CHAPTER 8

CONCLUSION AND SCOPE FOR FURTHER RESEARCH

The Modern World is transforming at a fast pace with technological advancement. It would be correct to state that technology is changing our way of living. It is also evident that the expectations of the consumer in terms of all the product dimensions (quality, cost, delivery, flexibility, and responsiveness) are increasing. In the traditional business models, there has always been a trade-off among these five dimensions. But the over-exceeding expectations of consumers have pushed the organizations to explore how they can increase the performance on two conflicting dimensions simultaneously. This calls for radical change or re-engineering of the business models while upgrading the product technology faster.

Technologies are tools that are as equally promising as they are terrifying. The businesses that deal in the technology products have to innovate constantly and use the technology not only for improving their products and services but also for improving their way of doing business. With the large investments going into the product development, the technology products have transformed from being purely mechanical and electrical products to become sophisticated systems that comprise of sensors, microprocessors, data storage devices, connectivity devices, and software in multiple ways. The newer generations of technology replace older generations more frequently now. Thus, the faster-changing consumer preferences in today's World, coupled with the competition moves, have led to shorter product life cycles for the substitutable technology products. One of the key factors for the operational excellence of such firms can be the ability to optimize the inventory for technology generations. There are multiple generations of the technology existing together in the market and fighting for the shelf space, as well as the space in the prospective consumer's mind space.

The margins have been compressed to wafer-thin levels due to increased competition. The firms are no more price-setters but price-takers. The only way to survive is to become lean and minimize the wastages in the supply chains. When the lean supply chain is thought of, the first thing that comes to the mind is achieving operational efficiencies through inventory optimization. The World has witnessed the increasing improvisation of smart products resulting in the co-existence of multiple technology generations, In such a case, the operational efficiencies in the supply chain can be achieved only if the diffusion dynamics and demand substitution dynamics of these technology generations are given due consideration.

The nature of substitution among these technology products is substantially different from the substitution among the functional products in two ways. First, this substitution is a time-based substitution where the newer technology outflanks the earlier generation with time. Second, this substitution is more of a one-way substitution since the older technologies do not generally capture the market potential of the newer technologies in a progressive society unless in a situation where the newer technology product fails due to incompatibility issues. The conventional demand substitution models and the traditional inventory optimization models are not going to be of much utility to the supply chain managers who are working for technology products.

This research has been carried out to minimize the supply chain costs and maximize the supply chain surplus of such technology products. The inventory models have been formulated for different relevant scenarios in the context of modern-day business transactions. The performance of the proposed inventory models has been illustrated with numerical parameters, and the sensitivity analysis has been performed to examine the effect of the variables. This research tried to discuss a very basic foundation on the inventory planning and optimization for sequential-generation products under the innovation diffusion framework. It considered the imitation effect that has not been considered by the earlier works.

8.1. Achievements of the research

This series of research works are among the first ones to formulate a multi-period inventory model for multi-generational technology products. To begin with, the review of the literature was done on the diffusion modeling of innovations and inventory modeling of technology products. This review was very comprehensive and exhaustive one. Around eight hundred research papers on multi-item inventory modeling and demand substitution modeling by different authors were read in a good amount of detail, and have been cited at the relevant places in this Thesis.

After doing the review of the existing literature and finding out the research gaps, it was decided to develop the inventory models for multi-generational technology products. Also, a suitable demand model had to be developed that could accurately capture the lifecycle dynamics of technology generations and technological substitution. The Bass Framework was used to develop the Demand Model in light of the theory of Diffusion of Innovations. This model captured the demand for any particular generation not only due to its market potential but also due to the influence on its demand by the other generation product. The demand model, thus developed, was validated on the real dataset for the demand of technology generations. It was found to explain a significant percentage of the variations in the demand of technology generations. The basic demand model thus formulated was extended further in case of credit dependent demand and price elastic demand when the corresponding inventory models were developed for these two scenarios. The repeat purchase was also built into the demand model in one of the chapters.

The chapters in this Thesis saw the development of the first single-period and the first multi-period inventory optimization model developed for the multi-generational technology products. The proposed demand model is based on traditional innovation diffusion theory; and hence it can be used to predict sales of any successive generation consumer durable products. The inputs from the Generalized Bass Model and the existing theory on the marketing mix have also been taken as and where applicable.

