DIFFUSION OF INNOVATIONS
IN THE SYSTEMS THINKING APPROACH

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Abstract

This article presents the process of innovation diffusion in the context of Systems Thinking. The Bass diffusion model is built and converted into a computer simulation model with all variables defined in terms of the System Dynamics (stocks and flows). The computer simulation on the Bass' model confirms a typical for real-life innovations behaviour. Various initial assumptions and their impact upon the innovation diffusion are tested.

Key words: *diffusion of innovations, systems thinking, System Dynamics, computer simulation.*

Introduction

The ubiquitous market competition compels enterprises to create new products and technologies offering innovative character and enhanced usefulness that will be appreciated by the customers. We may assume that innovations are the basic factor of enterprise development. Diffusion of such innovations depends on different conditions, i.e. market capacity (absorptiveness) and quality and velocity of the information targeting potential customers. The holistic approach towards the process of diffusion of innovations is possible thanks to systems thinking. Its tools enable us to explore interrelationships between the factors determining such a process. The decision making process may be enhanced by the good use of those tools, especially in case of decisions about the actions supporting diffusion processes.

This article aims at presenting the Bass diffusion model in form of a simulation model, constructed according to the System Dynamics method, which is one of the systems thinking tools. It also offers the results analysis of the simulation modelling made using software for simulation of dynamic models - Vensim®, PLE version.

The essence of diffusion of innovations

In a broad sense, diffusion can be described as a physical spreading of a given phenomenon in a certain environment. This term is adopted by various sciences; thus, we may use it in physics as a spreading of some substance or matter; in anthropology, as a spreading of a given cultural pattern or an idea. In economics, diffusion is inextricably bound up with the spreading of an innovative product or technology in a human and organizational environment (Gomułka, 1990, p. 71). Moreover, the term 'innovation' may have different economic meanings, and most frequently it concerns (Szatkowski, 2001, p. 17-18):

1) launching into market new, yet unknown to the customers, goods or an improved version of such goods,
2) launching a new untried production method,
3) reaching a new market, where a given production branch was absent,
4) reorganization of production processes,
5) securing a new source of raw materials or semi-finished products.

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The research on diffusion of innovations most frequently focuses on the identification of factors, both hindering and facilitating the diffusion process, which influence its duration and range.

The most common models describing diffusion of innovations are: the Rogers model, the epidemic model and the Bass model. Rogers divided customers according to the rate of receipt (adoption) of new products or technologies in a time. The first group, called *innovators* (about 2.5 % of society), are the people who are not afraid of risk and willingly undertake ventures connected with innovations. The second group constitute *early adopters* (about 13.5% of society), who follow the innovators. The third group - *early majority* (about 34% of society) is driven by a strong feeling of practicality. The next, fourth, group - *late majority* (about 34%) is formed by so called innovation sceptics. The last group are *laggards* (about 16%), who employ innovation only when, after some time, it becomes indispensable or very common (Mahajan, Muller and Wind, 2000, p. 6). According to Rogers, the adoption curve during diffusion resembles regular pattern, which reveals certain stages in the process of adoption for particular customers groups, i.e. slow increase, acceleration, reaching the peak and slow decrease.

Another approach to diffusion of innovations is based on the theory of epidemic. People who acquired an innovation and who appreciated it, 'infect' others to acquire it. The mathematical model of the epidemiological theory takes the following assumptions: there should be a constant population (number of individuals prone to infection) during the whole process of diffusion; constant frequency of relations between infected and 'healthy' individuals (potential purchasers); constant - definite probability that the innovation will be transferred in case of a contact between infected and healthy individuals and the premise that we get infected only once (acquired innovation cannot be lost). The diffusion of innovations follows a logistic curve (Gomułka, 1990, p. 72).

The basic Bass model (1969) is a prevalent diffusion model in such fields as management and marketing. It is also used as a tool for new products forecasting. Diffusion process according to Bass may be described with the following equation:

$$dN(t)/dt = p[m-N(t)] + (q/m)N(t)[m-N(t)] \qquad (1)$$

where: $N(t)$ – cumulative number of purchasers at time t,
m – size of potential purchasers,
p – coefficient of innovation,
q – coefficient of imitation,

This equation assumes that diffusion of innovations may occur thanks to external communication channels, such as advertising, media reports or others and imitation effect, e.g. word of mouth.

