Technology Forecasting: From Emotional to Empirical

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Technology Forecasting has evolved from being a methodology based on emotional responses to one predicated on data collection. The Theory of Inventive Problem Solving (TRIZ) is a theory based on empirical data that relates technological evolution to the same stages of biological macro-evolution. This paper will explore the major emotional forecasting methods as well as discuss part of TRIZ Technology Forecasting called Maturity Mapping. The reader will briefly be introduced to eight evolutionary trends based on TRIZ.

"Technology forecasting may be defined as the prediction of the invention, characteristics, dimensions, or performance of a machine serving some useful purpose... The qualities sought for the methods of prediction are explicitness, quantitative expression, reproducibility of results, and derivation on a logical basis. The difference between technological forecasting and speculation, then, lie primarily in the attempts of the forecaster to achieve precision in the description of the useful machine whose characteristics he is forecasting and in his attempts to place the forecast on a sound scientific foundation through the use of logical and explicit methods. A well-done forecast will state the predicted characteristics of the machine being forecast and make clear the means by which the forecast was arrived at"

– Ralph Lenz, Technology forecasting pioneer from the U.S. Air Force (Martino, 1969)

Introduction

Making strategic decisions for product development is one of the most difficult challenges the Research and Development staff of an organization. Deciding between the optimization of existing technologies or the development of a new core technology is one of them. There is a high uncertainty related to these decisions and although many decision tools are available and have been implemented successfully to various degrees, the decision-maker's intuition is sometimes the only element for directing the company's line of development. TRIZ, the Russian acronym for Theory of Inventive Problem Solving, is emerging as a powerful scientific tool that helps decision-makers to make these strategic forecasting decisions.

Assessment of a company's current technology should drive the direction of the R&D planning process. Ellen Domb suggests that "people tend to do an initial assessment of their product maturity based on their emotional state. If people are excited they will place their product in the 'growth stage' but if they are frustrated – maybe because of technical or physical contradictions – they will place it in the maturity stage" (Cowley & Domb, 1997). There needs to be a systematic process for assessing technology (Gahide et al., 2000).

Before discussing the technological maturity (and some forecasting) of self-heating container technologies, let us review several non-TRIZ forecasting methods:

a. Intuitive Forecasts
b. Consensus Methods
c. Delphi Method
d. Application of a Statistical Model
e. Application of a Causal Model
f. Analogy Method
g. Extrapolation
h. Structural Modeling
i. TRIZ based Technology Forecasting

Technology Forecasting Methods

Intuitive Forecasting

Intuitive forecasting is a very popular and widely applied methodology. "Asking the expert" usually provides the information for the forecast. It is assumed that the experts' base of experience and education is sufficient, in a particular field, to predict or forecast the vectors of expansion or evaluation. Records indicate the pronounced fallibility of this forecasting method. Arthur C. Clarke, in *Profiles of the Future*, describes some false predictions based on the "expert" intuitive forecasting by unquestioned authorities – in 1956, the Royal British Astronomical Society predicted that "space travel is utter bilge" (Clark, 1962). American errors utilizing this method are so prevalent that a special volume of them was compiled: "Erroneous Predictions and Negative Comments: Exploration, Territorial Expansion, Scientific and Technological Development" (Martino, 1969; Routio, 1996).

Consensus Method

A simple method of overcoming some of the disadvantage of intuitive forecasting is the use of a "panel of experts". The presumption is that many experts are more likely to be accurate than one. The Department of Defense has used this method successfully in the past (and probably the present as well). The U.S. Air Forces Project Forecast is an example of a large and successful application of the consensus method. Of course, the shortcomings of the intuitive method could also be compounded during the application of the consensus method (the possibility of a hidden bias being cancelled by a hidden counter-bias may in fact not materialize).

Delphi Method

To improve on the intuitive and consensus methods, the Rand Corporation developed the "Delphi Procedure," in which a panel of experts (like the consensus method) arrive at a consensus but, eliminating the regulating of committee bias by employing a series of questionnaires. The first phase asks for the panels' forecasts. The replies are compounded. The second phase requests comments on the Phase I compound forecast. Phase III is a derivative of Phase I based on the results of Phase II. A typical process might include five or six phases. A forecast convergence is the goal of this multi-phase process. Figure 1 shows the convergence of a hypothetical date for a certain even based on a multi-phase Delphi process.

Application of a Statistical Model

A statistical model is based on a series of observations on the phenomenon, and it delineates the pattern of the association

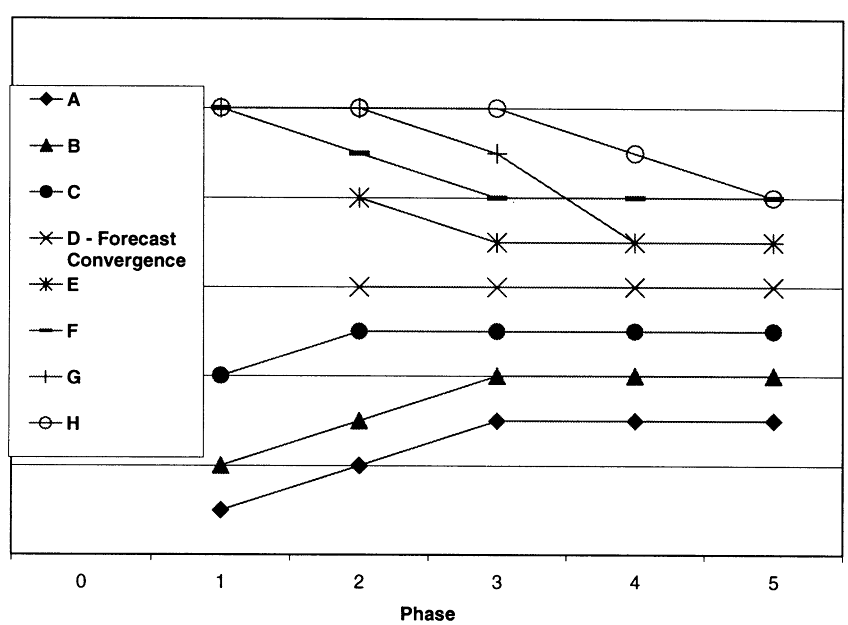

Figure 1. Delphi Forecasting Convergence Example (A, B, C, E, F, G, and H represent panel members). Notice that as the panel of experts forecast phase-by-phase that the data converges.

