

## **Modeling the Diffusion of Innovations Based on Individual Adoption Decisions**

### **An Object-Oriented Approach**

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### **Abstract**

Innovations are the drive for a company's growth and contribute substantially to its competitiveness in a world of falling economical barriers. New products are to be invented, developed and introduced into the market, if the success and existence of a company are to be preserved. Therefore it is not astonishing, that the explanation and forecast of the diffusion of innovations in a special market are a subject the management is vitally interested in.

Most of the models that are to support the difficult forecast of new product sales - among them the widely spread Bass model - are based on a describing view of the life-cycle of a product and generate s-shaped sales curves using only one single mathematical formula or maybe just a few. In these models the diffusion of new products seems to be predetermined by nature. The management only has to estimate the parameters and coefficients to forecast the cycle correctly.

This paper wants to present a different, a more individualistic and microanalytic point of view. Not the entire market, not the homogenous potential of the market is in the center of this model, but the single, individual protagonists of the market. Using the methods of object-oriented analysis (OOA), the relevant objects and their classes will be identified, the characteristics and conduct will be examined and their relationship among each other will be laid open.

This way, an object-oriented model of the market is created, a model of which one of the most remarkable features is the very natural copying of reality. Therefore it contains a much higher grade of explanation, and it can be more easily implemented to an object-oriented programming language, which makes it usable for simulations. The first results will be introduced in the final chapter.

## Modeling the Diffusion of Innovations Based on Individual Adoption Decisions

### An Object-Oriented Approach

#### THE BASS MODEL – AN AGGREGATED NEW PRODUCT GROWTH MODEL

The process of diffusion of new products can be formally shown by the function  $X(t)$ , which describes the relationship of time  $t$  and the stock of up to time  $t$  sold goods. This function and the sales  $S_t$  of a single period of time are the variables, which most of the diffusion models try to describe or explain more or less extensively. Great importance and among innovation management widely known has become the model of Frank M. Bass.

Bass examines the process of diffusion of durable goods and therefore avoids the problems of repetitive purchase. The sales during a certain period of time result from the not-served potential of buyers  $(N-X_{t-1})$  multiplied with the probability of purchase:

$$S_t = w_t (N - X_{t-1}) \quad (1)$$

$N$  represents the number of first-time purchasers of the innovation over the product life cycle,  $X_{t-1}$  the sales up to now, and  $w_t$  the likelihood of a demander buying the product at a certain point in time, supposing he has not bought it during the period from  $t=0$  up to  $t=t-1$ . Bass assumes for  $w_t$ :

$$w_t = \alpha + \beta \frac{X_{t-1}}{N}, \quad (2)$$

and therefore the following equation is found in literature as the Bass model:

$$S_t = \alpha(N - X_t) + \beta \frac{X_t}{N} (N - X_t) \quad (3)$$

The Bass model can be interpreted in two ways: One of the interpretations deals with equation (1), assuming that a purchaser has a mixed behavior with innovative as well as imitative elements. In this interpretation the potential of the buyers is structured homogeneously. All of the members of a social system are mixed in their characteristics equally and therefore can be called "as-well-as-adopters" or "mixed adopters".

In his own interpretation of the model, which is supported in numerous publications, Bass (1969) separates two types of purchasers: innovators and imitators. He assumes, basing on the results of adoption research, that they have different characteristics and conduct. According to this, innovators are open-minded towards innovations and buy them because of being interested. In their decision to purchase a new product they are stimulated only by exogenous factors, meaning that they decide independently from other consumers whether to adopt or reject it. Besides they are usually among the first users. The probability of their adoption is steady in time and independent from the influences of the social system.

Imitators as a contrast are influenced by the adoption of others, they buy because of others having bought the new product earlier. The probability of an imitative adoption is according to Bass (1969) "a linear function of the number of previous buyers", meaning that the will to buy increases parallel to the increasing saturation of the market  $X_t/N$ . The sales of a period therefore result according to equation (3) from the first buys of the innovators  $\alpha(N - X_t)$  and those of the imitators  $\beta X_t/N(N - X_t)$ .