Systems Thinking and Systems Dynamic method.

For a definition of systems thinking we may quote Senge (2006):

It is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "snapshots." It is a set of general principles—distilled over the course of the twentieth century, spanning fields as diverse as the physical and social sciences, engineering, and management. It is also a set of specific tools and techniques, originating in two threads: in "feedback" concepts of cybernetics and in "servomechanism" engineering theory dating back to the nineteenth

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century. During the last thirty years, these tools have been applied to understand a wide range of corporate, urban, regional, economic, political, ecological, and even physiological systems (p. 86).

In the light of such a definition, we may understand holistic systems thinking as a transition (Cempel, 2004):

1) from a part to the whole, bearing in mind the role of a part in the whole,
2) from system structure to its processes,
3) from objective to epistemic science (depending on the frame of reference),
4) from a concept of science as a "building" to a concept of "net" as a scientific metaphor,
5) from confirmed to approximate knowledge, as the next stage in approximation of reality perception,
6) from linear perception and implementation: *general sciences - applied sciences - development works - new process and product technologies*, to network interaction model, where each stage interacts with others,
7) from absolute truth to contextual statements that are locally true.

This means that systems thinking is directly connected with the notion of a system. A system can be defined as a set of interrelated parts (variables) isolated from the surrounding because of their connections. The system parts form its structure which is responsible for the behaviour of this system.

The basic principles of systems thinking are (Kauffman, 1980, p. 2ff):

1) every system is a subsystem of some larger system,
2) we are parts of some larger systems,
3) system structure is based on the network of feedbacks,
4) balancing feedbacks are responsible for the stability and balance in a system,
5) reinforcing feedbacks causes increase processes in a system,
6) complex systems behave anti-intuitively,
7) systems behaviour should be considered both in short and long time span.

The discipline of systems thinking aspires to comprehend and improve systems. During improvement processes, it is advantageous to use lever and reinforcement effects, i.e. ability to notice and locate actions and such changes in system structures which result in durable and essential effects (Meadows, 1999).

Systems thinking may cause many problems. Richmond (1996, p. 26) suggests that the reason for this phenomenon may be a cognitive overload, caused by the current process of school education, which focuses more on a teacher rather than students and their creative discovering of knowledge. He also points out that in systems thinking, it is indispensable to operate on seven categories of thinking. The first category is *closed-loop thinking*, which consists in perceiving a system as a set of continuous, mutually dependent processes, not a unidirectional relationship between a group of coefficients and a phenomenon that is caused by them. Such thinking informs us that we are a part of the system and that we are responsible for its behaviour. The second category is *dynamic thinking*, which is connected with the accurate interpretation of a system structure in context of given behaviour patterns or their combinations. It is aimed at understanding and analysing such behaviours in time for particular coefficients making up the system. It cannot be identical to the behaviour forecasting. It rather should be enhanced by tracking behaviour patterns that change in time and by considering the processes as closed-loops that, while following cyclical pattern, trigger specific events. The next category is *generic thinking*, which demands the ability to notice in

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a system both general and particular information responsible for its behaviour. It enables the proper response to a challenge of complexity and variability. The fourth category is *structural thinking*, which is responsible for determining basic feedbacks between variables that illustrate the cause and effect chain in a system, and for presenting them in form of casual loop diagrams. Without feedback analysis we cannot understand system behaviour, not to mention intentional influencing it. It represents thinking in terms of units of measurement, assigned to particular variables in a system. The fifth type of thinking is *operational thinking*, closely bound up with structural thinking. It assumes real reflection of actions, information flow and interrelationships in a system, without theoretical aspects and forecasting. The sixth category is *continuum thinking,* which is an expansion of generic thinking and is most frequently used for simulation modelling of a system. It determines the ability to select variables making up a given system which constitute logical function of other variables. It combines relations and correlations between variables. The last category of thinking is *scientific thinking* which allows quantification of processes and phenomena in systems. Yet its main role consists in formulating and testing hypotheses concerning system modelling processes and examining models' correctness (Richmond, 1996, pp. 34-43).

The System Dynamics method is directly connected with systems thinking. This method was devised by J. W. Forrester at the end of 1950s in Boston, at the MIT Sloan School of Management. The basis for the analysis in System Dynamics is a mental model which becomes a casual loop diagram. The diagrams lead to a formal system model, which is constructed according to traditional management theories, employing the laws of cybernetics and computer simulation.