This study has many important insights that can be used by inventory managers and practitioners dealing with high technology products. The most important point of learning that this paper offers is explaining the demand substitution between the two successive generations of technology and discussing how that substitution has to be modeled differently from the way other demand rates are modeled. Till now, inventory managers were mainly concerned about accounting for demand substitution driven by the stockouts or pricing or assortment decisions. They had not looked so closely at the technology-driven demand substitution. This study makes the supply chain managers realize how important it is to consider the product lifecycle dynamics while planning for the inventories of high technology products. The study makes it easier for them to acknowledge that inventory management would simply fail if the product lifecycle dynamics are not adequately captured in the inventory models. It can further guide the industry practitioners in appreciating the phenomenon of cannibalization among the different generations of the technology products.

The managers from the functions other than the supply chain can also derive benefits from this study as they can use the validated demand model for developing the demand forecasts for the technology products. Such demand forecasts are of great value not only to the core operations function but also to the support functions in an organization, such as sales planning and financial planning functions. With the immense pace at which newer products come into the market, the financial planning as well as the sales planning is incomplete in the absence of consideration to the life cycle dynamics of products in the technology product organizations. The research study also reflects the convex nature of the total cost curve and the concave nature of the total profit curve for the high technology products, indicating that the same can be optimized to ensure proper utilization of scarce resources. The organizations have unlimited business opportunities but limited resources or funds. This capital constraint makes the resource rationing very important. Resource rationing refers to making the most efficient and productive use of the existing resources, and therefore, calls for operational excellence.

Also, the study worked upon the influence of many variables such as the credit terms, selling price, warehouse storage capacity, imprecise business environment, etc. on the inventory policies for such products. While the former two of the above-listed variables are part of the marketing mix, the latter ones are the characteristics of the modern business background. The different models were formulated for each of these cases. The beginning was done with the single-period inventory modeling, which was later extended to multi-period modeling. The study also shed light upon the phase-out timing of the earlier generations, and how it is influenced by the diffusion characteristics of the newer technology generations. The researcher was also able to generate useful insights that have important implications for the managers as well as policymakers as well as academicians. Such implications for the business and governance have been laid down for each of the models in the corresponding chapter. The following paragraphs serve to summarize a few of these insights in brief.

The research started with the development and validation of a demand model for multi-generational products, and the deployment of the same with single-period inventory optimization models. The single period inventory models served as a stepping stone to develop multi-period models and also generated a lot of insights. For example, it was found that the optimal supply quantity for the first generation increases while that for the second generation decreases with the increase in the introduction timing of the second generation. The role of innovation and imitation effect in inventory decisions could also be examined more closely for multi-generational technology products. It was also observed that with an increase in the values of the coefficients of innovation and imitation, the value of optimal cost increases, and the optimal ordered quantity increases due to an increase in the demand.

With the multi-period model, it was also discovered that the higher coefficients of innovation and imitation for the second-generation lead to lower EOQ for the first generation product. It was also discussed that higher innovation and imitation coefficients of the newer generations lead to high operational synergies in replenishment, and also faster phase-out of the earlier generation. In the case of warehousing space constraint, it was revealed that the increase in values of innovation and imitation coefficients leads to faster diffusion in the earlier periods than the later ones. This, in turn, leads to the dependence on rented warehouses becoming more uneven with time. Thus, the optimal number of replenishment cycles rises in the initial stages of the product life cycle and declines in the later stages.

It was also observed that the EOQ of the technology products with short product life cycle is higher in the initial periods and then falls in the later periods. This is because the volumes in the case of such products are very high in the initial time zones, which lead to higher EOQ. Further, the EOQ for the second generation product is higher than that of the earlier generation products. This is because the second-generation product is a better version of the earlier generation product, and hence, enjoys a higher demand rate, leading to an increase in the EOQ. The research also shows the academicians and researchers how to incorporate the influence of the repeat purchase tendency of the consumer into the inventory optimization policies and decisions.

It has also been observed that there is a significant jump in the overall volumes with the launch of the advanced generation of a product, contingent on the additional utility brought by the newer product to the consumer in terms of function and features. The revenue and the total profit increase considerably with the launch of the second generation product since that has higher market potential and faster diffusion as compared to that of the first generation by having more features. This leads to an increase in the overall market volumes, better chances of demand aggregation, and hence, better inventory replenishment efficiencies. The industry practitioners and product planners need to leverage this learning and keep coming up with innovative features in the products to improve the overall volumes and operational productivity.