$\alpha$  is called the coefficient of innovation,  $\beta$  the one of imitation. These however cannot be equated with the part of innovators and imitators in the potential of the market. Schmalen, Binninger and Pechtl (1993) show, that the part of the innovators - and, of course, the one of the imitators as well - is determined by the proportion of the two coefficients and therefore is not identical with  $\alpha$ . The meaning of  $\alpha$  and  $\beta$  is reduced to a numeric form of the importance of the innovators and imitators for the process of diffusion. In practical usage they mainly are parameters, which have to be estimated from data of the previous periods, because experience and knowledge of the management, e.g. about the readiness to accept innovations, can't be transformed into concrete terms of  $\alpha$  and  $\beta$ . A Bass model filled up with historically estimated parameters does give a pretty good approximation of in reality observed patterns of diffusion: you get  $R^2$ -results, which are often situated near by 0.9 (Bass 1969).

The Bass formula is without any doubt very suitable to generate s-shaped, close-to-reality diffusion curves. But: this very simply structured and aggregated model is not suitable to answer a big part of the problems appearing in coherence of the process of diffusion. The answer to the question of the motif for the demander to buy the new product is rather unsatisfactory: it doesn't seem enough to assume that a small part buys it because of external influences, e.g. through the media, because of curiosity or as a status symbol, while the bigger part buys it because others have bought it earlier and social pressure for adoption was created. What influence advertising, price of the goods or their quality has in the process of diffusion and why these factors have their influence is not answered either. And further on, the division of the consumers in the Bass model into two groups, the innovators and the imitators, does not really match with real consumers and their various characteristics and behavior patterns.

Other authors do not put as much emphasis on the aspect of social pressure as a cause for imitative adoption, but stress the importance of communication for the diffusion of new products. Milling (1986) for example has derived the equation modeling the imitative buys with the help of combination theory and verifies it with the interaction between adopters and potential buyers.

The degree of explanation of the Bass formula has reached a much higher level by the efforts to interpret it as a model for the process of communication in-between the consumers. But some questions still remain unanswered and some points of criticism undisproved. For example, Böcker and Gierl (1988) criticize the assumption, that every buyer of a product necessarily appears as a sender of information, which has to be positive and say that this is not very close to reality. And further, some other for the progress of diffusion relevant relationships in communication like the "personal selling" or contacts in advertising can hardly be interpreted into the Bass formula.

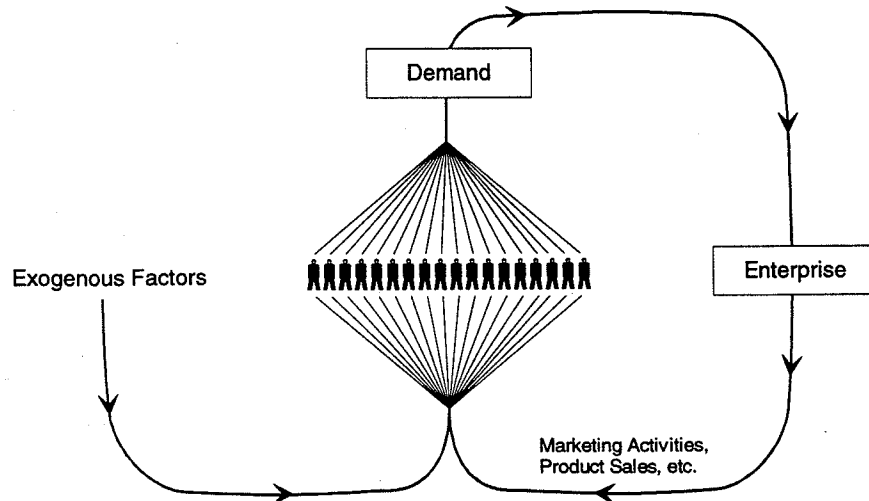


Figure 1: The Microanalytical Point of View

An aggregated macro-model as the one of Bass is only in a very limited way suited to explain the in reality very complicated process of the diffusion of new products in a social system. Deeper knowledge about the process of market and its influence on the diffusion of innovations cannot be derived from a macro point of view. The starting point of the Bass model, a homogenous buyer potential, has to be given up for an individualistic, microanalytic point of view as it is shown in Figure 1. This would put the single consumer into the center of research and would explain the influence of actions of the enterprises as well as of other exogenous and endogenous factors on the demand by their effect on the individual buyer.