Traditional management facilitates the identification of a problem that is subject to system modelling, the selection of variables influencing the examined problem and considering information flow between these variables. The variables are in descriptive form that appears in minds of people modelling and in reports, statements, etc. They may also occur as numeric data, i.e. quantitative data for the examined system (Kwaśnicki, 1998, p. 9). The main drawback of the traditional management is the lack of ability to detect holistic system behaviour.

Cybernetics, relying on the feedback theory, puts an emphasis on dynamic relations between variables, exploring their interrelated behaviour and variability. It helps discerning significant and insignificant information, and then it facilitates its structuralization and formalization in the mathematical models. Solution of such models (often consisting of non-linear relations) demands proper numerical method, which, in case of System Dynamics, is computer simulation. It allows to examine inter-correlations of variables in a ready-made model and to forecast their behaviour in the future.

The core of this method is the research on behaviours of whole systems as well as of their particular parts. The most frequent behaviours distinctive for systems are: exponential growth, goal seeking, oscillation, S-shaped growth and S-shaped growth with overshoot.

The Bass diffusion model with dynamic variables

Systems models represented with the System Dynamics method consist of three types of variables:

1) stocks - describing a condition of a given system and generating information for all decisions and actions,
2) flows - directly influencing the value of stock variables,
3) auxiliary variables- which link with one another using informational bonds allowing to determine unambiguously the cause and effect direction in a system.

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They complete the full system image and indicate the importance of its components.

Therefore, taking into consideration the requirements of this method, we may present the Bass diffusion model as follows (Figure 1):

Figure 1. Dynamic Bass Model.
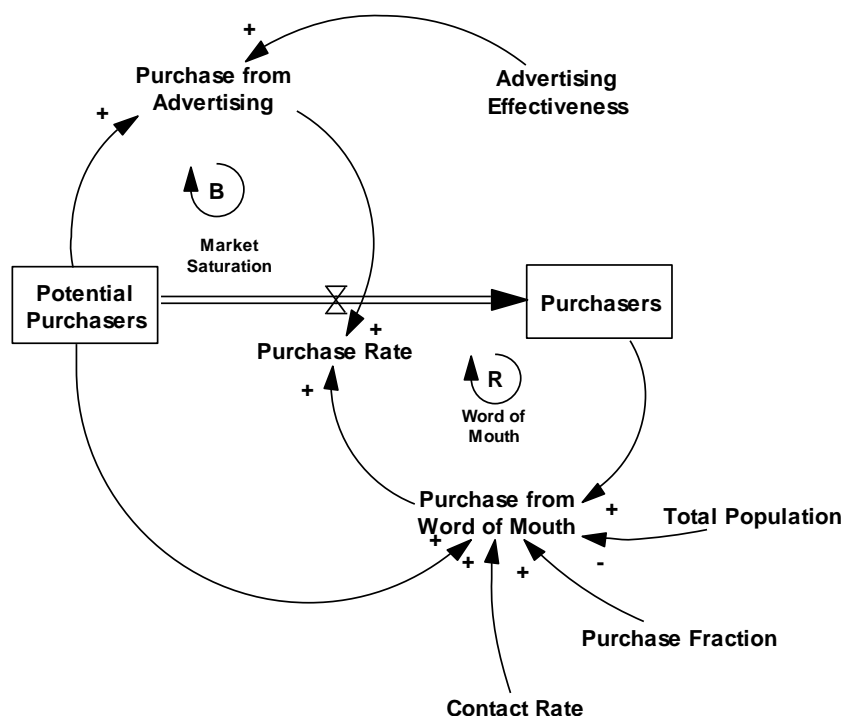
Source: Author`s elaboration on the basis of Sterman (2000, p. 333).

The model consists in two stocks: *Potential Purchasers* and *Purchasers*. *Purchasers* variable is increased by *Purchase Rate* flow, being the total of such auxiliary variables as: *Purchase from Advertising* and *Purchase from Word of Mouth*. *Purchase from Advertising* variable is influenced by *Potential Purchasers* variable and *Advertising Effectiveness* constant. *Purchase from Word of Mouth* variable consists of *Purchasers* variable and the following constants: *Total Population, Contact Rate* and *Purchase Fraction*.

