event probability is high, ramp-up only occurs in late periods, if at all.

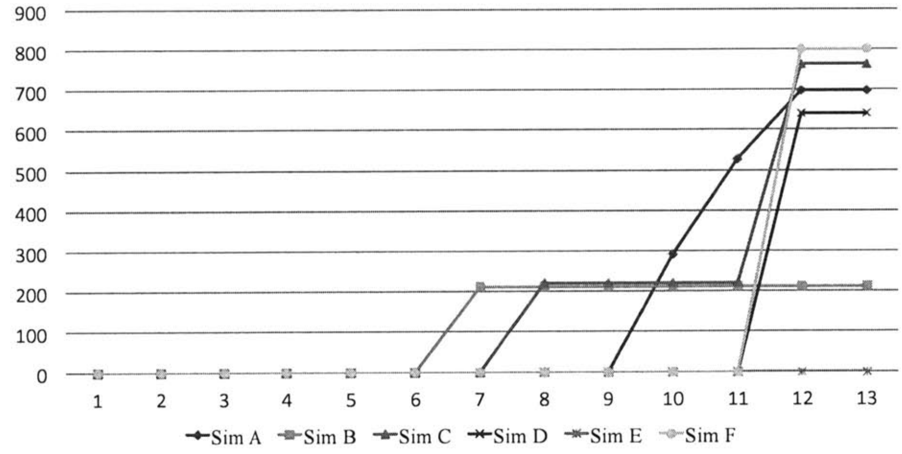


Figure 4-8 Fast-Mover High-Value SKU (Q) inventory policy results

When high value SKUs were tested (figure 4-8), overall inventory levels were far higher, and showed at least a two or three-step ramp-up, reflecting the need to balance high penalty costs for item-shorts with the expense of losing valuable inventory.

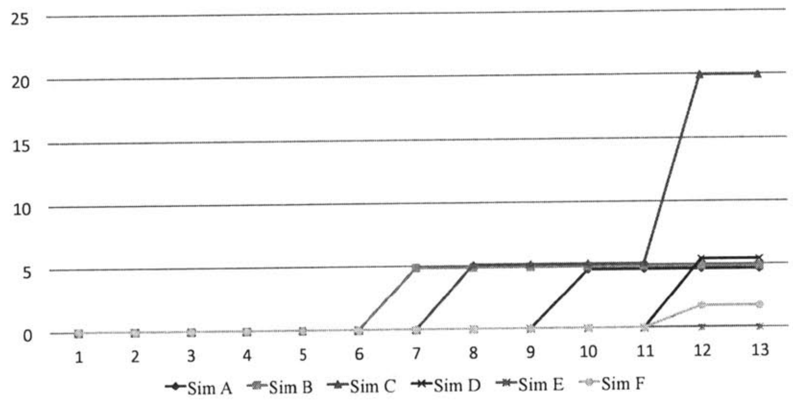


Figure 4-9 Figure Slow-Mover High-Value SKU (Y) inventory policy results

In a similar scenario with a low-demand item (figure 4-9), risk in the system suggested that alternative inventory pushes be kept extremely low.

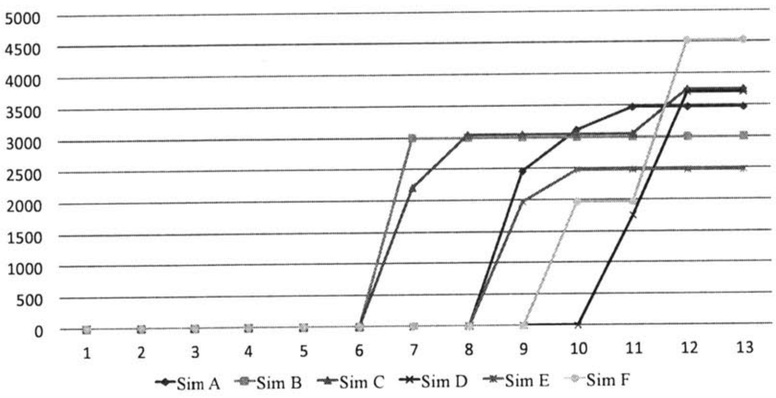


Figure 4-10 Fast-Mover Low-Value SKU (K) inventory policy results

In figure 4-10, a high-demand, low-value SKU forces the system to push-alternative inventory regardless of the simulation parameters. The high variety in the first period of inventory push is based on the need to properly balance the risk of switching the system given different possible event scenarios and the high volume of product in the system.

For many of the individual SKUs, extra cost for alternative inventory came close to exceeding the expense for item-shortages, hence resulting in full ramp-up at an earlier period. In addition, in the optimistic scenarios in which item-short penalties were relatively low and salvage costs high, inventory levels in period 10 were reduced to significantly low levels, reflecting almost equally likely probability that the sudden-death even would or would not occur. Overall, the more nuanced behavior of the individual SKUs suggests that if a bulk push strategy is attempted, the specific needs of certain customer types and product lines may not be adequately represented.