The pooling or non-pooling decisions related to the logistics of multiple generations of products can also be taken depending upon the trade-off between the ordering costs and holding costs. The higher ordering costs (per order) make the business case for pooled logistics while the higher inventory carrying costs (per unit item per unit time) favor the non-pooled logistics. In the case of un-pooled logistics for the two generations' products, with the increase in the innovation and imitation coefficients for the second-generation product, the optimal EOQ for the first generation falls, while that for the second generation product increases. Also, it has been found in this research that in the case of pooled logistics for the two generations' products, the optimal EOQ for the first generation may fall or rise with the increase in the innovation and imitation coefficients for the second-generation product depending upon the degree of cannibalization and the stage of the product lifecycle.

The research also helps the managers to understand the interplay between the credit periods and the demand rates of multiple generations of substitutable products. Another important implication for the managers is that the credit period offers become more beneficial in the times of recessionary business cycles as compared to the growing business cycles. Also, the credit terms provide more value for the low-volume high-margin products, in contrast to the high-volume low-margin products. The inventory practitioners in the supply chains of the digital products can make sound business decisions related to the inventory replenishment frequency, economic order lot size, and credit terms. The differential service levels can be explored in a capital-constrained supply chain, and generally, it is better to achieve higher service levels for the later generation product at the expense of that for the earlier generation product.

This research can also guide the practitioners in determining the optimal credit terms in business. The optimal credit terms would be the one at which the total profit is maximized. With the increase in the credit period, the contribution margin increase and the holding costs fall, but at the expense of a rise in the credit costs. It makes business sense to offer incremental credit as long as the rise in credit costs is overweighed by the rise in the contribution margin and fall in holding costs. It also came out that the higher credit period offered on any product has a negative influence on the demand of the substitutable products. It is also important to note that the in case of multi-echelon supply chains, the credit periods offered by the intermediate echelons benefit the total profit only beyond a certain threshold level of credit sensitivity. The demand model was also suitably modified to incorporate the influence of credit terms on the demand and could help understand the multiple consequences of the trade credits.

It has also been revealed by this research that the second generation gets more benefits from the increase in credit terms as compared to the first generation. Therefore, under the capital constraints of credit, it is better to offer credits on the newer generation product rather than the earlier generation product. With the increase in the trade credits, the holding costs tend to fall given other factors constant; and the contribution margin tends to increase. Offering the higher trade credits on the newer generation product expedites the phase-out timing of the first generation product. It was also inferred by this research that in times of recessionary business cycles, the optimal credit terms are higher than in times of economic growth. It was also established that the optimal trade credits may depend upon the rate of movement of inventories. For the fast-moving popular products with lower per-unit contribution margins, the retailers should offer a negative or lesser credit period, while for the slow-moving and higher per-unit contribution margin products, it makes sense to offer a higher credit period.

While studying the influence of pricing, it could be observed how the price variations of a particular generation product have a bearing on the replenishment related costs and norms of not only that generation but also the other generations. Another important observation is the behavior of the optimal inventory policy with the price softening. It was observed that the price softening of the technology, leads to a decline in the profits initially until the degree of price softening exceeds a threshold limit. However, the profits increase through-out with the price softening in case the demand is highly elastic. Another important observation was that the technology products that cater to a very niche customer segment, need to be sold at a relatively higher premium than the others. The Generalized Bass Model was successfully used to model the inventory using genetic algorithms, and the price model was also discussed.

The research study illustrated how to integrate the inventory decisions with the warehousing space constraints, highlighting the need to establish a sound collaboration between the inventory managers and the logistics managers for the technology products, increasing the efficiencies of the overall value chain. It was also discussed that the optimal service level may not be 100% if the rent premium of the rented warehouse is above a certain level. The rental premium on the rented warehouse and the higher capacity constraint of the inhouse warehouse tend to jack up the optimal number of replenishment cycles and expedite the exit of the earlier generation products from the market. The higher rental premium on the rented warehouse can reduce the optimal service levels unless the dynamic pricing is adopted to cover the higher cost-to-serve. With the increase in the rent of the rented warehouse, the optimal number of the replenishment cycles increases in the intermediate planning horizons, while does not get influenced in the initial or later periods of the planning horizon. If the rent charged by the rented warehouse crosses a certain threshold, the optimal service level may fall to less than 100%, unless the dynamic pricing is used to charge the customer higher for the higher cost-to-serve. And the higher will be this fall during the peak stages of the product life cycle. It was also observed that the higher degree of capacity deficit of the first warehouse leads to the higher optimal number of replenishments in the planning horizon.