In the model, there are two typical feedbacks: reinforcing feedback consisting of such variables as: *Purchasers → Purchase from Word of Mouth → Purchase Rate → Purchasers* and balancing feedback consisting of the following variables: *Potential Purchasers → Purchase from Advertising → Purchase Rate*.

The variables are linked according to the following mathematical equations:

Potential Purchasers = INTEG (-*Purchase Rate*, *Total Population – Purchasers*)   (2)
    Units: Persons.

Purchasers = INTEG (*Purchase Rate*,0)   (3)
    Units: Persons.

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Purchase Rate = Purchase from Advertising + Purchase from Word of Mouth (4)
    Units: Persons/Year.

*Purchase from Advertising = Advertising Effectiveness * Potential Purchasers* (5)
    Units: Persons/Year.

*Purchase from Word of Mouth = Contact Rate * Purchase Fraction **
Potential Purchasers * (*Purchasers / Total Population*) (6)
    Units: Persons/Year.

Simulation on the Bass model

For simulation purposes, let us consider the example of the sale of second-generation IBM mainframes (transistor-based), in the years 1960-1978. The quantitative sales amount was presented below (Figure 2).

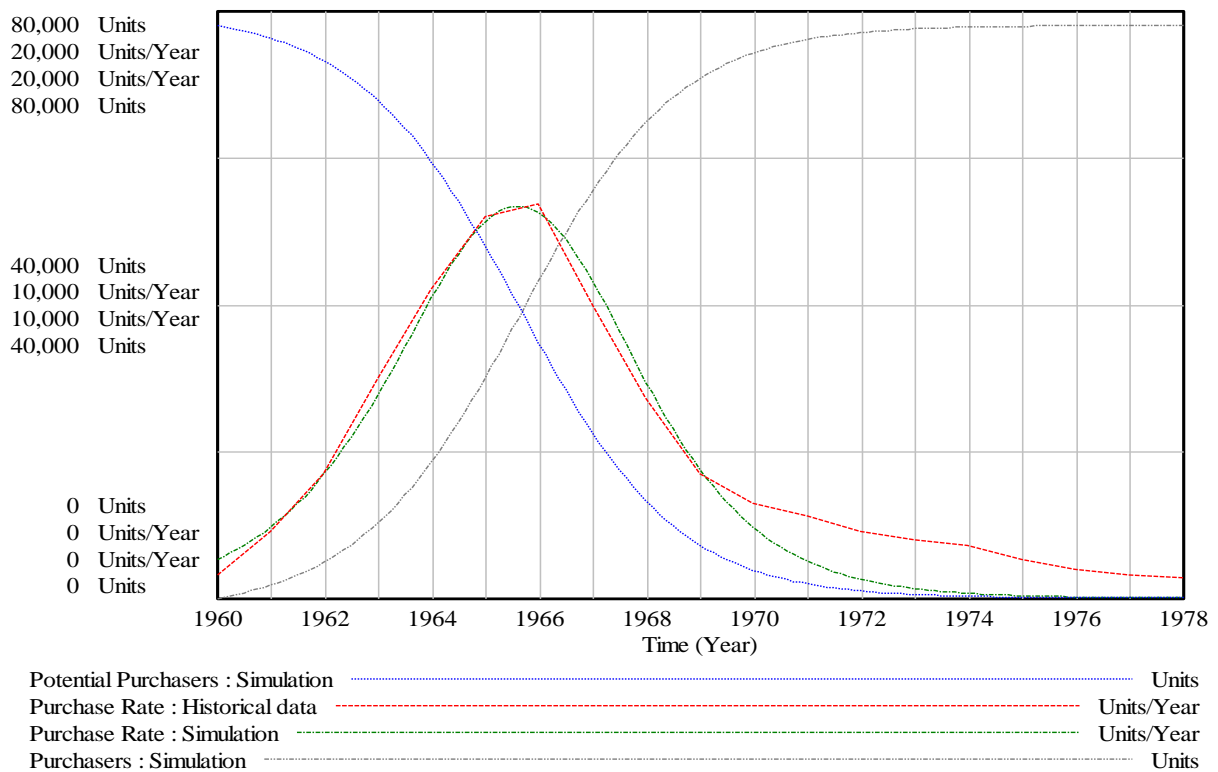**Figure 2. Sales of second-generation IBM mainframe.**
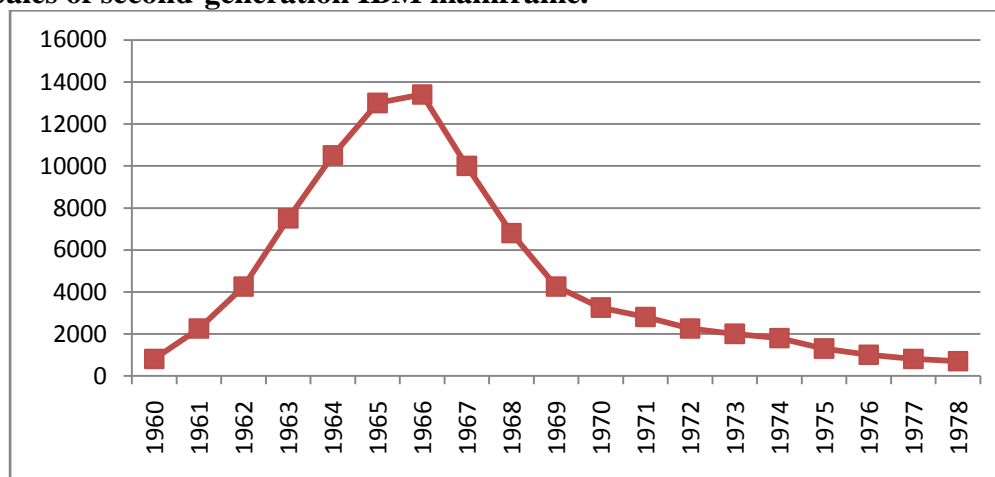
Source: Author`s elaboration on the basis of Mahajan and others (2000).