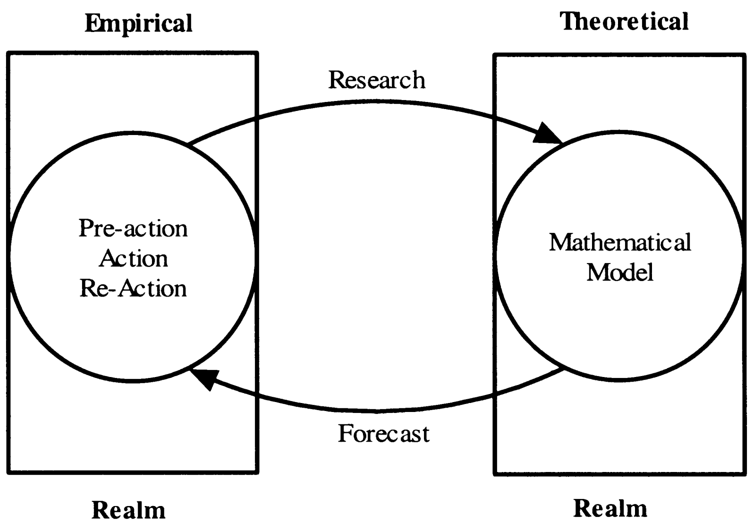

Figure 2. The Method of Prediction on the basis of a Descriptive Model

between the various factors or variables of the phenomenon that are of interest. Descriptive models that are used in forecasting are often quantitative, but qualitative ones are used as well. Figure 2 indicates the method of prediction on the basis of a descriptive model. Many events, such as descriptive phenomenon, are single occasion events and as such they are a difficult phenomenon to model. Therefore, the application of a statistical model necessitates a thorough understanding – lengthening the forecasting process.

Application of a Causal Model

A causal model is similar to a statistical model as it also describes, through research, the development of a phenomenon to be predicted. It is an improvement on the statistical model as it also provides the causative agent(s) for the occurrence of the phenomenon to be predicted. An understanding of the invariance of the phenomenon gives the forecaster good grounds for forecasting as this invariance is conjectured to remain valid into the future. A causal model is normally based on a population and is therefore valid only in that context. A causal model limitation of concern is the necessity to assume uniformitarianism (invariance as a function of time).

A famous example of a large causal model was fabricated by the so-called Club of Rome in 1972. This model, published in the book *The Limits to Growth*, consists of dozens of variables, including the world population, birth rate, industrial and agricultural production, the non-renewable resources, and pollution. In the model, the levels, or physical quantities which can be measured directly, were indicated with rectangles, rates that influence those levels with valves, and auxiliary variables that influence the rate equations with circles. Time delays were indicated by sections within rectangles. Real flows of people, goods, money, etc. were shown by solid arrows and causal relationships with broken arrows. Clouds represent sources or "sinks" (exits of material) that are not important to the model behavior.

The Club of Rome started building their "World Model" by first constructing five sub-models. These concentrated on the five "basic quantities": population, capital, food, non-renewable resources remaining (measured as now remaining fractions of the 1900 reserves), and pollution. One of the sub-systems included the causal relations and feedback loops between population, capital, agriculture, and pollution. Finally, the researchers combined all the five sub-models and thus created the final World Model, part of which is illustrated in figure 3.

Analogy Method

This method utilizes analogies between the phenomenon to be forecast and some historical event or popular physical or biological process. To the extent that the analogy is valid (all analogies become invalid at a certain level), the initial event or process can be used to wake a prediction about future developments of a technology (see Figure 5). The technological forecaster uses the analogy method consciously and deliberately, examining the model situation and the situation to be forecast in considerable detail to determine

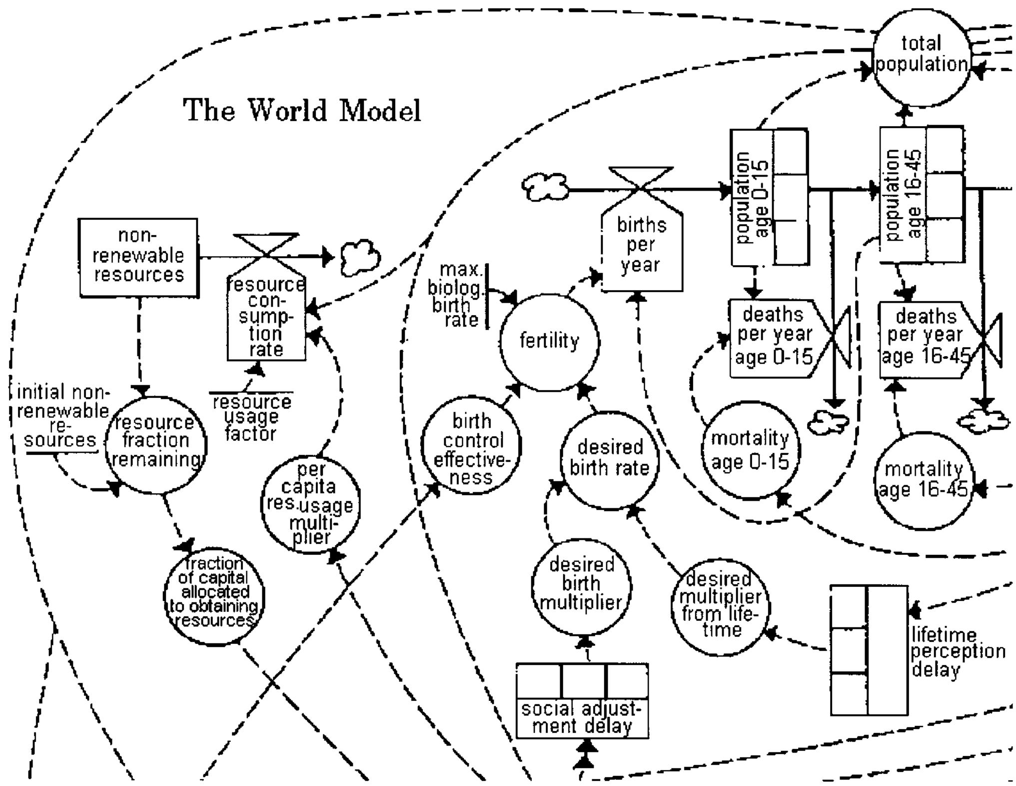

Figure 3. The World Model. (Routio, 1996)