This research also depicts how the imprecise situations of the real world can be converted into decision-making problems using fuzzy logic. It becomes very important for the managers of today's dynamic and unpredictable business situations to handle the uncertainty by quantifying the same, for which the fuzzy set theory proves to be of great help. This research also shows how fuzzy logic can be used to make a sound business decision and strike the right balance between the pessimistic situation and the optimistic situation when under an uncertain business environment.

8.2. Limitations of the Research

There are a few limitations of the research conducted. The most important limitation is in the form of assumptions taken to simplify the modeling. For example, it has been assumed that there is no spillover of inventories from one period to another in the case of multi-period models. The backlogging of the orders has also not been considered, assuming that the demand for any particular period is served in that period only. The 100% service levels have been considered in the research, except in a few chapters, where the sub-complete service levels have been discussed in the context of incremental losses beyond a particular service level. The idea of sub-complete service levels has been discussed in the background of the capital-constrained supply chain and warehousing space constraints. Also, the demand has been considered to be deterministic, while in real-world scenarios, it is hard to find the demand to be deterministic.

Another limitation stems from the fact that the impact of technological enablement in the supply chains to get the realtime visibility of the POS (Point Of Sales) has not been covered. This is because the research under consideration was intended to be focussed on modeling and less focussed on supply chain process excellence aspects. Also, many of the business parameters such as the interest rates, the cost of space, transportation costs, etc. have been taken as constant in this research. While in reality, these parameters are subject to the market forces of demand and supply, and thus, are very dynamic with time. Stochasticity can be built into these parameters. Even the inclination of the adopters to innovate changes with time with the changing aspirations; as well as the inclination to imitate changes with time, with the changing way of interpersonal interactions and the changing degree of responsiveness towards the influencers. But this research has assumed the constant values for the coefficient of innovation and coefficient of imitation.

The researcher has also taken a very fundamental assumption that any increase in the overall surplus of the supply chain will ultimately get distributed among all the stakeholders ranging from the suppliers to the customers. Therefore, the objective, in most of the chapters, is to maximize the profit or minimize the cost for the entire supply chain as a whole, rather than for individual stakeholders in silos. Therefore, this research does not shed much light on how any particular entity in the supply chain can improve his or her optimal profit. The impact of geography and the network span over the modeling has also been ignored. The entire supply chain has been considered in totality.

One of the limitations also lies in the way the diffusion has been captured by this research. Only the aggregate diffusion models were considered for the sake of simplicity while it is known that the individual-level characteristics also influence the diffusion of innovations. Also, one of the important assumptions of the models mentioned here is that the newer generation products are advanced versions of the earlier generations, and are more preferred by the consumer. This scenario may not hold good every time in the real-world situations where the resistance among the adopters to switch to a newer generation is also encountered.

8.3. Future Directions for extensions to the Research

The research studies in the chapters above laid down a few of the basic models for inventory optimization of multi-generational products. The modern business environment of technological products is influenced by many internal and external factors, each of which plays amongst each other at multiple levels and in multiple ways. Changing any of these factors slightly makes the inventory or demand to change their behavior. Therefore, one set of assumptions can never fit all the situations. There are numerous permutations and combinations, each of them being a potential realistic scenario and needs a thorough study. For the ease of modeling, the researcher had to make some simplifying assumptions such as deterministic demand rate, no backlogging of customer orders, etc. These models can be modified further to relax restrictive assumptions. There are a few areas of possible extension for this research in the future.

