ANYLOGIC-Based Dynamics Model of the Bass New Product Diffusion Process

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Abstract. This study introduces a dynamic model of the Bass New Product Diffusion Process implemented through ANYLOGIC. The objective is to comprehensively investigate the underlying dynamics governing the diffusion of new products. Through meticulous construction and exhaustive validation via simulation, our model successfully captures the intricate dynamics of the Bass Diffusion Process, yielding highly accurate outcomes. This research sheds light on previously unexplored aspects, underscoring the potential of the model. In conclusion, the dynamic model, facilitated by ANYLOGIC for the Bass New Product Diffusion Process, not only serves as a robust tool for analyzing the dynamic traits of product diffusion but also carries profound industry implications, laying a foundation for industries to gain deeper insights into market penetration, potentially leading to more strategic product launches and targeted marketing efforts in the future.

Keywords: Bass model; New product diffusion; System dynamics

1 Introduction

If a company wishes to maintain a leading position in market competition, it often needs to continuously engage in the research, development and launch of new products. Through the research, development, and launch of new products, a company can gain market recognition and customer pursuit, squeezing the strategic space of competitors. At the same time, it can obtain high premium returns during the new product entry stage. However, for companies, the development of new products, in addition to having the aforementioned appealing possibilities, also comes with characteristics of high investment and high risk. If not handled cautiously, it could inflict substantial losses on the company.

The process by which a new product is gradually recognized by the market, if it can be accurately described and captured, will be extremely beneficial for reducing the risks of launching new products for a company. That is to say, accurate forecasting of sales volume changes after a new product is launched is an essential guarantee for a company to achieve its new product competition strategy. At the same time, this prediction also

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determines how a company conducts production planning and control, which, in turn, will bring about demand fluctuations at all levels of the supply chain.

However, new products refer to products that are newly launched, of which similar products often do not exist or are scarce. Therefore, methodological difficulties arise in the forecasting of their sales volume. The Bass Model was first proposed by marketing professor Frank Bass in 1963, and it was initially used primarily to predict the diffusion pattern of new products. Hence, it is also referred to as the New Product Diffusion Model. The New Product Diffusion Model is a mathematical model established based on specific diffusion theory, which can be used to fit the rules of sales volume changes after the launch of new products, and to identify factors affecting sales volume changes [1].

With the advancement of computer simulation technology and the emergence and updating of modeling tools, how to use new technologies and new means to perform more effective simulation has become a research field for the effective application of the Bass Model. The aim of this research is to establish a Bass New Product Diffusion Process Dynamics Model based on ANYLOGIC, to explore the dynamic mechanism of the new product diffusion process. We will use ANYLOGIC software to establish the model and carry out simulation validation, to discuss the effective combination of theoretical models, technical methods, and tools in the field of new product diffusion.

2 Research Methods and Tools

2.1 System Dynamics Modeling

Currently, there are three mainstream modeling paradigms: System Dynamics Modeling, Agent-Based Modeling, and Discrete Event Modeling. Fundamentally, these three modeling paradigms represent three different perspectives that modelers can adopt when mapping the real-world system into the model world.

Top-Down Perspective: In the System Dynamics paradigm, modelers are advised to abstract from individual objects and think holistically from the perspective of total quantities and feedback loops. We can simplistically understand this as viewing the system from a "top-down" perspective.

Bottom-Up Perspective: In Agent-Based Modeling, modelers first observe individual objects in the system, understand their core characteristics and behaviors, then understand possible interactions between objects, and consequently form the overall behavioral state of the system [2]. We can simplistically understand this as studying the system from a "bottom-up" perspective.

Left-to-Right Perspective: The Discrete Event Modeling paradigm adopts a process-oriented approach: the dynamics of the system are represented as a series of operations performed on entities. We can simplistically understand this as studying the system from a "left-to-right" perspective.