### THE OBJECT-ORIENTED PICTURE OF THE PROCESS OF MARKET

Concerning the methods of microanalytic modeling of the process of market object-oriented techniques are just asking to be used, because using them makes it possible to create a very natural, direct picture of the real world. Not procedures or functions, not the single mathematical steps are the aim of simplification, but the protagonists, their attributes and actions are situated in the center of abstraction. The unity of characteristics and conduct of the objects is preserved. And, in addition, expanse as well as time is included in the process of modeling. It is illustrated as an area, in which the different in the process of diffusion involved objects are situated and move, meet and exchange information and innovative products (Figure 2).

After an intense analysis of the entire conduct of the market and its participants five basic classes of objects are found: enterprises, suppliers, consumers, products and (advertised) information.

Enterprises are complex organizations, which combine inside an extensive process of transformation input-factors into a product. They use the system of trade, symbolized by the class of the suppliers, to sell their goods in the market. An object of the suppliers presents the products of a producer, concludes bills of sale and completes transactions.

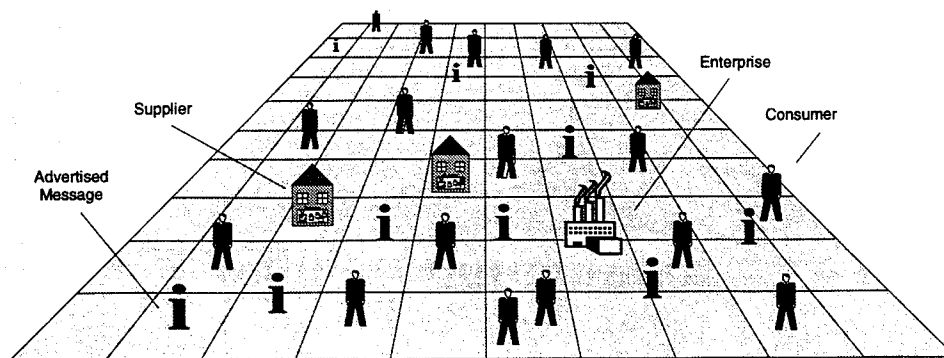


Figure 2: The Objects of a Market

Trade is usually said to have the following functions: the functions of space, time, quality, credit, stock and advertising. Even though the object "supplier" is very schematized in the market model, the most important of the mentioned trade functions can still be modeled. The products have to be offered to a demander in the way he wishes it concerning place, time and quantity. This is fulfilled in the model by spreading the suppliers geographically throughout the area of the market, and therefore reducing the distance in-between them. By offering several products the suppliers fulfill the function of stock, and by exhibiting products and by giving information about new products to the demanders they take part in advertising. Only the functions of quality and credit are not considered in the model.

The class of the consumers is too complex to be described in just a few words. It will be applied to in two own chapters, in which the individual process of adoption will be shown and the characteristics and relationships of communication between the consumers will be set out.

An industrial product, being an argument of offer and demand, of buying and selling, is distinguished at a high level of abstraction by the following basic characteristics: it has a producer and (proprietary) name, a level of quality, a limited duration and a price. The quality of a product is hard to find. A lot of factors influence the quality and therefore it is almost impossible to define exactly, what factors decide about the level of quality. Anyway one can try to make the quality of a product comparable by combining the most important factors into a quality index. Among these factors are for example the technical level of a product, its potential, the quality of workmanship, the design, the lifespan. In the model of the market is assumed, that all factors of quality can be combined into a general opinion about the quality and therefore make it possible to compare products in an objective, rational way. The price is a relatively easily and objectively found characteristic. In the model the producer is the deciding authority, the suppliers do not have any authority concerning the price. Therefore a world of price-obligation is portrayed.