If we assume that: *Total Population* = 78000; *Purchase Fraction* = 0,0013; *Contact Rate* = 500; *Advertising Effectiveness* = 0,017 and if we set simulation step 0,125; we obtain the simulation results which are presented in Figure 3.

After the analysis of the showed results, we can notice that while the number of *Potential Purchasers* decreases, the number of *Purchasers,* who initially learn about the innovation from external sources, in this case from the advertisement, and then from internal sources, i.e. word of mouth, increases. In the early stage, when *Purchasers* curve grows, up to the intersection with *Potential Purchasers* curve, *Purchasers* variable value increases are growing. In the same time, sales value, described by *Purchase Rate* variable increases as well. *Purchase Rate* reaches its maximum in the second half of 1965, which coincides with the numbers of *Potential Purchasers* and *Purchasers* being equal. After this time, the increases of *Purchasers* curve are diminishing. It is caused by the fact that after 1965, the *Potential Purchasers* values are lower than the values of *Purchasers* variable and less *Potential Purchasers* "switch" to *Purchasers* (the reserves of *Potential Purchasers* stocks decrease slower and slower to the complete depletion). *Purchasers* curve becomes a logistic curve, typical for diffusion of innovations.

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Figure 3. Behaviour of the Bass Model selected variables.
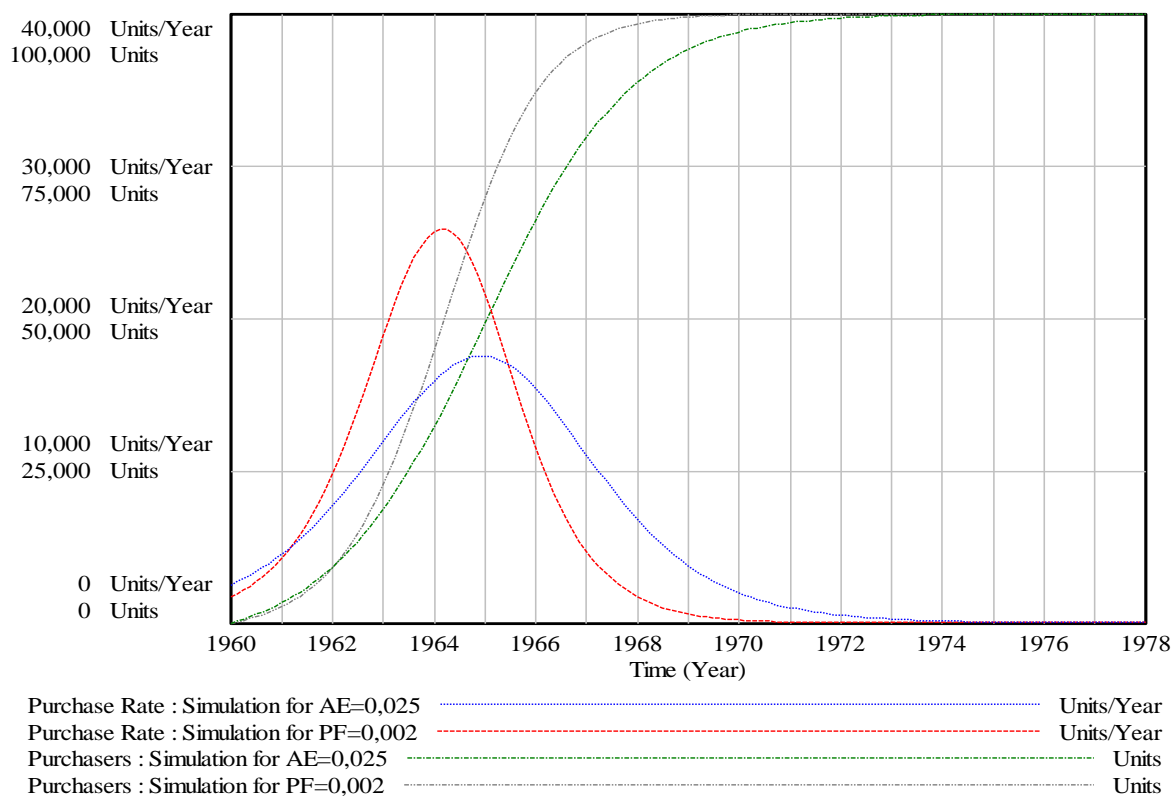

Source: Author`s elaboration (Vensim® PLE).

While comparing sales values presented by *Purchase Rate* simulation curve with historical data, we may claim that they are almost identical, except for the years 1969-1978, when the simulation curve has lower values than the real one. It results from the model structure, which determines *Purchase Rate* curve behaviour according to the bell curve.

One of the opportunities of the computer – based simulation and modelling is the fact that we can change the initial assumption and examine different simulation results. Therefore, we may see what the sale of the second-generation IBM mainframes would be, if we changed the following values:

1) *Total Population* = 100000; *Advertising Effectiveness* (AE) = 0,025;
2) *Total Population* = 100000*; Advertising Effectiveness* (AE) = 0,017; *Purchase Fraction* (PF) = 0,002.