4.3 Summary

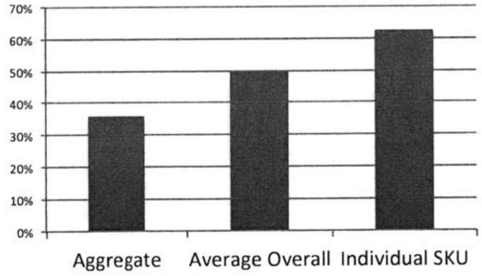


Figure 4-11 Percentage in profit increase when using k-factor 10 beta distribution

As figure 4-11 shows, profits were especially high when the model was applied to individual SKUs. However, aggregate results did not trail far behind.

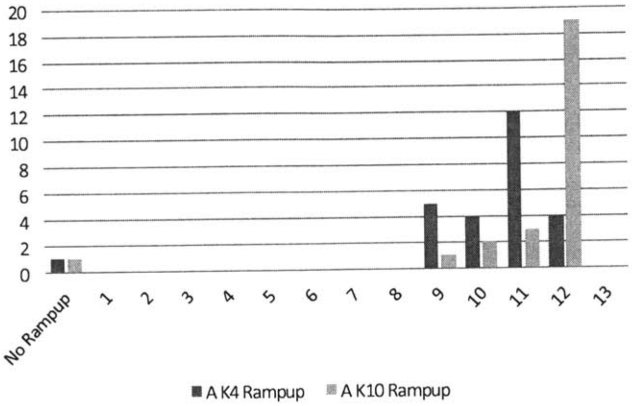


Figure 4-12 Overall alternative inventory push for K-factor of 4 and 10 with lead-time A conditions (same-period delivery) by number of runs

K-factors reflecting variance in event probability had one of the largest impacts on overall performance improvement (figure 4-12). In general, greater expectations about specific approval dates translate into a higher variance in distribution, and in this case justify a later and higher ramp-up of inventory.

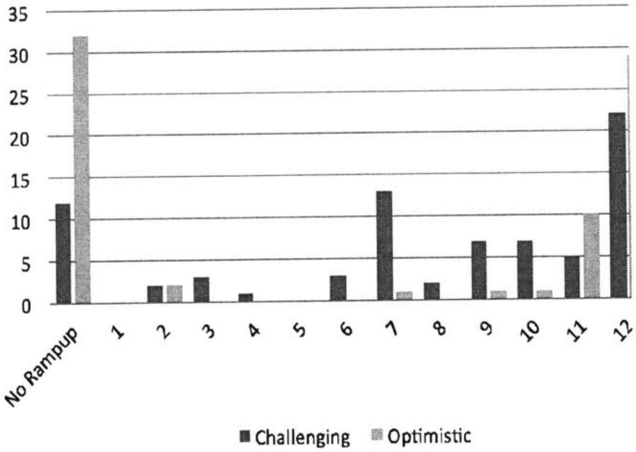


Figure 4-13 Challenging Scenario versus optimistic scenario alternative inventory pushes by number of runs

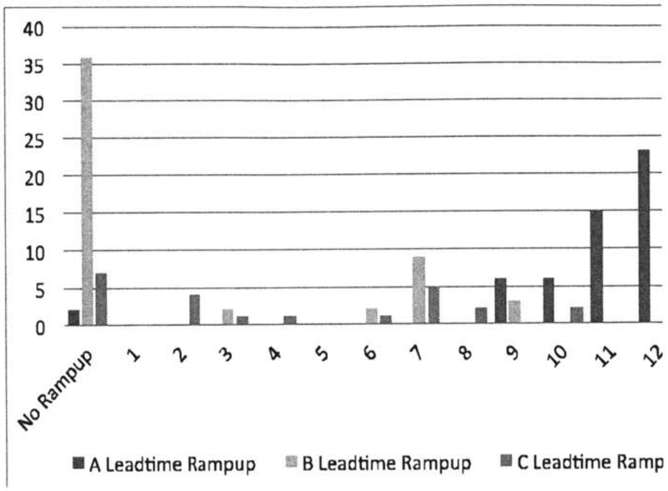


Figure 4-14 Impact of alternative lead-time policies on alternative inventory push by number of runs

In cases in which challenging scenarios were tested, ramp-up tended to occur earlier in the system, in order to mitigate risk from high penalties. However, optimistic scenarios provide a greater strategic incentive to ramp-up inventory at a later time (figure 4-13). Overall, slower lead-times often cancelled out the benefit of pushing alternative inventory altogether because of the inability to respond quickly in time to the increased likelihood of sudden-death (figure 4-14).