Advertised messages of the enterprises are illustrated as objects of information about the products. Information itself though is immaterial. Anyone who wants to spread information has to use, e.g., advertisements in newspapers, posters, brochures or television or radio spots. The carriers of information are of a concrete character and can be found in ascertainable places. This is why information can have a geographical position in the model, even though it is abstracted from its carriers. And further, information has the characteristic of stimulation, which shows the effect of, e.g., a television-commercial or a poster has on the consumer.

### THE INDIVIDUAL DECISION TO ADOPT AS A BASIS FOR THE MODELING

A consumers' decision whether to buy or not to buy a new product is especially if it concerns expensive, technically superior and seldom bought goods not a spontaneous action, but it is a process, that is spread over a certain period of time and can be structured into several phases as shown in Figure 3 (Rogers 1983).

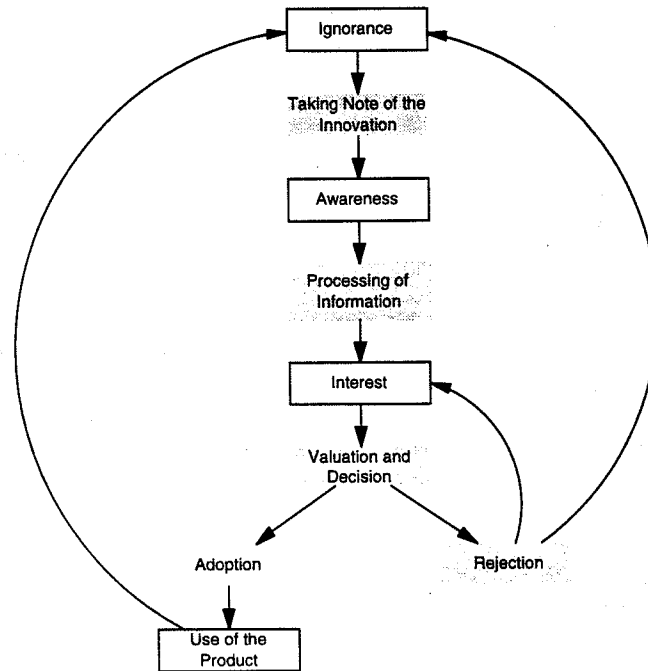


Figure 3: Adoption Cycle of a Single Consumer

In the beginning the consumer is in a state of ignorance; he does not know that a new product is offered to the market. He only gets to know about the innovation by advertisements, by seeing it in shops or window displays, or by recommendation of a buyer, who has bought it earlier. The first contact usually happens by chance and does not necessarily lead to a formation of opinion. But the consumer now knows about the product, and during the process of at first passive, later on active collect and cope with information he gets increasing interest in the innovation. As sources of information he has the messages of the advertising, exhibition and consult of the suppliers or personal recommendation of users. When the consumer discovers, that he would be able to solve an existing problem or would achieve an improvement of his situation with the help of the good, he enters the phase of evaluation. He evaluates the information about the efficiency and the price of the innovative product with the help of his own, personal utility function. If the usefulness of the new product surpasses his level of demand, he decides to adopt, else to reject.

In case of a positive decision to adopt the phase of acting begins: the consumer is willing to buy and wants to purchase the product from a supplier. If he finds or knows a supplier, he buys it and starts to use it. The phase of usage has its features in the experiences the adopter gains with the innovation: positively, if the product fulfills his expectations and does have the promised characteristics, negatively, if not. When the phase of usage begins, the cycle of adoption is finished. The circle closes, when the adopter gets to know about a new and even better generation of products.

If the new product doesn't fulfill the demands of the consumer, if it is too expensive or too low in quality, he doesn't buy and finds himself locked inside a never-ending succession, out of which he can only escape if quality or price or both change towards his wishes or he gets to know about

another innovation. If this does not happen, he never adopts and the potential of the market remains unoccupied.