We obtained the following simulation results (Figure 4):

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Figure 4. Simulation results with changed coefficient values.

Source: Author`s elaboration (Vensim® PLE).

The obtained results indicate that in the first case, when the *Advertising Effectiveness* constant was increased, IBM mainframes sale would have reached the maximum in 1965, amounting to 17500 units, and the market would have become saturated already in 1972. The second case illustrates even faster diffusion of the innovated product, thanks to the increase of *Purchase Fraction* constant. Thus, the maximum sales value (equalling about 23000 units) would have fallen on the beginning of 1964, and the market would have become saturated in the first half of 1969.

Conclusions

Systems thinking tools enable us to have an insight into interactions between particular variables forming a given system. In case of the Bass diffusion model, they allow to discover the dynamics resulting from quantitative transition of customers from Potential Purchasers to Purchasers level. That is possible due to the observation of the first, external factor, i.e. the advertisement (which is responsible for diffusion of innovations) and the gradually appearing second - internal factor, i.e. word of mouth. The above presented model is very general and it concerns the basic diffusion of the innovations model introduced by Bass in 1969. It ignores such factors as: innovation price, possibility of repeat innovation purchase and range of minimum expenditure indispensable for the realisation of innovation. Undoubtedly, taking the above parameters into consideration would result in more reliable research on diffusion of certain innovation. That would provide an invaluable clue for the strategic plans prepared by the enterprises.

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Abstrakt

*Powyższy artykuł przedstawia proces dyfuzji innowacji w kontekście myślenia systemowego. Model dyfuzji Bassa
pokazany jest w formie modelu symulacyjnego, zawierającego w swojej budowie dynamiczne zmienne, takie jak:
zmienne akumulacyjne i zmienne przepływowe. Komputerowa symulacja przedstawionego modelu potwierdza
charakterystyczne zachowania poszczególnych zmiennych modelu w czasie oraz bada ich zmianę w odpowiedzi
na przyjmowane różne założenia początkowe.*

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