5 Discussion

The results listed above show the sensitivity of the model to item-short penalties as well as SKU profiles, event probability certainty, as well as lead-time conditions. At a minimum, the results illustrate the need to rapidly ramp-down normal inventory as the sudden-death event approaches. Changing estimates for license approval behavior produced the greatest impact on overall outcomes. Rather than accepting these results, the emphasis is on conveying the methodology for assessing a set of assumptions, and the relative impact on the model.

Overall, alternative inventory build-up was highly impacted by alternative inventory costs, whereas normal inventory ramp-down was relatively unaffected (see appendix). Results showed a high correlation between both alternative inventory costs and item shortage costs and optimal alternative inventory ramp-up strategies. For low volume SKUs, alternative inventory levels were far below normal inventory levels, and often remained at a static level, rather than ramping up, during the final three or four periods.

In general, for high value SKUs in the challenging scenario, ramp-down of normal inventory was more gradual. For optimistic scenarios, the same SKUs resulted in a more rapid ramp-down, with clearance often reported in period 11. This behavior was replicated among the aggregate SKUs as well.

Slow-moving SKUs often resulted in alternative inventory being pushed in only the final three periods. However, for the fast-movers, alternative inventory often was pushed as early as period nine, the fifth-to-last-period. The few aggregate examples in which inventory buildup occurred this early showed this result because of the need to rapidly build up in successive periods without exceeding production capacity constraints. However, in the case of simulations for individual high-volume SKUs, this period nine ramp-up was not a moderate reaction to provide extra capacity for later periods. Instead, it represented significant buildups of inventory. The discrepancy between the earlier ramp-up recommended for these individual SKUs, and the later ramp-up for the aggregate portfolio suggests that high-volume SKUs may need to be analyzed at a higher degree of granularity to determine proper inventory strategies.

In several additional runs, initial slow ramp-up behavior was the result of the need to ramp-up inventory over the course of several periods without exceeding the production constraint.

Sometimes unusual results were produced, including an early sudden uptick in normal inventory after a ramp-down, or the delay of alternative inventory sourcing until the final or next-to-final period despite a high level of inventory set. By examining the outputs of specific cost functions—for instance profits in a sudden-death scenario, the source of the change could be identified, whether it be a lack of precision in the dynamic programming algorithm, a fault in the model, or a genuine insight into underlying behavior. An earlier uptick after ramp-down for instance was shown to be a fault in the probability model—that was then fixed by resetting the conditional probability formula in line with the approach of Greenshtein and Mehrez (1997). In the case of the delayed alternative inventory push, the output was correct and significant. In this case, it was a response to the additional weighting of earlier periods because of the lower probability that they would undergo a sudden-death event

6 Conclusion

The inventory model created in this case is still a work in progress. However, the project has already yielded several insights. Firstly, the design of the model hinged on properly understanding a logic of conditional probabilities. Intuitive reactions to sudden-death scenarios sometimes consist of a binary response of "should an organization focus either on pushing additional inventory or on ramping-down?" However, when the event of sudden-death is mapped out over time, the decision can be seen in a framework in which "when" takes primacy over "what." The relative merit of a strategy based on prioritizing ramp-down or ramp-up is dwarfed by one which focuses on the sequential adjustment of strategy in line with an imminent state change. The analogy presented earlier of an elephant walking a tightrope conveys the paradox forced upon a "bulk-organization" by the need to suddenly act with precision. The large volume of product affected by the change event studied in this case requires that the organization learn to turn-on-a-dime. Ill-coordinated adjustments can result in overcapacity and collapse.

The analysis of the data from simulations was conducted in light of the need to present an iterative method to progressively drive organizational change. A proper analogy here would be that of setting up base camps in the course of summiting a mountain (Byrnes, 2010, 219). The emphasis here is to promote an inquiry into the factors that dramatically affect the system. Item-short costs and alternative inventory costs have a dramatic impact on optimized policies. Without inter-team cooperation towards deriving at realistic understandings of these parameters, it will be hard to produce a sensible solution to the upcoming sudden death event. The same situation applies in terms of capacity constraints. There is general awareness of the need to not interrupt existing production schedules when preparing for this event scenario. However, institutional constraints prevent greater visibility into the overall system in order to quantify capacity constraints. As Yossi Sheffi writes, responsiveness to disruption or crisis can be used to increase agility in an organization. In his work on long-term risk resilience, he argues that companies should use possibilities rather than precise probabilities to assess potential strategies (2015, 314, 362). However, the event scenario described in this case presents a unique case in which probabilities can be used to drive possibilities, and to make a concrete case for opening up visibility into new sectors of the supply chain. Approximate dollar figures can even be shown with this thesis' model to demonstrate the potential liability of not doing so.