The reason why this article chooses the System Dynamics paradigm to construct a new product innovation model is because the selection of different paradigms mainly considers factors such as system modeling goals, available data, and the nature of the problem. The research objective of this article is defined as generally viewing the process of new product launch and diffusion, as well as the relationship between core influencing variables in the process. In the modeling process, the lack of data is a basic premise. Relatively speaking, System Dynamics is more abstract and holistic, and the study of the problem relies more on reasonable assumptions rather than specific data. Therefore, we choose System Dynamics to study this issue.

2.2 Selection of System Modeling Tools

Currently, in response to the three system modeling paradigms mentioned above, many software developers on the market have developed and provided a number of system modeling tools, such as AnyLogic, Vensim, etc. Among them, Vensim is a software tool that only supports System Dynamics modeling, while AnyLogic can support all three modeling methods on a single platform.

Although both of these modeling and simulation software can be used to establish models to study the dynamic behavior of systems, they have some notable differences.

Scope of Use: ANYLOGIC is a multi-model modeling and simulation software that can be used to build various types of models, including System Dynamics models, network flow models, Agent-Based models, etc. Vensim is a modeling and simulation software for System Dynamics models.

Model Construction: ANYLOGIC's model building is more flexible, allowing models to be built through code or a graphical interface. Vensim's model building is mainly done through a graphical interface.

Simulation Capability: ANYLOGIC has stronger simulation capabilities and can perform various types of simulations, including dynamic simulation, static simulation, single-point simulation, etc. Vensim's simulation is mainly dynamic.

Visualization: ANYLOGIC provides rich visualization features, which can help users more intuitively understand the operation of the model. Vensim also provides some visualization features, but not as extensively as ANYLOGIC.

In summary, ANYLOGIC is a powerful modeling and simulation software that can be used to build various types of models and has strong simulation and visualization capabilities. Vensim is software focused on modeling and simulation of System Dynamics models, with strong simulation capabilities, but relatively weak visualization capabilities [3].

Moreover, AnyLogic possesses a core advantage, where modelers can choose different abstraction levels to start building the model, and effectively change them while handling the model, thereby combining different methods into one model [4].

In choosing modeling and simulation software for this research, considering our own needs comprehensively, on one hand, we need strong simulation and visualization capabilities. At the same time, we wish to choose different abstraction levels to start building the model and consider the possibility of establishing various types of models for extension, choosing ANYLOGIC as the tool software for this modeling.

3 Research Results: System Dynamics Modeling Process and Experimental Design of the Bass Model

3.1 Introduction to the Bass Model

The Bass model has three key parameters - market size, innovation coefficient, and imitation coefficient.

- Market Size (m): This is the total number of potential customers after conducting a demand forecast for the entire market.
- Innovation Coefficient (p): This represents the ratio or probability of innovators within potential customers adopting the new product at a certain moment.
- Imitation Coefficient (q): This represents the ratio or probability of imitators within potential customers adopting the new product at a certain moment, used to explain "word of mouth" or "social contagion" effects.

The crowd corresponding to the innovation coefficient is referred to as innovators, defined as those in the population who make decisions without being influenced by others in the social system. Usually, the first batch of product purchasers is referred to as innovators. Aside from innovators among the product purchasers, other users will also be influenced by various impacts from the social system, and as the number of product users increases, the influence on subsequent product users will become increasingly significant. We call this crowd imitators, corresponding to the imitation coefficient. It can be seen that the difference between imitators and innovators is that innovators are not influenced by others, while imitators are influenced by others in the social system in their purchase timing.

