

DEMAND-SUPPLY INTERACTION AND PRODUCTION CAPACITY PLANNING FOR SHORT LIFE CYCLE PRODUCTS

*Rong Pan, Department of Industrial Engineering, Arizona State University, PO Box 875906,
Tempe, AZ 85287, 480-965-4259, rong.pan@asu.edu*

*Adriano O. Solis, Department of Information & Decision Sciences, University of Texas at El Paso,
El Paso, TX 79968-0544, 915-747-7757, solis@utep.edu*

*Bixler Paul, Dell Americas Logistics, Dell, Inc., 13301 B McAllen Pass, Austin, TX 78753,
512-723-9884, bixler_paul@dell.com*

ABSTRACT

Revenues and profits from short life-cycle products depend upon careful formulation and execution of production plans in response to demands in the marketplace. We propose a set of mathematical models, which are based on cumulative demand patterns, for optimizing the investment return over the product's life cycle in a capacitated production facility. A modified Bass diffusion model is used to characterize the product demand pattern with consideration of demand-sales interaction. We develop cost models based on production costs, inventory carrying costs, backlog costs, and cost of lost sales for a number of different production scenarios. The optimal production rate is obtained by minimizing the total cost. We also investigate the benefit of an initial build-up of inventory before the product's sales period starts.

INTRODUCTION

Short life cycle products generally take the form of perishable goods or products characterized by constant innovation such as personal computers and other consumer electronics. The impact of short product life cycles on supply chain design and performance is of significant interest due to the uncertainty and risks involved. Managing short life cycle products is a challenge in today's highly competitive global business environment; profits generated from new products would hinge on careful formulation and implementation of production plans far ahead of the start of production. Production planning for cost minimization/profit maximization requires accurate forecasting and detailed analysis of the demand signals and the dynamic demand-sales interactions. This study shall delve into the mechanics of short life cycle products, diffusion patterns, and the effects of short life cycles on supply chain design. A review of the literature on production planning of short life cycle products clearly indicates that the research done in this area is in its infancy and is very limited.

We develop generalized mathematical cost models to better explain the demand-supply interaction occurring in short life cycle products. Following is the skeleton of our research:

1. Develop a demand-production model using the Bass diffusion model [1].
2. Develop cost models based on inventory, backlog, lost sales, and production costs for the different production scenarios.
3. Develop a mathematical model to incorporate the discount factor into the above cost model.
4. Develop a modified demand model to incorporate the interaction between demand and sales for the different production scenarios.
5. Develop a demand model where there is an initial build-up of inventory and generate corresponding revenue and cost models for the different production scenarios.

The Bass model posits that the instantaneous rate of adoption of a new product by the population of potential adopters at any time period is subject to two means of communications: mass-media (external) and word-of-mouth (internal). The external communication influences ‘innovators’, while the internal communication describes the interaction between innovators and ‘imitators’.

Previous researchers (e.g., [2]) utilize Bass’ instantaneous demand which is deterministic to calculate the optimal strategies. In our case, we model demand to be cumulative over the entire product life cycle and present a case where the production plan is matched against the cumulative demand profile in various settings. We use a graphical approach to develop a solution to our problem. In our models we establish the build-up policy as inventory build-up before the advent of the product life cycle where at time 0 we have sufficient inventory for sales to diffuse into the market.

Let p , the “coefficient of innovation,” and q , the “coefficient of imitation,” be two parameters that represent the extent of the external and internal communication levels. Let m be the size of the target population. We consider the following Bass model of cumulative demand:

$$D(t) = m \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}} \quad (1)$$

We establish four scenarios where the production plan is matched against the demand profile:

1. Production plan is barely satisfying the demand generated from the beginning of the product’s life cycle;
2. Production rate is satisfying some demand (to a period of time when the demand overtakes the production) with inventory but total demand cannot be met by total production quantity;
3. Production completely satisfies the total market capacity and is terminated when the total production quantity reaches the total demand quantity; and
4. Production rate is so high that it reaches market capacity much ahead of actual complete market consumption, that it carries inventory to satisfy the demand.

For each of the above scenarios, we develop cost functions for cost minimization to establish the optimal production plan for a given set of parameters which govern the demand profile. For instance, in the first case, the total cost will be a sum of total production cost, backlog costs, and cost of lost sales, and will be a function of the parameters m , p , and q , as well as unit production cost α , unit backlog cost ω , and unit lost sales cost χ .

FINDINGS AND FUTURE RESEARCH

In this paper, we develop deterministic models to study the effect of production capacity on the demand and sales behaviors in products with short life-cycles. Cost functions over the entire product’s life cycle are built and they can be utilized for finding the optimal production rate at the beginning of the life cycle. We also study the effects of an inventory build-up strategy to satisfy the sharp increase of demand at the growing stage of life cycle.

The contribution of this research is different from previously published papers (e.g., [2] [3]) in the way that we use cumulative demand to analyze the demand-sales interaction. Our solution is more graphical in nature and the cost models associated with the different scenarios aid in developing a production capacity plan. From several numerical studies (for brevity, those studies are not included in this report), we draw the following conclusions:

We know that changing m (market capacity) does not have much of an influence on the shape of the demand curve. However, the shape of the demand curve can drastically vary with the change in p (the coefficient of innovation) and q (the coefficient of imitation). As p increases, the curve tends to grow sharply which indicates that the product reaches a major percentage of the market capacity in a short period of time. This typically entails a scenario in the market where consumers are trying the new product without the word-of-mouth communication (this is typically applicable when there is plenty of advertisement in the news/entertainment media).

However, an increase in q (coefficient of imitation) would tend to boost the sales by generating consumers who are waiting and watching the product from the time it was introduced into the market.

The cost coefficients $\alpha, \chi, \omega, h, l$ which constitute production, backlog, inventory, lost sales also play a vital role in deciding the appropriate strategy for building a production plan. The higher the cost coefficients for a respective cost component, then the strategy is to minimize the total cost of the component by reducing the area under the curve which constitutes that cost component. On the other hand, if the coefficient of the cost component is not very high, the strategy would suggest that the large area under the curve should be the cost component with low coefficient. In many practical situations, we see that the cost of inventory is at a higher priority than the cost of backlog and cost of lost sales due to immediate implications to the financial status of the company. However, in order to maintain an optimal solution, we need to have a balance in the various costs involved.

In the build-up strategy, it is very important to establish the start time of production which would decide the total inventory quantity prior to the beginning of the sales period. Another important factor is the cost coefficient associated with the holding of inventory at the beginning of the product's life cycle. We have developed cost functions for the different scenarios presented. With the parameters m, p, q defined from market research, one can develop an appropriate production plan.

In this paper, only deterministic demand models are applied. Demand-supply interaction modeling with stochastic demands is yet to be researched in this field, and it will be considered in our future research.

REFERENCES

- [1] Bass F., 1969. A new product growth for model consumer durables, *Management Science*, 15(5), 215-227.
- [2] Ho T., Sergei, S., and Terwiesch C., 2002. Managing demand and sales dynamics in new product diffusion under supply constraint, *Management Science*, 48(2), 187-206.
- [3] Kumar, S., and Swaminathan, J.M., 2003. Diffusion of innovations under supply constraints, *Operations Research*, 51(6), 866-879.