A future step would likely consist of further dividing the parameters of the "zero-sum" logic underlying the problem at the SKU level. This would include information about specific service level necessities, capacity constraints on production, as well as profit targets. The benefit of this model is that it is flexible enough to be used successively with input from different members of an organization in order to identify bottlenecks and opportunities in the course of a state-change. Planning for event scenarios will likely continue to be increasingly important for organizational operations. However, the ability to grasp the conditional nature of these problems does not come about intuitively. This thesis has identified iterative processes as essential for analyzing various responses to such an event-scenario. To those ends, the dynamic programming method created to address this problem is a tool for identifying blind-spots in an operational system in order to re-conceptualize the problem. In the run-up to the simulations presented above, several additional iterations of the model were initially implemented. The results derived from these runs revealed that the models contained assumptions that needed to be re-examined. These were eventually discarded to better replicate real-world scenarios. Afterwards, the newly improved version of the model had to be run afresh. And this process is intended to continue.

In essence, the workflow presented is a dynamic optimization program within a dynamic optimization program. This process of chipping away at the proper model was time consuming. However, the framework emphasized process rather than final result. In a scenario with several moving parts, such as the one studied here, this must be the approach. Decisions can be made at any step along the way. However, as time changes, so do both objective conditions—such as the increasing likelihoods of chance events, as well as the ability to understand systematic responses and constraints. The correct approach hence requires a constant breaking-away from established assumptions, and a reengagement with critical thinking about both the internal system and the external problem.

The solution proposed in this thesis was designed to meet the needs of the thesis partner. However, the solution is applicable to all organizations that face a similar scenario, which loosely can be understood as a low-level of internal systems integration "by design" as well as the need to accomplish a system-wide state change due to an event which will require a comparably "scientific" integration of operations across the board. In order for the system to prepare for the sudden-death event properly, a snapshot must be created of the overall system, derived through an iterative process consisting of informational inputs and experimentation by team members, depicted loosely in the figure below. This method promotes expanded visibility into both the internal nature of the supply chain as well as into the risk and problems posed by the external change event (figure 6-1).

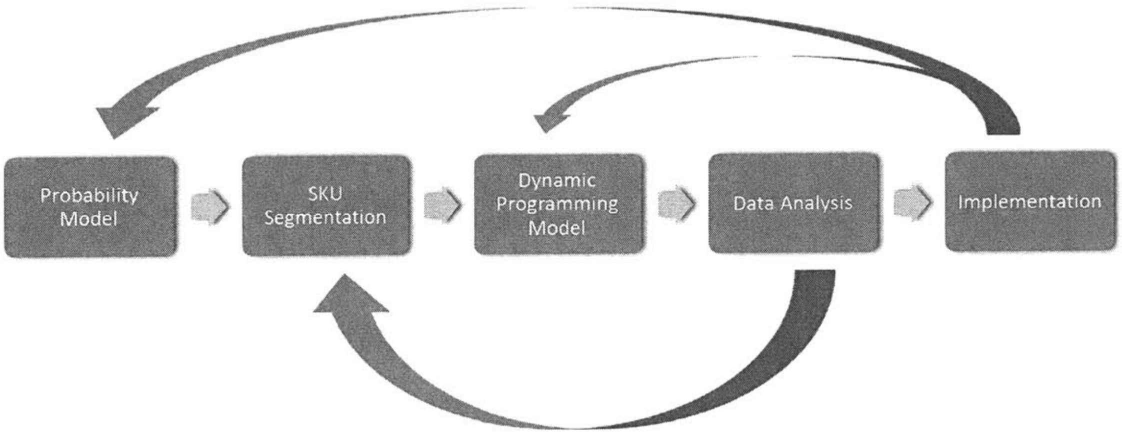


Figure 6-1 Model Process and Larger Iterative Framework

This approach is highly relevant to organizations facing a scenario with a zero-sum outcome. In this case, the organization aspires to integrate its operations enough for a limited period in order to comply with tax regulations without crashing its productive system or its supply of life-critical components. And unsurprisingly, much of the limited body of literature on "sudden-death" supply chain problems is derived from the military. One of the initial cases for example pertained to assessing when to ramp down production of parts for naval aircraft (Brown, 1964). Another influential study examined how order periods could be reduced for the production of maps for Israeli aircraft that were both expensive to produce and prone to "sudden-death" obsolescence because of changes in ground conditions (David, 1997). In military situations, broadly, decisions must be made based on both a complex internal organization with a series of resource capacities as well as on limited information about the opponent. In the end, decisions are calculated with a win or loss outcome in mind. In this study, the domestic front is represented by the internal operations of the organization, including the many byzantine paths through which individual components of the corporation coordinate supply fulfillment. The foreign front is representing by the licensing decisions made by Chinese authorities. Just as in a wartime situation, the best made plans often can come up short due to inadequate knowledge about organizational capabilities or about the external situation. Thus, the toolkit provided in this thesis will only be as useful as the quality of informational inputs derived for the model.