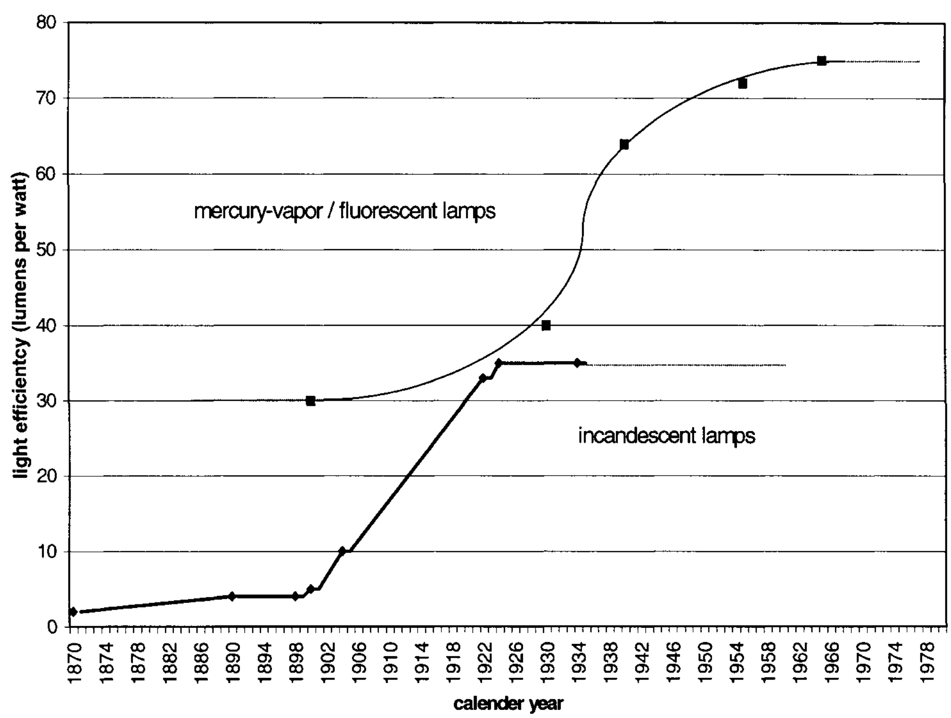

Figure 4. Growth Curves. (Martino, 1969)

the extent to which the analogy is valid. An example of this approach is delineated in the book, *The Railroads and the Space Program: An Exploration in Historical Analogy**. The forecasters used 19th century railroad development as an analogous system to the U.S. space program. The utilization of growth curves is used to predict the advance of some technologies (analogous to biological or physical processes – the "'S" curve, see Figure 4):

Extrapolation Method

Trend extrapolation is one particular method of solving the prediction of the inflection problem associated with the "S" curve of the analogy method (when is the curve going to change slope, B). Instead of focusing on a single device and attempting to predict the future course of development of that device, the trend extrapolation method considers a series of sucessive devices while performed similar functions. These may be considered individual representations of a broad area of technology (see Figure 6). The extrapolated trend will eventually reach a physical limit and will loose its validity as the trend approaches this physical limit.

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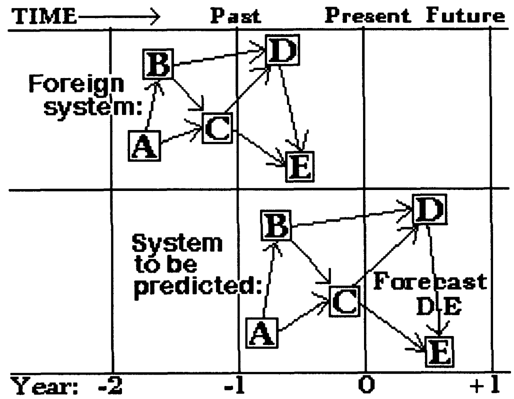


Figure 5. Predicting the Development of a Technology. If a foreign system consisting of elements A, B, and C produces elements D and E, an analagous system with elements A′, B′, and C′ can be predicted to produce elements D′ and E′, where A′, B′, C′, D′, and E′ are elements in the system to be predicted.

Structural Modeling

Structural modeling is an attempt to develop a mathematical or analytical model of a technology-generation process. As with mathematical model of any process the purpose for model construction is to identify certain key elements, identify the functional aspects of those elements, and express these functional aspects symbolically or mathematically.

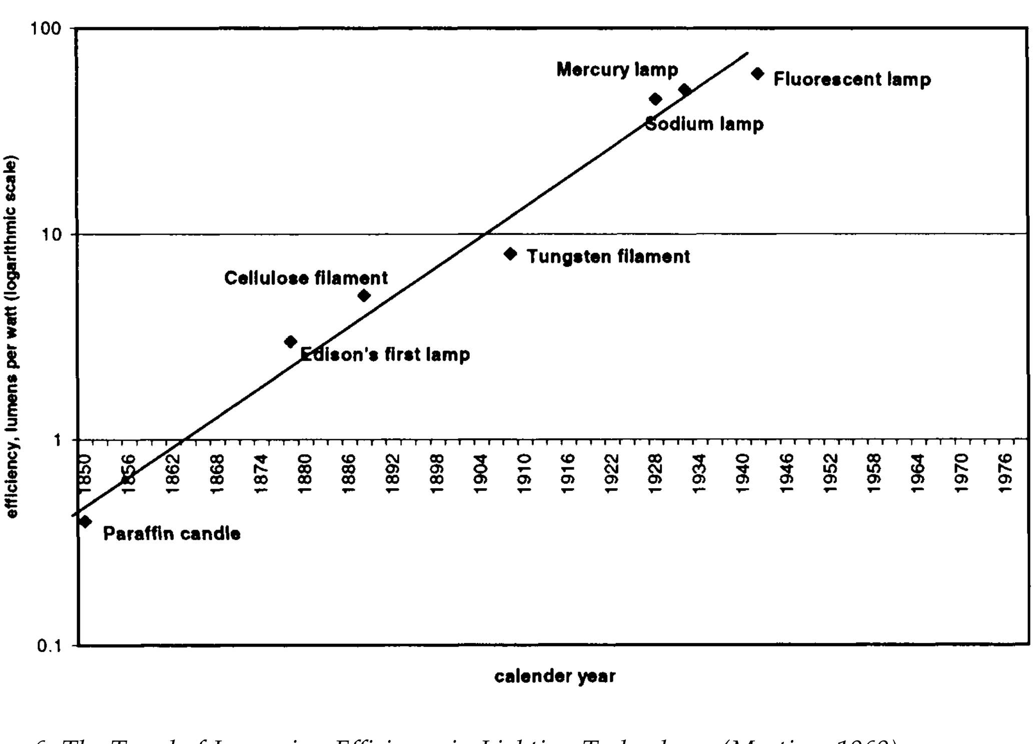


Figure 6. The Trend of Increasing Efficiency in Lighting Technology. (Martino, 1969)

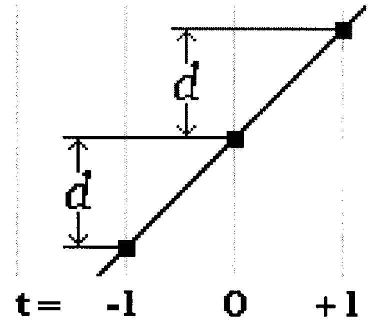


Figure 7. A measurement, d is measured between t=-1 and t=0, that d can be applied to t=1 to extrapolate the trend value at time t=1. This can be applied to t=any time as long as the trend value does not violate a physical limit. (Routio, 1996)

Structural models tend to be abstract and reductionistic in their approach in removing what are denied to be non-essential functions (see Figure 8).