### THE INFLUENCE OF COMMUNICATION ON THE PROGRESS OF DIFFUSION

Communication – defined as the exchange of information – is the initial as well as the drive for the process of diffusion. The interaction between the objects of the market creates incentive to buy and has influence on the extent and speed of the diffusion of new products. According to who asks whom personal and mass communication can be distinguished (Kroeber-Riel 1990). Personal communication happens between two persons and is called primary or direct communication. An important, maybe the decisive feature of personal interaction is the immediate information feedback. The sender receives the reaction of the receiver almost without any loss of time. This is not possible in mass communication.

Mass communication addresses the broad, anonymous audience. It uses the media (e.g., television, radio, newspapers) to carry information. A direct contact in-between the participants is not achieved, the immediate feedback is missing. This is the cause for the effect of mass communication not being easy to estimate. In addition, advertising in mass media often causes personal talks, in which the contents is picked up and discussed. One must not only assign a direct effect to mass communication, indirect effects, which come from the multiplication of communication in smaller groups, are not to be disregarded.

In the object-oriented model of diffusion both forms of communication are shown explicitly. The innovating enterprises advertise on the one hand actively in the media, on the other hand they use passively the adopters of their innovation as a source of information for other interested people. An object “information about a product“ has two kinds of functions: firstly it causes a stimulation for the potential buyer, and secondly it is used as a source of information about the advertised product. It is assumed, simplifying the situation, that one piece of information can only work in one single period. The enterprise therefore has to decide for every single period how extensively it wants to advertise and how much information it wants to have spread about its products.

The realization, that a human being is only capable of accepting and coping with a certain amount of information (thesis of information overload, Jacoby/Speller/Kohn 1974), is taken into consideration in the model by not having the demander stimulated every time he gets information. Only a certain part of the contacts is supposed to cause a reaction of the potential buyer.

Next to advertising in media another form of mass communication is implemented to the model: the effect of advertising by the distributor, e.g., by window displays. Not always there has to be personal contact between the seller and demander, more often the consumer passes by the shop than enters it, and he only glances, if he does, at the display. Not every geographical identity of demander and seller leads to an intense dialogue, this only happens, if the demander expressly wants to buy, if his demand has risen. However, even if this demand does not exist, it still might come to a to advertising similar stimulation of the potential buyer. It again is supposed that this only happens with a certain part of the potential buyers. Spontaneous purchase, which is made without thinking, is left out of consideration in the model.

Mass communication is inferior to personal communication by the means of efficiency and influencing. Two kinds are considered in the model: firstly the personal dialogue of suppliers and demanders and secondly the one of adopters and demanders. In reality the personal contact between seller and potential buyer often leads to adoption, in the model in every case the demander is willing to buy and the supplier has the product in stock. Direct mouth-to-mouth information is supposed to be

the most efficient and the trustworthiest. This is symbolized in the model by giving more value to an information given by an adopter than to one given by advertising or suppliers.

But in personal communication, too, not every personal meeting leads to an intense exchange of information. Determined by their personality, humans are different in their willingness to communicate. In the model, this willingness of adopter or demander is illustrated by a random variable, which shows the probability of communication.

Influence of the Enterprise	Communication Method	
	Mass Communication	Personal Communication
big	Advertising	
middle	Product – Buyer (Shop Window, Display, ...)	Seller – Buyer (Personal Selling)
small		Adopter – Buyer

Table 1: Communication Influencing the Diffusion Process

The kinds of communication shown in the model are once again summarized and structured in means of them being influenced by the management. While an enterprise can determine its advertising absolutely independently, it has only indirect influence on the other kinds of communication. It can decide where and, depending on the channel of distribution, how to present the innovation. The personal communication though it only can influence indirectly by the means of the factors price, quality and duration. Other possible forms like training of the sellers are not illustrated.

The effect of the forms of communication on every demander is different. Everyone judges information from advertising, of suppliers or former users in a different way, everyone has different preferences. These preferences, too, are illustrated by another random variable. A demander, who for example has a very low preference on advertising, shows almost no reaction on external influences, one, who prefers the recommendation of an adopter does not react more imitatively than one, who buys independently from the opinion of others.