Nevertheless, the benefit of this approach is that it highlights information gaps for the overall organization. Various assumptions regarding licensing times can easily be entered into the application, showing the changes required in order to meet basic operating standards. In this case, the model's recommended policies based on different inputs such as estimated license approval times can be shared with regulatory affairs and other teams to emphasize the importance of data sharing. This way, various groups can see that their information directly affects the formulation of strategic operational responses. It was hard to convince regulatory affairs of the necessity to share information about past license application dates. The same would apply to other potential bottlenecks in similar projects, whether they consist of estimating sales value, inventory holding costs or lead-time requirements. For organizations examining potential adjustments in inventory because of an ongoing merger or divestiture, shortage costs may be adjusted radically to reflect the relative strategic importance of a particular line of products. If the company is getting out of a market, stocking-out of products for a specific line may not be as grave a threat.

Unsurprisingly, the problem addressed in this thesis was described by the thesis partner as a "supply chain problem" that was "really not about a supply chain." It was also described as a problem that would be increasingly essential to tackle in the future. Both observations point to the need to integrate thinking across organizations in the present context. This is the aim the approach described in the thesis above and accompanying model intends to achieve.

References

Barankin, E.W., Denny, J. (1960). Examination of an Inventory Model Incorporating Probabilities of Obsolescence. Technical Report Statistical Laboratory, University of California, Berkeley, CA, 1-21.

Brown, G. B., Yu, J. Y., Wolfson, R. J. (1964). Dynamic Modeling of Inventories Subject to Obsolescence. *Management Science* 11(1) 51-63.

David, I., Greenshtein, E., Mehrez, A. (1997). A Dynamic-Programming Approach to Continuous-Review Obsolescent Inventory Problems. *Naval Research Logistics* 44 757-774.

Byrnes, J. (2003) Dell manages profitability, not inventory. *Harvard Business School, Working Knowledge Series.*

Byrnes, J, (2004) Fixing the healthcare supply chain. *Harvard Business School, Working Knowledge Series.*

Byrnes, J. (2005) You only have one supply chain? *Harvard Business School, Working Knowledge Series.*

Byrnes, J. (2010) *Islands of Profit in a Sea of Red-Ink.* New York, NY: Penguin Group.

Cobbaert, C., Oudheusden, D. V. (1996) Inventory Models for fast moving spare parts subject to "sudden-death" obsolescence. *International Journal of Production Economics* 44 239-248.

Deutsch, P. (2015) *Chasing Capital.* New York, NY: Oxford Press.

Nozick, R. (1974). *Anarchy, State, and Utopia.* New York, NY: Basic Books.

Perez-Franco, R. (2016) *Rethinking Your Supply Chain Strategy: A Brief Guide.* Cambridge: MIT Supply Chain Strategy Lab.

Pierskalla, W.P. (1969). An inventory problem with obsolescence. *Naval Research Logistics Quarterly* 16(2) 217-228.

Sen, A. (1981) *Poverty and Famines: An Essay on Entitlement and Deprivation.* Oxford: Oxford University Press.

Sheffi, Yossi (2015) *The Power of Resilience.* Cambridge: MIT Press.

Song, Y., Lau H. C. (2004). A periodic review inventory model with application to the continuous-review obsolescence problem. *European Journal of Operational Research* 159, 110-120.

Song, J. S., Zipkin, P. H. (1996). Managing inventory with the prospect of obsolescence. *Operations Research* 44(1) 215-222.

Taylor, T. (2001) Channel Coordination Under Price Protection, Midlife Returns, and End-of-*Life Returns* in Dynamic Markets," *Management Science* 47 (9).

Teunter, R. H., Syntetos, A. A., Babai, Z. M. (2011). Intermittent demand: Linking forecasting to inventory obsolescence. *European Journal of Operational Research* 214 606-615.

Zacks (2015). "Medtronic: Covidien Integration, Long-term Growth Hold Key. From: http://www.zacks.com/stock/news/177222/medtronic-covidien-integration-longterm-growth-hold-key