Parameters p and q determine the expected adoption speed of new products: a product with a high innovation coefficient will be quickly adopted by the market even if its imitation coefficient is low; a product with a low innovation coefficient will initially be adopted very slowly by the market even if it has a high imitation coefficient. The adoption scale of new products is influenced by m. For the Bass diffusion model, the following equations hold:

$$a(t) = p + q \times U(t)/m$$

$$n(t) = p \times P(t) + q \times P(t) \times U(t)/m$$

where:

- a(t): The probability of consumers purchasing the product at time t (assuming consumers buy only at t)
- n(t): The number of consumers purchasing the product at time t
- p: Innovation coefficient (external influences, e.g., advertising effect)
- q: Imitation coefficient (internal influences, e.g., word-of-mouth effect)
- P(t): Number of potential consumers at time t
- U(t): Number of product adopters up to time t
- m: Total number of potential consumers for the new product

The advantages of the Bass model in new product demand forecasting include: the Bass model can describe the product diffusion process quite accurately using only three parameters (maximum market potential, innovation coefficient, imitation coefficient); the non-cumulative adoption curve of the Bass model is very similar to the product lifecycle curve from market entry to exit, making it persuasive in describing product development[5]; by applying the Bass model, and solving for a few parameters of the model, the sales volume changes of the product throughout the entire sales cycle can be described based on the model curve[6].

3.2 Defining System Boundaries and Constructing a Stock and Flow Diagram

In the previous part of this article, we have identified that the problem to be studied in system simulation modeling is to accurately predict and describe the diffusion process of new products. We have also clarified that we hope to solve this problem through the Bass model. At the same time, we choose system dynamics as an appropriate modeling method and ANYLOGIC as the tool software for this modeling.

Now, we need to define the boundaries of the system, that is, determine which factors belong to the elements within the system and which factors belong to elements outside of the system. This will help us better grasp the operating laws of the system. At the same time, we determine the stock and flow: stock represents the quantity of a certain material or information in the system, while flow represents the flow rate of a certain material or information in the system. When establishing a system dynamics model, we need to determine the stock and flow in the model and clarify their relationship.

At this stage, we need to analyze the model to decide how to describe it in terms of system dynamics. We need to distinguish the key variables of the model and their impact patterns, and then establish the stock and flow diagram of the model. When constructing the stock and flow diagram, consider which variables should be modeled with stock, flow, or variables.

In the system dynamics model, stock represents the quantity of a certain material or information in the system. The stock can be determined or unknown. Flow represents the flow rate of a certain material or information in the system. The flow can be positive, indicating that material or information is flowing into the system; it can also be negative, indicating that material or information is flowing out of the system.

There is a close relationship between stock and flow. The change in stock is determined by the change in flow. In the system dynamics model, changes in stock can be predicted by calculating the flow. For example, when studying the water level of a reservoir, the water level can be considered as a stock. If the reservoir is storing water, then the water flow into the reservoir is positive, and the water flow out of the reservoir is negative. By calculating the flow, you can predict what changes will occur in the water level of the reservoir [7].

When constructing the stock and flow diagram, consider which variables have accumulated over a period of time. In our model, purchasers and potential consumers are stocks, and the purchase rate is flow. We hope to construct the system dynamics overall model of the model as shown in Figure 1.