### THE OBJECT-ORIENTED ANALYSIS MODEL

In Figure 4 you can see a graphic model of the action of the market. In it the most important attributes and methods of the classes and their objects are illustrated, as well as their system of relations, using the notation of Coad and Yourdon (1991).



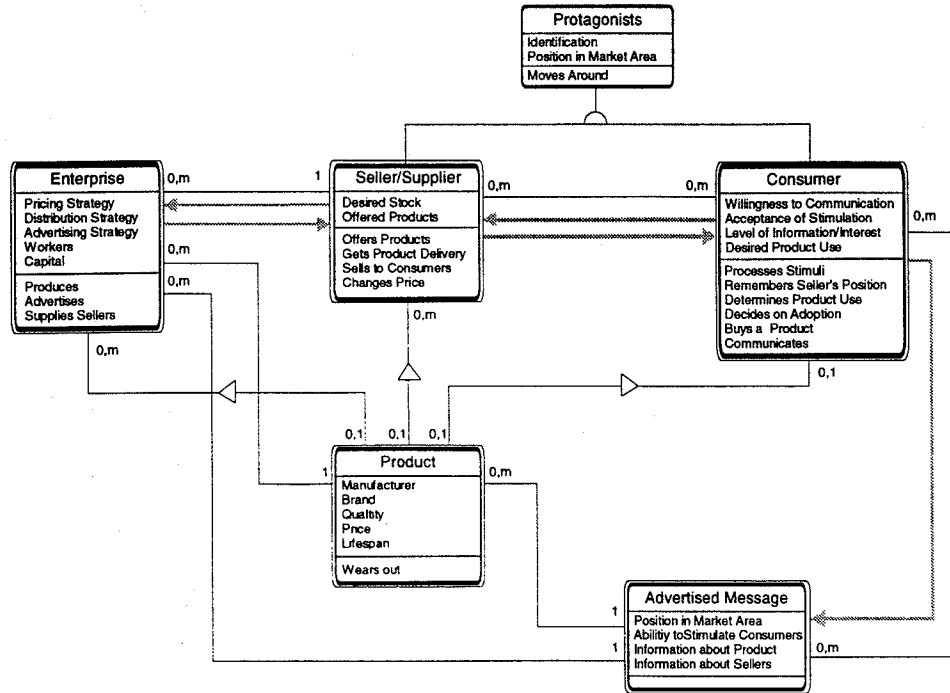


Figure 4: OOA-Model of Market Process

The thick gray arrows symbolize the exchange of information in-between the objects. To do this, the receiving object calls a method of the sending object. Three communication relationships can be found in Figure 4. An object of a consumer can receive advertised messages about the products, symbolized by the arrow between message and consumer. In addition, suppliers and consumers can communicate and, of course, enterprises and suppliers as well.

Relationships between the objects are shown by one straight line. Enterprises and suppliers have gotten a 0,m-1-relation, meaning: 0 up to m suppliers are assigned to an enterprise, vice versa one supplier can only sell the products of one single enterprise, the distribution of a product therefore can only be executed by producer-bound shops. This simplification of reality makes it easier to implement, but still is allowed, because there can be more than one shop at a place.

The object "product" is associated with the object "enterprise" and has beyond this a special feature: three so-called Whole-Part Structures (Coad and Yourdon 1991), which are marked in Figure 4 by triangles. Every product is produced by only one enterprise, and it is according to the situation either in stock at the enterprise, in the shop of the supplier or in usage of a consumer. It is assumed, that suppliers and enterprises can have none, just one or several pieces in stock, while consumers can own only one. Using a Whole-Part Structure it is shown, that one object is included in another, that there is a kind of an "is-part-of"-relationship between the objects. The special characteristic of this Whole-Part Structure in Figure 4 is that at a certain point in time only one of these "is-part-of"-relationships can exist: a product can only be owned by a consumer, a supplier or the producing enterprise.