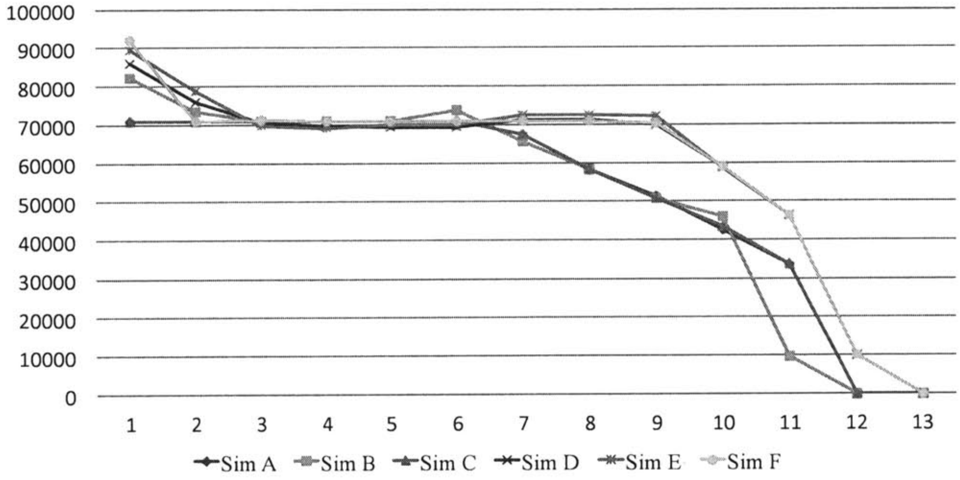
Appendix

Appendix Table 1: Aggregate SKU parameters tested in the model

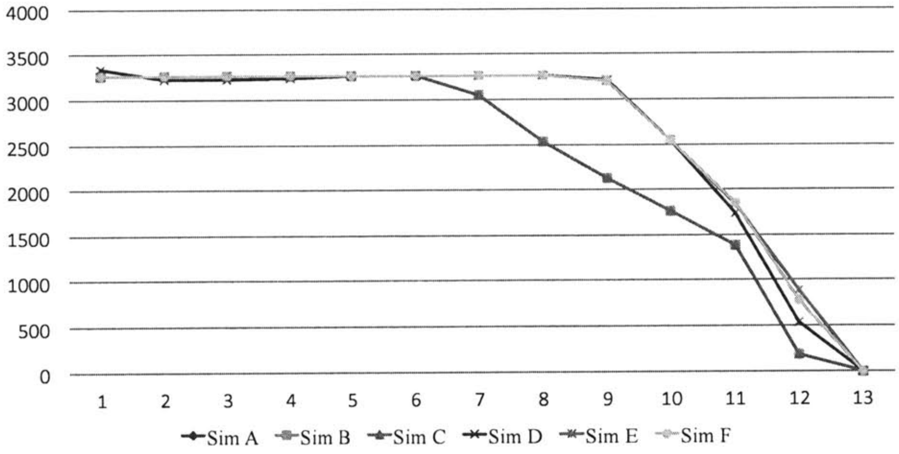
ID	Category	mean	sd	cost	Penalty for Item Stockout	Salvage Price	Price Factor	Scenario
A	Fast Mover	36221	12993	122	364.90	0.1	1.5	Challenging
B	Fast Mover	36221	12993	122	182.45	0.5	1.5	Optimistic
C	Slow Mover	1200	772	199	597.66	0.5	1.5	Challenging
D	Slow Mover	1200	772	199	298.83	0.1	1.5	Optimistic
E	High Cost	4450	1891	272	815.32	0.1	1.5	Challenging
F	High Cost	4450	1891	272	371.77	0.5	1.5	Optimistic
G	Low Cost	32970	11848	46	245.82	0.1	1.5	Challenging
H	Low Cost	32970	11848	46	68.72	0.5	1.5	Optimistic
I	Overall	37485	13280	164	492.55	0.1	1.5	Challenging
J	Overall	37485	13280	164	246.27	0.5	1.5	Optimistic