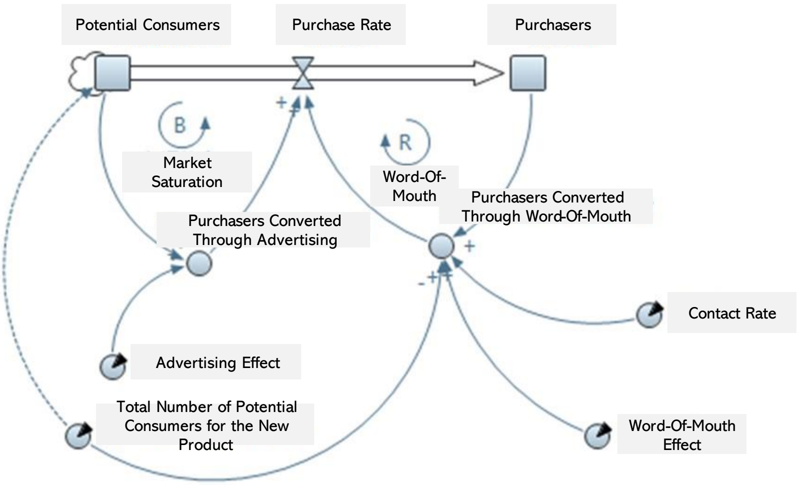

Fig. 1. System dynamics model of diffusion of Bass new product

3.3 Positive and Negative Correlations

The "+" symbol in Figure 1 indicates a positive correlation between the two variables on either side of the link. Within the realm of system dynamics, a positive correlation refers to a relationship wherein an increase in one factor leads to an increase in another. For instance, when analyzing a company's sales revenue, a positive relationship exists between advertising spend and sales: the more is invested in advertising, the higher the sales revenue.

In Figure 1, several pairs demonstrate a positive correlation. These include potential consumers and buyers converted through advertising; buyers converted through advertising and purchase rate; buyers and those converted through word-of-mouth effects; and buyers converted through word-of-mouth and purchase rate, all illustrating this type of relationship.

Conversely, the “-” symbol in Figure 1 denotes a negative correlation between the two variables linked. Negative correlation refers to a relationship where an increase in one factor leads to a decrease in the other. For example, in studying urban traffic congestion, there exists a negative correlation between the degree of congestion and road width: the wider the roads, the lower the congestion level.

In Figure 1, there is a negative correlation between the total number of potential consumers for a new product and those converted through word-of-mouth effects.

3.4 Reinforcing and Balancing Loops

In Figure 1, we observe two feedback loops: one named “Market Saturation” which is a balancing loop, and another named “Word of Mouth” which is a reinforcing loop.

In system dynamics, feedback loops refer to the mutual influence among variables within the system. Feedback loops can either promote variable growth or hinder it. The former is referred to as reinforcing loops, which can drive the system into a state of accelerated growth, or make the system's behavior unstable. The latter is known as balancing loops, which can stabilize the system's behavior or decelerate its growth.

System dynamics models typically encompass multiple feedback loops, which can interact with one another, crafting complex system behavior. When establishing a system dynamics model, all feedback loops must be considered, and their impact on the system determined.

In the context of the Bass Model of new product diffusion studied here, "Market Saturation" operates as a balancing loop. This is because, with an increase in the purchase rate, the number of potential consumers will decrease. Subsequently, as the number of potential consumers diminishes, consumers converted through advertising will also reduce. Further, a reduction in consumers converted through advertising will, in turn, suppress the purchase rate.

Conversely, "Word of Mouth" within the Bass Model of new product diffusion acts as a reinforcing loop. This is due to the fact that as the purchase rate increases, the number of buyers will increase. Subsequently, with an increase in the number of buyers, the number of buyers converted through word of mouth will also rise. Further, an increase in buyers converted through word of mouth will then further propel the growth of the purchase rate.

3.5 Establishment of Parameters and Equations

In the process of system dynamics modeling, the establishment of parameters and equations is a pivotal step. We need to utilize the fundamental elements of system dynamics (such as stocks, flows, and rates) to formulate equations. These equations describe the interactions amongst various variables within the system. The parameters and equations in this model are presented as shown in Table 1:

Table 1. Bass new product diffusion kinetics model parameter table

VARIABLE NAME	PARAMETER OR EQUATION
Purchasers Converted Through Advertising	Potential Consumers * Advertising Effect
Advertising Effect	0.011
Total Number Of Potential Consumers For The New Product	100000
Word-Of-Mouth Effect	0.015
Contact Rate	100
Purchasers Converted Through Word-Of-Mouth	Purchasers * Contact Rate * Word-of-Mouth Effect * Potential Consumers / Total Potential Consumers for New Products
Purchase Rate	Purchasers Converted through Advertising + Purchasers Converted through Word-of-Mouth