The relationships consumer/supplier and consumer/message gives the information, that at a certain point in time, created by spatial proximity of the objects certain associations exist. 0 up to m suppliers can therefore be assigned to a consumer, who can contact all of them. The same is valid for the advertised messages.

The object-oriented model of Figure 4 was transformed into a working, object-orientedly programmed PASCAL-program to make it suitable for simulation. Finally the first rudiment results of a few simulations shall be introduced.

### THE SIMULATION OF THE MARKET

The correct-to-the-day-simulation of a market with 2500 consumers, 10 suppliers and 1000 advertised messages a period shows, that the model is able to generate curves of diffusion, which at least seem to be valid (Figure 5). An intense control of the validity of the model and especially of the needed parameters has not been made yet. The assumptions about the characteristics of the involved objects, which lead to the in Figure 5 outlined conduct, all lay open, are mostly founded on theoretical cognition and are ready to be checked individually. The curve is very similar to the one created by the Bass formula. But not being continuous and the fact that using the right magnification "stairs" would appear, does suit better to the empirically found diffusion curves than the straight lines of the Bass model.

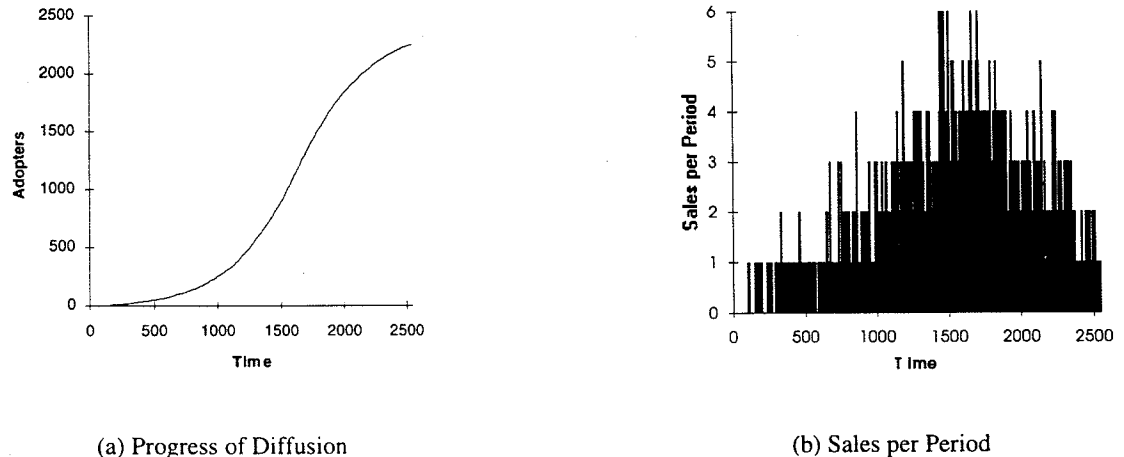


Figure 5: Results of Simulating the Model

The model explains the process of diffusion by the interaction of a number of influencing factors: communication is a main one, but added are actions and decisions of the enterprises concerning price, quality, duration and availability of the product, or the consumers and their characteristics, their willingness to communicate or their moral concepts. Being microanalytically and object-orientedly structured the model has the advantage of almost unlimited enlargement. Other variables, characteristics and methods can be rather easily integrated in the model.

Probably the main advantage of the microanalytic model is the much better ability to explain. Although in a widened Bass model the effects of changes in price on the sales could be examined and illustrated correctly, the behavioristic explanation would be missing. The outlined model is able to examine the effect of an action of advertising on the behavior of the consumer. Therefore it makes it possible not only to find qualified starting points for actions of the enterprises, but it gives in addition sound explanations for the effect of each action.

Finally we can memorize: It is possible to generate patterns of diffusion in the way they are observed in reality in a model, which puts the decision to buy of an individual buyer into the center of research and which ascertains explicitly the demand as an aggregate of these single buys. A model like this is

able to give a number of information and data about the conduct of diffusion, from which new knowledge can be won and behavioristically sound recommendations for the acting of a management can be given.

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