Appendix Table 2: Individual SKU parameters tested in the model

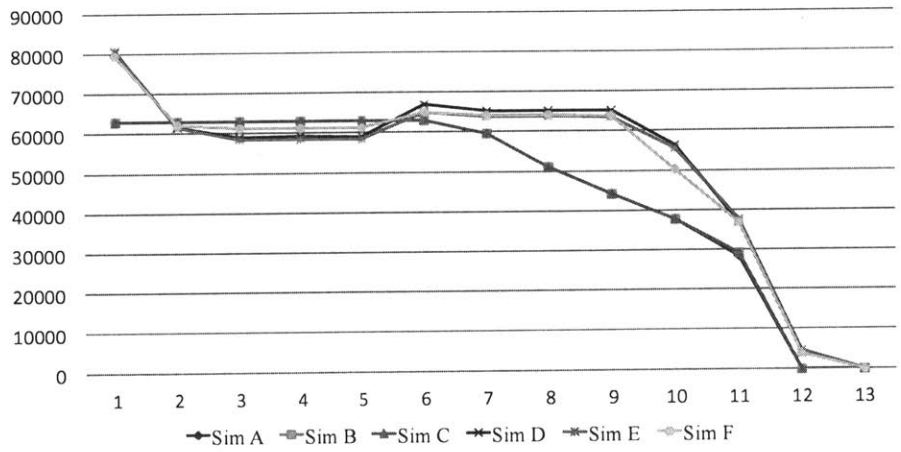
ID	SKU	mean	sd	cost	Penalty for Item Stockout	Salvage Price	Price Factor	Scenario	Category by volume	Category by value
K	179710645	2243	1096	23.82	223.82	0.1	1.5	Challenging	Fast Mover	Low Value
L	179710645	2243	1096	23.82	35.73	0.5	1.5	Optimistic	Fast Mover	Low Value
M	179712640	347	211	23.16	223.16	0.1	1.5	Challenging	Fast Mover	Low Value
N	179712640	347	211	23.16	34.75	0.5	1.5	Optimistic	Fast Mover	Low Value
O	179712540	66	51	25.00	225.00	0.1	1.5	Challenging	Fast Mover	Low Value
P	179712540	66	51	25.00	37.50	0.5	1.5	Optimistic	Fast Mover	Low Value
Q	175565000	492	305	142.82	342.82	0.1	1.5	Challenging	Fast Mover	High Value
R	175565000	492	305	142.82	214.23	0.5	1.5	Optimistic	Fast Mover	High Value
S	187827108	52	77	73.02	273.02	0.1	1.5	Challenging	Mid Mover	Mid Value
T	187827108	52	77	73.02	109.53	0.5	1.5	Optimistic	Mid Mover	Mid Value
U	176804010	51	88	65.21	265.21	0.1	1.5	Challenging	Mid Mover	Mid Value
V	176804010	51	88	65.21	97.81	0.5	1.5	Optimistic	Mid Mover	Mid Value
W	279712600	46	109	114.82	314.82	0.1	1.5	Challenging	Mid Mover	High Value
X	279712600	46	109	114.82	172.23	0.5	1.5	Optimistic	Mid Mover	High Value
Y	187823213	10	12	95.57	295.57	0.1	1.5	Challenging	Slow Mover	High Value
Z	187823213	10	12	95.57	143.35	0.5	1.5	Optimistic	Slow Mover	High Value



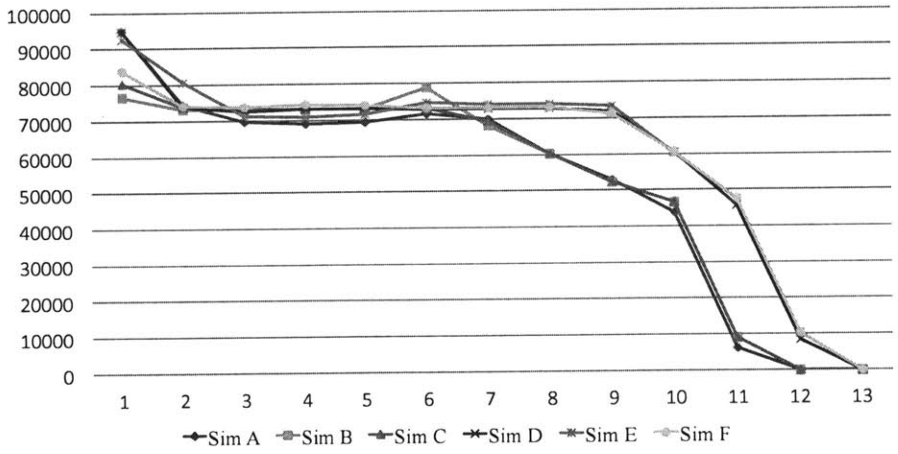
Appendix Figure-1 Fast-Mover Aggregate SKU (A) ramp-down



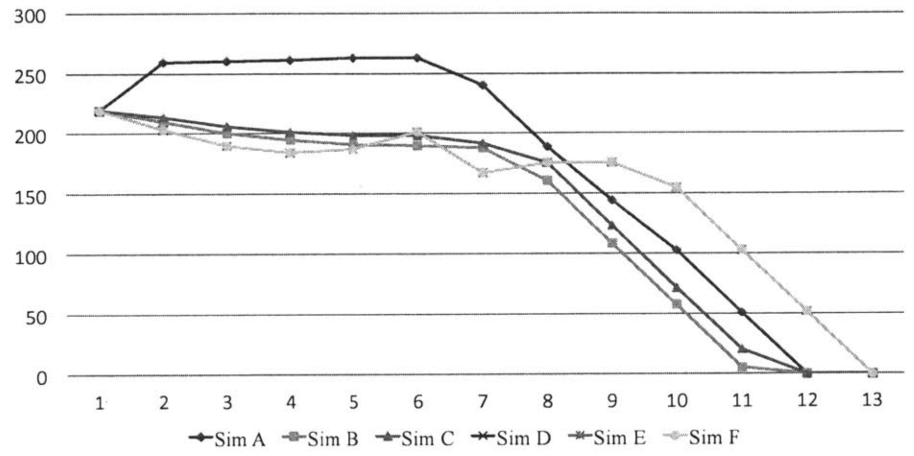
Appendix Figure-2 Slow-Mover Aggregate SKU (C) inventory policy ramp-down