TRIZ Technology Forecasting

Altschuller found that any system is evolving in a biological pattern, meaning that it will go through four main stages also known as: infancy, growth, maturity, and decline. These stages are plotted on the biological "S-Curve" on Figures 9a and 9b.

Three main descriptors are used to assess the life cycle stage (or technological maturity) of a technological system on its S-curve.

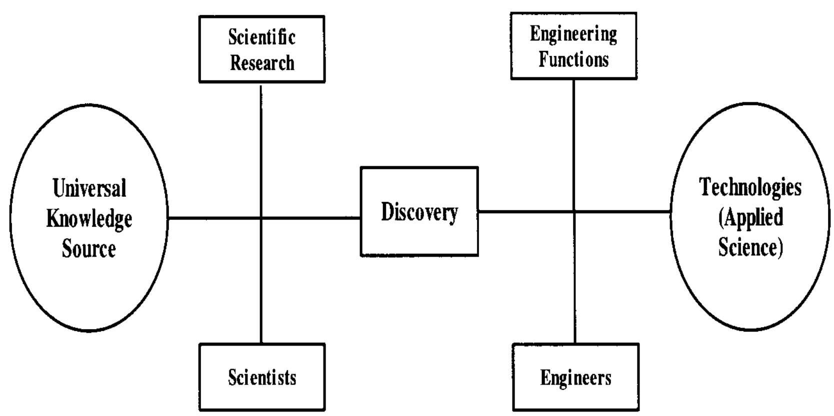


Figure 8. Structural Model of the Technology-generation Process (Each Block Conceals a Sub-model).

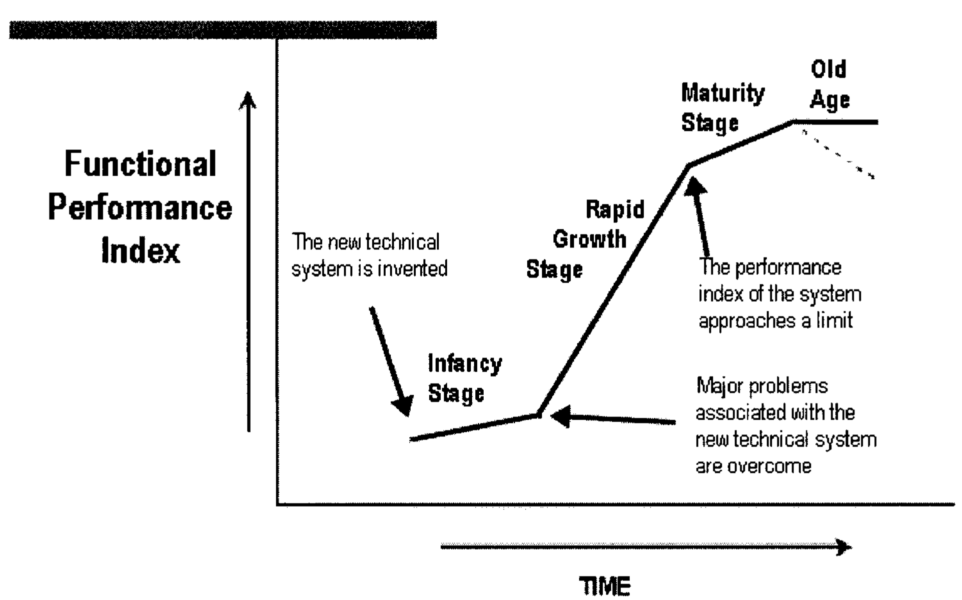
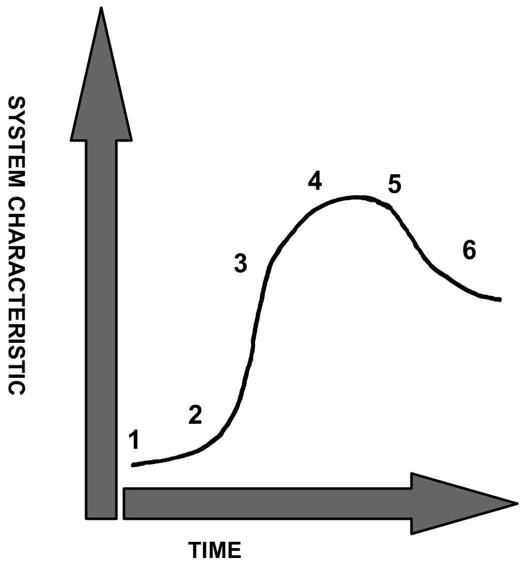


Figure 9a. System Evolution. (Gahide et al., 2000; Gibson et al., 1999; Slocum, 1999; Slocum et al., 1999; Slocum, 1998)



Stage 1 – pregnancy, a system does not yet exist but important conditions for its emergence are developing.

Stage 2 – birth, a new system appears due to a high-level invention and begins developing slowly.

Stage 3 – childhood, begins when society recognizes the value of the new system.

Stage 5 – adolescence, begins when the resources on which the original system is based are mostly exhausted.

Stage 5 – maturity begins when a new system (or the next generation of the current system) emerges to replace the existing one.

Stage 6 – decline, begins if the new system does not completely replace the existing system, which still has limited application.

Figure 9b. System Evolution. (Slocum, 1999; Gahide, 1999)

They are:

1) the number of patents per time period
2) the level of innovation per time period
3) technical performance per time period

Each descriptor has a characteristics profile or shape as shown in Figure 10.

The company can collect data to construct each of the descriptor curves. The shapes of each of the descriptor curves are compared with the shapes of the characteristic curves. A composite analysis of the three curves provides a data-driven assessment of the maturity of the company's technological system.