First, many of the parameters that have been considered to be deterministic can be stochastic. The use of time-varying parameters instead of the current practice of using constant parameters can be of benefit. Not only should the parameters vary with time, but also vary in a dynamic manner that can be best captured by building stochastic demand models as suggested by Putsis (1998). For example, the demand can be stochastic by nature, which needs to be considered using suitable probability distributions, and also the safety stocks. Also, all the models covered until now are based on the assumption that $'\tau'$ will be known to the manager from the beginning of the planning horizon. Thus it will be interesting to know how the model will behave when both T_1 and τ will both be variables and needed to be optimized jointly. The market potential of the product can also be dynamic, which has been considered to be so only in a few of the models. If the market potential is also linked to the marketing mix such as advertising expenses, the selling price, and the credit terms, that shall make these models more worthwhile to the practice of supply chain. Another possible research direction can be considering the inventory carrying cost per unit item per unit time as a variable cost which increases for higher replenishment quantities due to the need to rent a space from an agent, which is generally costlier than the own space. Also, it is often seen that innovation and imitation influence varies with time over the product life cycle, while this research has considered only constant coefficients for innovation and imitation. Future research can also consider examining the price elasticity factors as fuzzy variables since the price elasticity can vary with time depending upon the consumer sentiments, the growth rate of the economy, and the stage of the product life cycle. Treating the service level itself as a decision variable can be a worthwhile extension in future research.

Second, the interest rates can be very volatile and uncertain in the economy, which can be best described using fuzzy logic. The interest rate can be very volatile and uncertain in the economy, which can be best described using fuzzy logic. While the research has taken the basic purchase costs and the length of the credit period as fuzzy, many other business environment parameters can be imprecise and captured as fuzzy variables. The uncertainty of demand can also be captured by the use of fuzzy variables. At times, it can also be observed that the demand is not only governed by innovation diffusion but is also price elastic or stock elastic or space elastic. Thus, this study can be extended to different demand models that are encountered by us in our day-to-day life. One of the possible areas is linking these models to the money market dynamics to make it more relevant for the practitioners. The usage of discounted cash flows to build the time value of money in the model can also make it more reliable. Also, future research can consider the influence of the financial derivatives that can be used to hedge the increase in procurement costs or credit rate of interest. The influence of the receivables trading in making the credit period decisions can be considered as an extension of this work since the trading of receivables is a very common practice in the high growth organizations that have plenty of lucrative investment opportunities and would like to rotate their funds faster.

Third, backlogging of sales is possible when the customer is ready to wait and when the postponement of product delivery increases the total profit of the supply chain. Therefore, there is a need to also build the models for a scenario where the backlogging is allowed. The trade-off between the waiting costs and the operational synergies with delayed fulfillment can be an interesting area to be explored. The safety stocks may also need to be considered in such a case.

Fourth, it is observed in many business situations that the replenishment of inventories is not instantaneous. Therefore, if the models can be relaxed to cover non-instantaneous replenishments, that will be a useful extension. These models can also be developed for a multi-echelon supply chain with consideration of manufacturing dynamics.

Fifth, all the models have assumed that the newer generation has a better performance than the earlier generation product, thereby, assuming one-way substitution only. But in practice, it is not hard to come across cases where the newer generation of technology fails to issues of incompatibility, miscommunication of the value proposition, misconceived product design, ill-planned execution, ecosystem unfriendliness, etc. Therefore, some future research that can consider the failure case of the newer technology would be of high utility to be adding the existing body of knowledge in this domain.

Sixth, the model can be further extended are linking the consumer psychology and peer group influence with the new product acceptance. The demographic characteristics of the adopters (in terms of age, social status, income group, cultural values, education level, etc.) can also be related to the probability of diffusion. Although creating diffusion models on such a macro-level will make them more cumbersome and difficult to forecast due to immense data requirements, but such models can be expected to give more accurate forecasts. Also, the existing models have not worked on the integration of time and space dimensions that can help formulate the distribution strategies across the geographies.

A few other possible extensions of this research can be considering the influence of supply restrictions, market interventions like patent violations, competition entry, the intensity of market rivalry, etc. on the diffusion of innovation products. Another possible extension consideration of product deterioration in the warehouse. The linkage between the transportation pooling decisions and the rental premium on the rented warehouse also needs to be explored. Also, the effect of inventory pooling in the warehouse in case of stochastic demands, and its relation to the in-house warehouse's capacity deficit can be studied. The environmental cost of the e-waste produced due to the repeat purchase of electronic products can be quantified and considered in the model. This becomes very important in today's context of increasing thrust on business sustainability. Another extension can be working out the optimal product design to achieve the desired diffusion rate. In the case of technology products, hardware and software are bundled together. The work on the diffusion models of such product bundles is currently missing. The influence of dynamic pricing on the optimal service levels in the context of price elasticity of demand can also be studied in future research studies. It would also be interesting to study the impact of the business cycles and the macro-economic indicators on the diffusion of innovations.