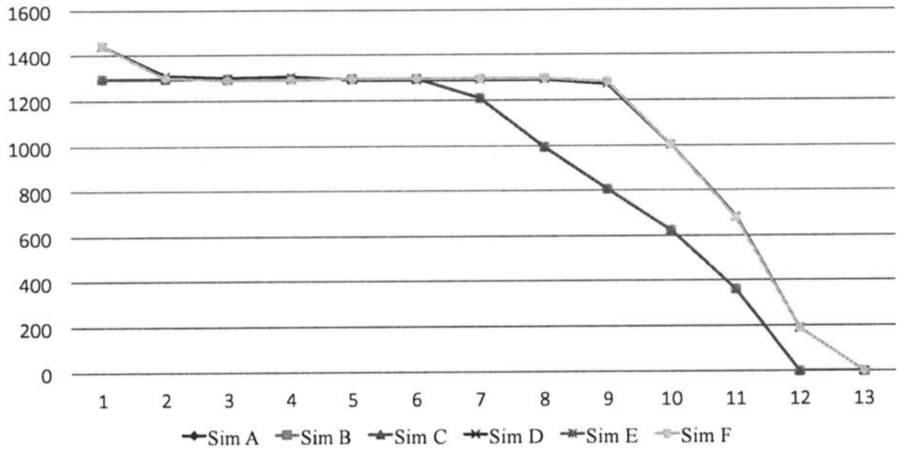
Appendix Figure-3 Low-Cost Aggregate SKU (G) inventory policy ramp-down



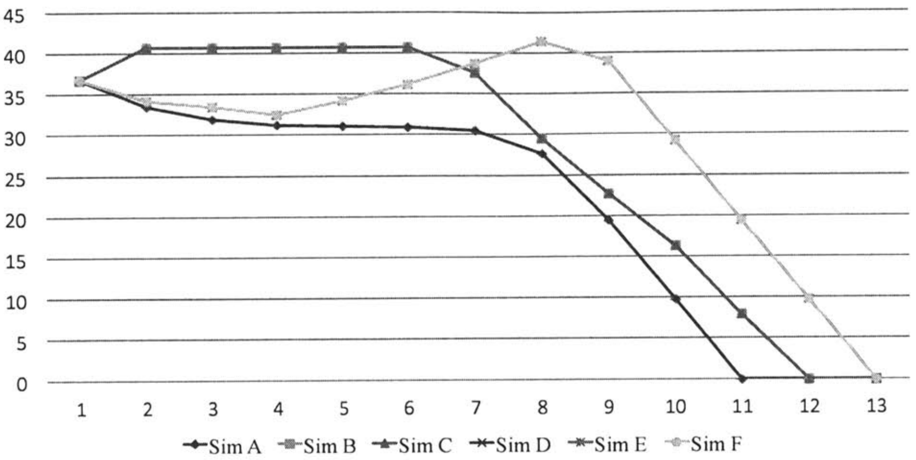
Appendix Figure-4 Overall Aggregate SKU (I) inventory policy ramp-down



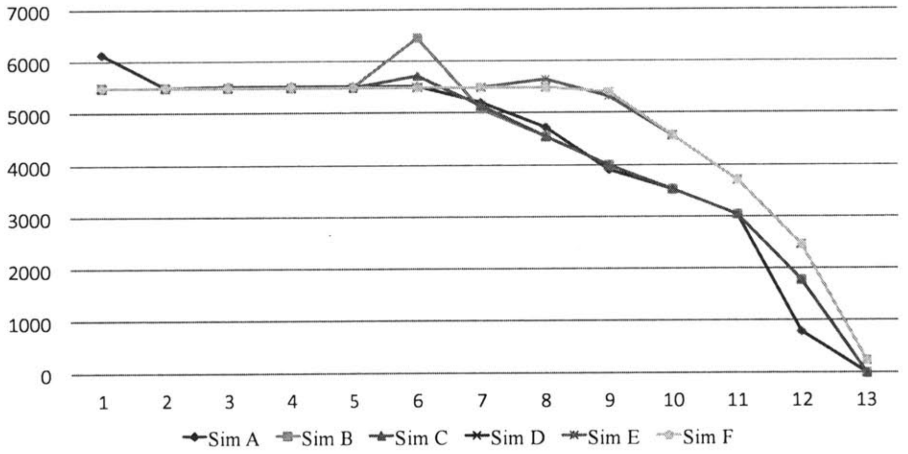
Appendix Figure-5 Mid-Mover Mid-Value SKU (S) inventory policy ramp-down



Appendix Figure-6 Fast-Mover High-Value SKU (Q) inventory policy ramp-down



Appendix Figure-7 Slow-Mover High-Value SKU (Y) inventory policy ramp-down



Appendix Figure-8 Fast-Mover Low-Value SKU (K) inventory policy results