Other descriptors are sometime used to refine the maturity of a system such as cost reduction-related inventions. Darrell Mann defined "cost reduction-related inventions" as inventions that relate to making the product cheaper – such as improvements to manufacturing technology or method of assembly. The number of such inventions

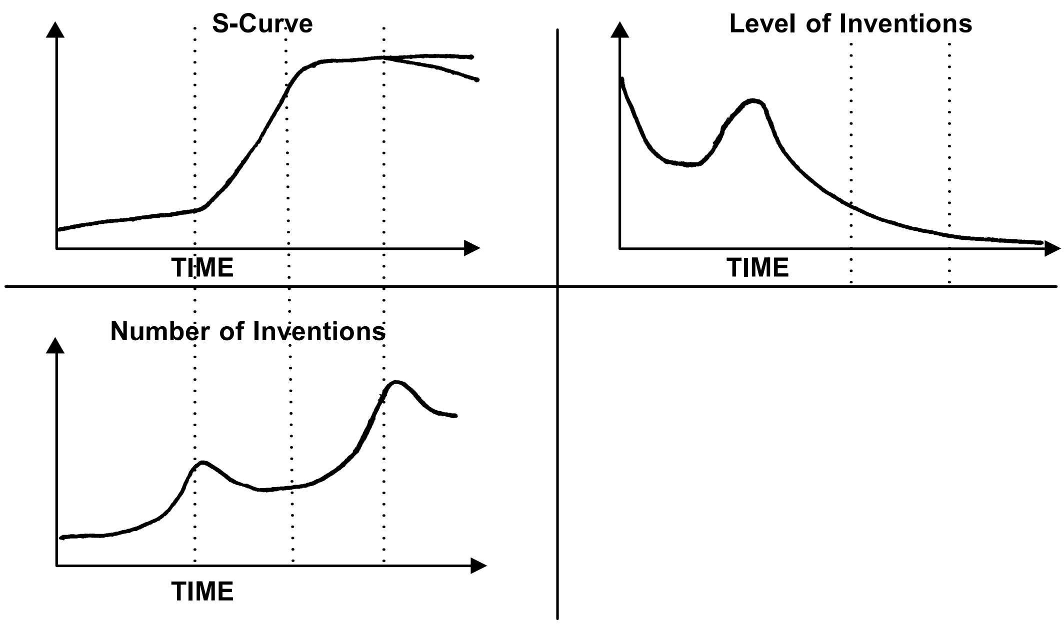


Figure 10. Descriptor Characteristics Profiles. (Slocum, 1999)

tends to increase as the system matures, as Figure 10 shows.

Patterns of Evolution

Patterns of evolution represent a compilation of trends that document strong, historically recurring tendencies in the development of manmade or natural systems (seen in the intellectual literature or the historical evolution of products). The eight fundamental trends will be presented below (these trends are the main tools for technology forecasting).

Altshuller identified eight original trends. The eight original trends are:

1) biological evolution,
2) increasing ideality,
3) evolution toward dynamization and controllability,
4) complexity-simplicity,
5) evolution with matching and mismatching elements,
6) non-uniform development,
7) evolution toward micro-level and the use of field, and
8) decrease human involvement. (Attshuller, 1984; Savronsky, 2000; Terninko et al., 1998; Slocum & Clapp)

Several books and papers have been published that describe these patterns as well as algorithms for applying data-based technology forecasting and directed product evolution.

Systematically applying the patterns of evolution to a company's technological system will result in a number of possible solution paths. The solutions or directions recommended by one trend are not unique as they often overlap one onto another. Once a company has generated multiple solution paths, management decisions can be made to develop the R&D plan for the company.

Self-heating container technology (see figure 11) has had patent activity starting from 1976. The patent activity during the ensuing 23 years has been varied and non-consistent. These particularities make self-heating technology an ideal candidate for maturity mapping. Data was collected relevant to the technology that would provide necessary information to create the required graphs represented in figure 10. The search criteria was devised using Boolean operators selected to insure

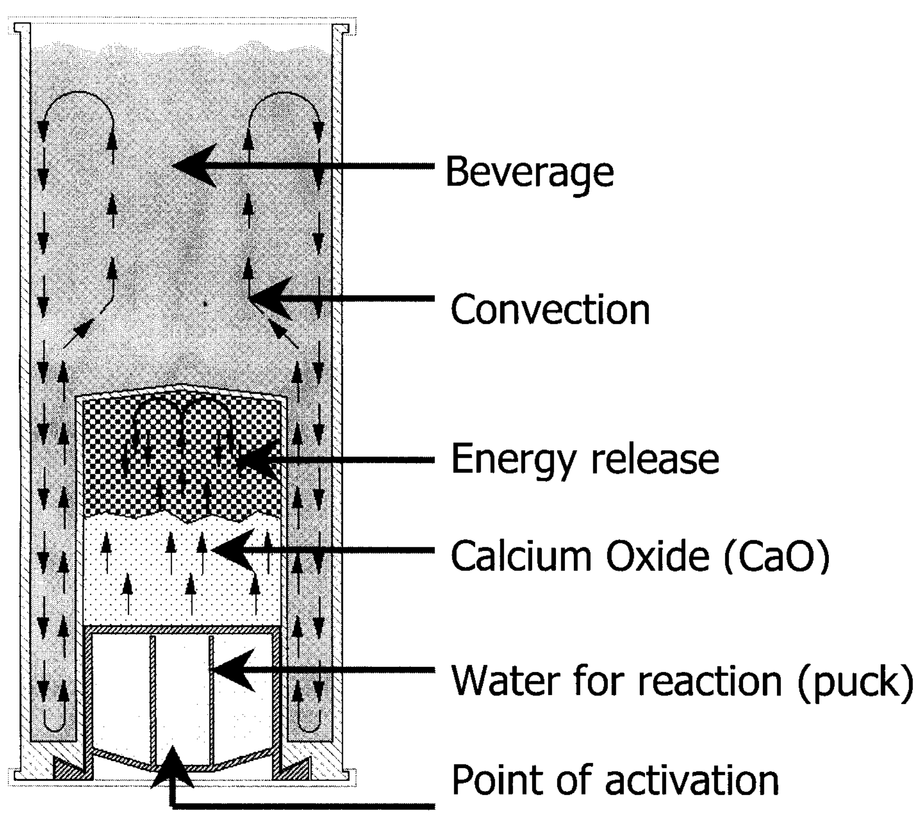
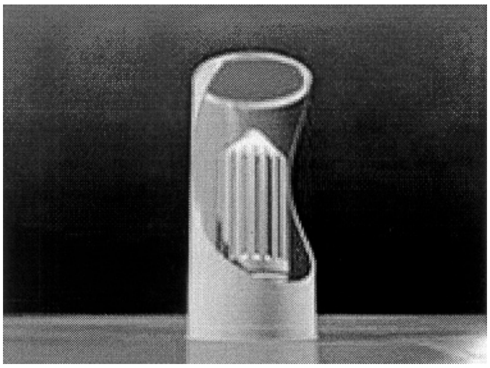
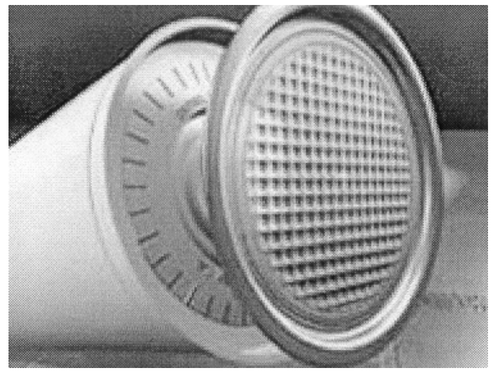