3.6 Running Simulations

Next, we proceed with running simulations of the model. Through the simulation, we observe that based on the parameters and equations of this model, the potential consumers, initially numbering 100,000, are all converted to purchasers after 8 simulation cycles. Throughout the entire conversion process, the purchase rate displays an inverted U-curve, as shown in Figure 2:

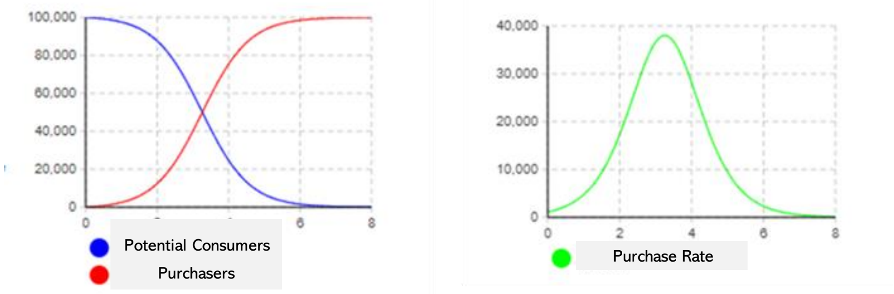

Fig. 2. The simulation results of the diffusion process dynamics model of Bass new product

In the initial stage, the purchasers in the Bass model correspond to the population represented by the innovation coefficient, also referred to as innovators. In this study, the innovation coefficient is determined by advertising effects. These innovators make their decisions not due to the influence of others in the crowd but are the first batch of users to purchase the goods.

We observe that the speed at which a new product is anticipated to be adopted is determined by two parameters: the advertising effect, representing the innovation coefficient, and the word-of-mouth effect, representing the imitation coefficient. The innovation coefficient in this study is lower than the imitation coefficient, therefore the initial adoption speed in the market is slow. However, precisely because the imitation coefficient is relatively high, after the initial phase passes, there is an acceleration period. As the number of purchasers among the innovators increases, the growth loop caused by the word-of-mouth effect takes a dominant role in the system dynamics, leading to a rapid conversion of a large number of potential consumers due to the word-of-mouth effect.

Subsequently, the "Word-of-Mouth" growth loop is restrained by the regulating loop of "Market Saturation." With the reduction of potential consumers, the purchasers who can be converted also gradually decrease. This causes the system's growth to slow down and eventually stabilize.

4 Conclusions

When dealing with unknown markets, participants interlinked with each other, and products deemed as radical innovations, forecasting the introductory behavior of new products is requisite. The Bass diffusion model is widely utilized to describe the system dynamics of new product growth. Hitherto, the classical approach has adopted a top-down method, employing system dynamics techniques, wherein the Bass model is used to delineate the behavior of the entire system—applying global equations to specific scenarios—without considering the behavior or interaction of components [8].

System dynamics modeling is a prevalent method, which can be employed to explore the dynamic behavior of systems. In establishing the Bass New Product Diffusion Model, utilizing system dynamics models enables a clear articulation of the system's operating mechanisms, making the model's interpretation easier. Concurrently, system dynamics models can use computer simulations, quickly yielding results, and facilitating model validation.

Furthermore, through the system dynamics model based on ANYLOGIC, the visualization of the model can be conducted through charts and other forms, making the model's results more intuitive. Researchers, by simulating the model, can delve into the dynamic behavior of the system, aiding our understanding and exploration of the system's mechanisms. In sum, the Bass New Product Diffusion Process Dynamics Model based on ANYLOGIC is an effective tool for researching the dynamic process of new product diffusion.

Simultaneously, numerous features during new product introduction embody a phenomenon of emergence formed by bottom-up, local interactions based on different entities. This also presents certain difficulties to the business modeling methods of system dynamics [9]. The next step of research will combine bottom-up agent-based modeling methods with top-down system dynamics modeling methods, so as to represent both global situations and characterize emergent, local interactions based on different agents from the bottom up.

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