Figure 11. Diagram of the Ontro Self-heating Container. (Slocum & Lundberg, 2001)

capture of relevant and associated self-heating technologies. The abstracts were then reviewed for relevancy and the database was modified accordingly. A properly constructed search can reduce the abstract review period while a search criterion that is too broad in nature will significantly increase the abstract review period.

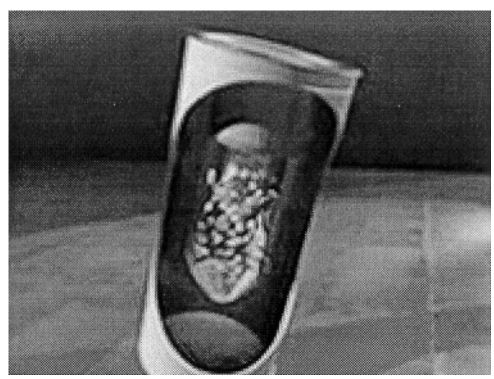


Section showing body and cone

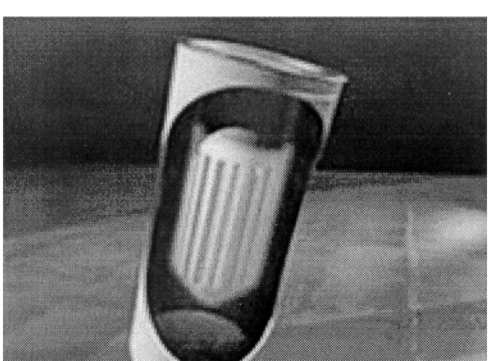


Metal end for the bottom of the container

Metal end for the top of the container



Draining of the water onto the CaO



Energy release from the cone to the beverage

Performance

Sustained core temperature was selected as the primary performance characteristic to trend. Data concerning sustained core temperature was collected from literature and company specifications for the last twenty years. This data was plotted as Figure 17. The core temperature sustainment is measured in seconds beginning when the specified core temperature is reached and ends when the specified temperature is no longer maintained due to exothermic exhaustion (the nominal required temperature is monitored and considered attained to +/− 5°F). A portion of the energy created is required to thermally con-

Figures 12, 13, 14, 15, and 16. Images of the Ontro Self-heating Container Indicating Assembly Configuration and Principles of Operation. (Slocum & Lundberg, 2001)

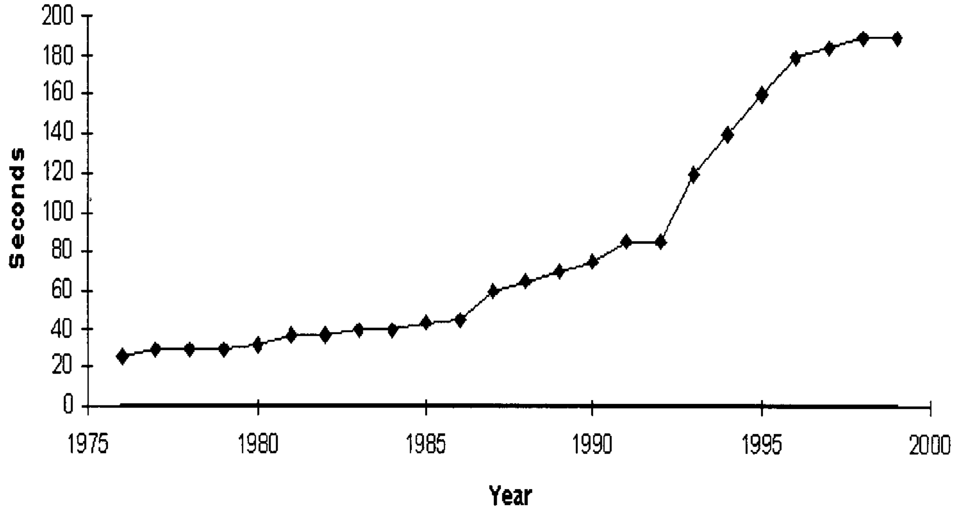


Figure 17. Sustained Core Temperature Against Year. (Slocum, 1999)

dition internal membranes and is therefore not directly translated to the temperature elevation of the beverage. Due to this, beverage temperature was also selected as a primary performance characteristic. Beverage temperature would be the final quality criteria performance would be based on as it is directly transferred to the customer (see figure 18).

Number of Inventions

The number of self-heating technology patents was collected from a patent database and these figures were collected and plotted, see Figure 19.

Level of Innovativeness

The associated aggregate level of inventiveness for the patents disclosed in figure 19 are plotted as figure 21. The criteria used for level determination was primarily a combination of the following categories and the individual patent ranking versus each. The category list used was as follows (see also Figure 20):

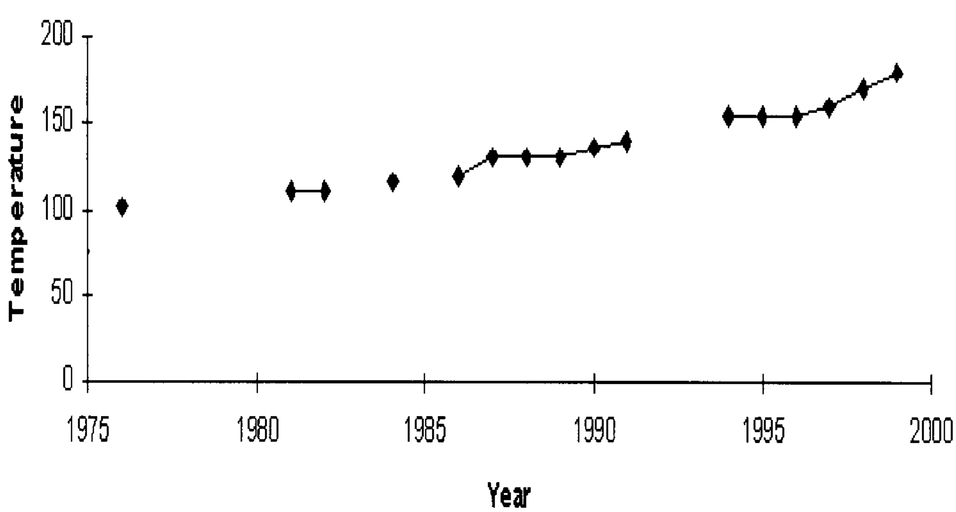


Figure 18. Beverage Temperature Increase. A Second Performance Criterion was Plotted for Beverage Temperature. There are Noticeable Differentiations in Core Temperature and Beverage Temperature. (Slocum, 1999)

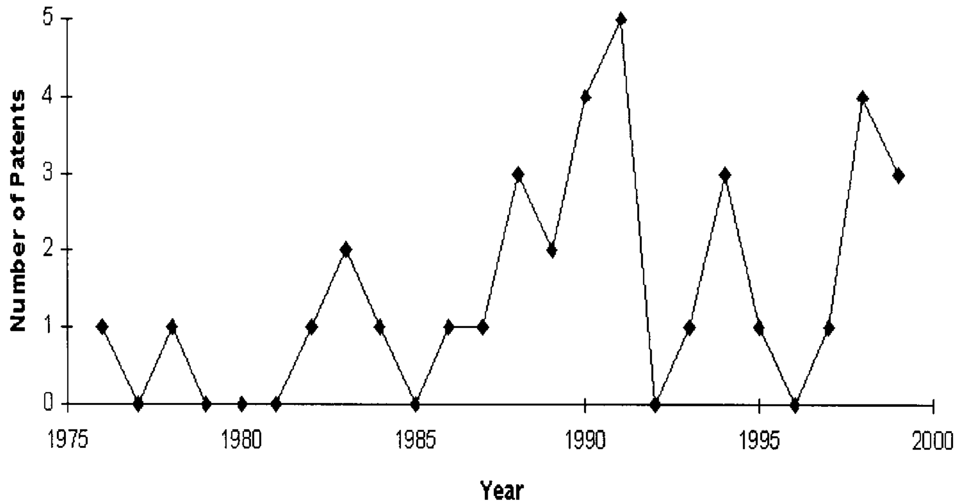


Figure 19. Patents Per Year for Self-heating Technology (and relevant criteria not specifically naming "self-heating"). A chart produced by Invention Machine TOPE 3.0 is reproduced below indicating almost identical information (demonstrating accuracy of the IMC search engine(s)). (Slocum, 1999)

Required trial and error iterations, if known or surmised (acknowledge strength or weakness of any assumption(s))
Presence or absence or invisibility of a contradiction(s) (administrative, technical, or physical)
Number of contradictions
Strength of the contradiction(s)
Impact on the relevant field
Impact on science
Degree of system change

Conclusions

The stage indicators placed the existing self-heating technology in the infancy stage. This is demonstrated by superimposing the predicted curves from figures 9a and 9b over the experimental data from Figures 17, 18, 19, and 21. In each case, the correlation suggests an immature status. A clear strategic implication was realized: invest in the production and marketing for this technology. Previous tech-

Level	Nature of the Solution	Where Did the Solution Come From?	Percentage of Patents in This Level
I	It was obvious!	The designer's narrow specialty field	~30%
II	Some modifications were made.	A single branch of technology	~55%
III	A radical change was made.	Other branches of technology	<10%
IV	Solution is broadly applicable.	From science – little known effects and phenomena of physics, chemistry, and geometry	3-4%
V	A true discovery previously unknown. Figure 20	Beyond limits of contemporary science	<1%

Figure 20. (Gahide et al., 1999; Altshuller, 1984; Savransky, 2000; Terninko et al., 1998)

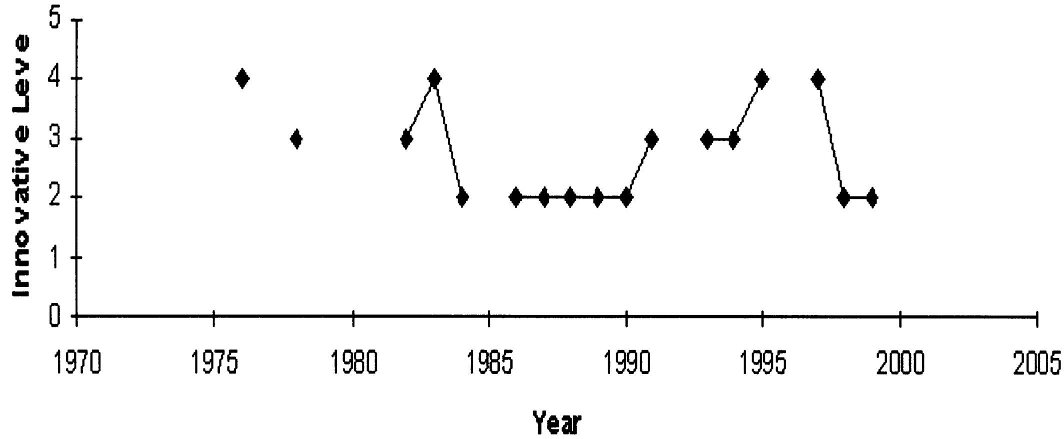


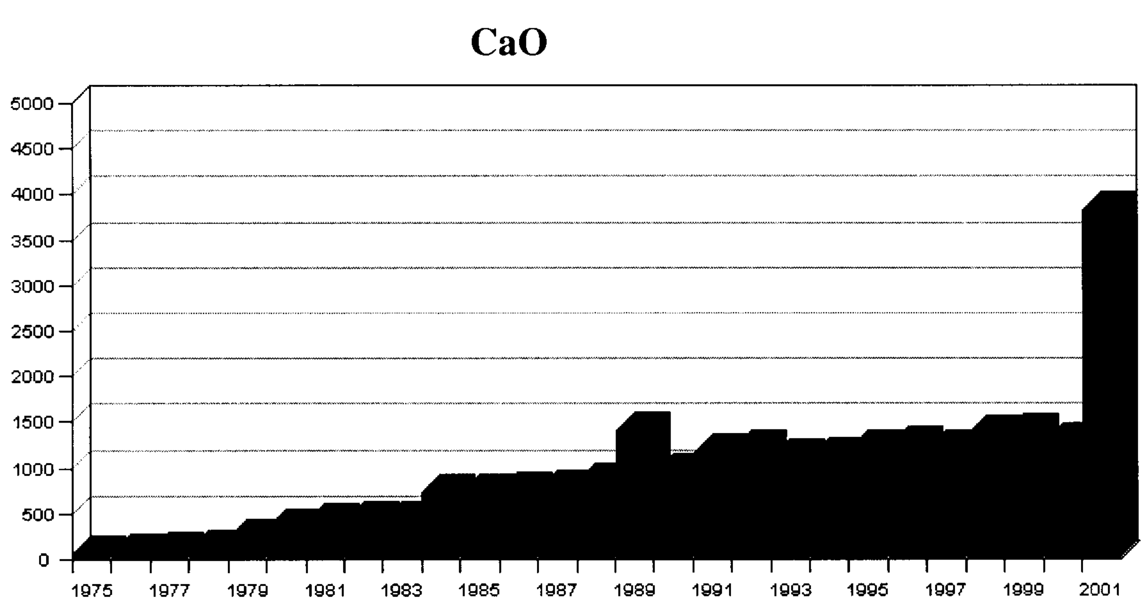
Figure 21. The Highest Level of Inventiveness per Year

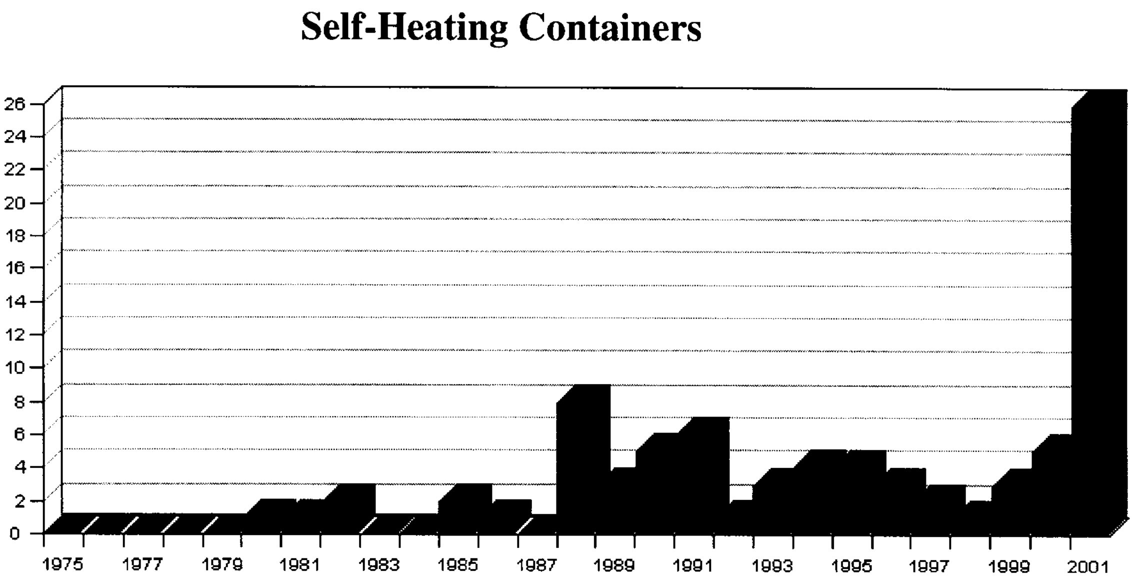
Note: The highest level of the inventiveness is represented per annum as an indication of the overall state-of-the-art in self-heating technology during the time frames indicated. (Slocum, 1999)

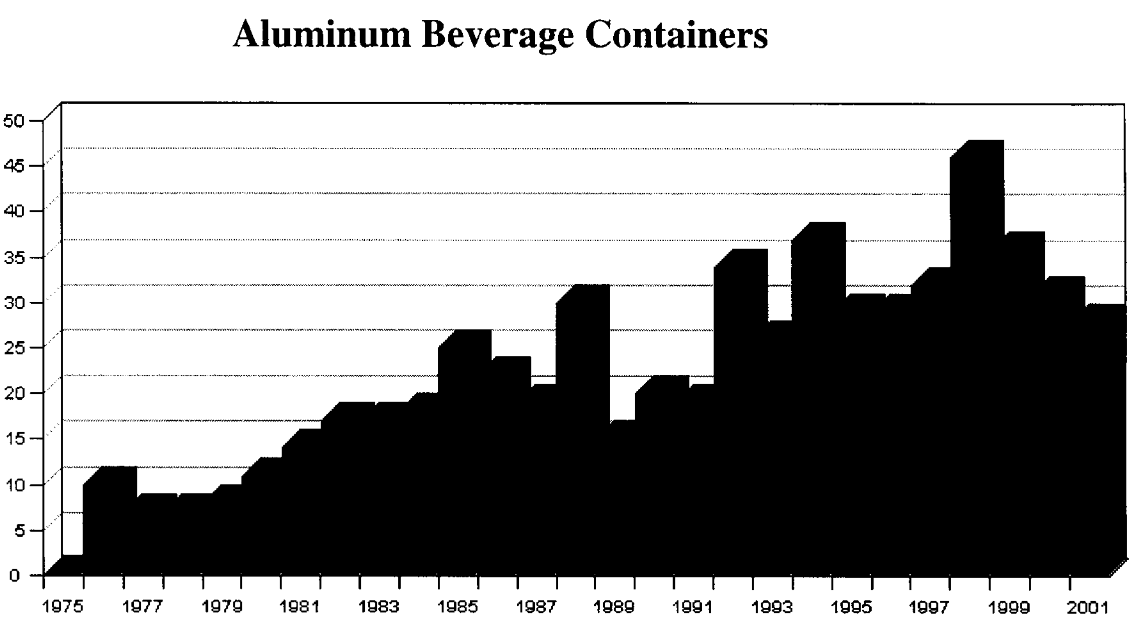
nologies were employed but the peak core and beverage temperatures realized were inadequate due to secondary limitations (or problems) associated with the technology in question (e.g., cost to manufacture, weight, safety). Therefore, there were several s-curves that were initiated but each declined prior to the emergence of the technology. This is the first cycle of this technology that has emerged. Several secondary problems were resolved and innovative design and utility patents were filed that will protect this technology as it matures. Maturity mapping will be utilized to insure the growth of this technology is understood and strategically managed to maximize profitability. Resources will be directed to a superceding technology at a point conducive to the maintenance of a positively sloped profitability curve.

Appendix A

Raw data on the number of patents issued per year for calcium oxide (the solid reactant used in most self-heating containers), self-heating containers, and aluminum beverage containers.







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