4th International DAAAM Conference
"INDUSTRIAL ENGINEERING – INNOVATION AS COMPETITIVE EDGE FROM SME"
29 – 30th April 2004, Tallinn, Estonia

TRENDS IN POSITIVE AND NEGATIVE SYNERGY AT MECHATRONIC SYSTEMS

Toivo Tähemaa

Abstract: *The paper discusses the problems of mechatronic products development aiming at the synergy of its allocated technologies and synergy between user and system. Special attention is paid to the use of product development context and design for reliability at elaboration of mechatronic systems. It is shown that in addition to the classical approach to the reliability at mechatronic systems development it is also necessary to take the reliability of the allied technologies and man-machine interfaces into account. The importance of the prognosis of the dependability characteristics of non-safety-critical mechatronic systems design is discussed. It is shown that dependability prognosis makes it possible to select the ones from alternative design solutions which are by price/reliability ratio competitive on the market.*

Key words: product development, mechatronics, mechatronic systems design, reliability.

1. INTRODUCTION

The goal of current paper is to show the relations between reliability and functionality of non-safety critical mechatronic products by using terms positive and negative synergy. Mechatronics here is a design philosophy that utilizes a synergistic integration of mechanics, electronic control and information technology to develop enhanced products, systems or processes (Buur, 1990). As lot of systems need human as system operator the synergy between these indefinite man-machine combinations is also under the observation. This new aspect is added, caused by new results got from non-safety critical office equipment observation at years 1998 to 2003.

Hard competition has forced producers to invest lot of resources into product development of such mechatronic equipment reliability. To be able to stay on the market a lot of useful and not so useful functions are included into the devices. To fulfil the requirements of the user would be probably bigger in case of wider functionality. Probability to be a market leader it is better to have new successful function first on the market. Lot of such functionalities are boosted up by successful marketing activities and many of them last only in short period. How this race in functionality is influencing overall strength of the products is the one core issue of this work. Situation is illustrated in Fig. 1.1.

To stay in top with the leaders, many producers use the reverse engineering method for copying successful ideas. It leads to half success because the hidden details and wrong integration logic can enlarge influence of negative synergy and pull down the reliability of whole system. Negative synergy effects are usually removed during the follow-up product development when customers and service are involved but it does not happened without full understanding of product integration logic.

In spite of that sometimes the reverse engineering process give good results and is at the same time would be very cost-effective. It forces the idea-leaders to cut down development or production costs as well. Both, cut-down of development and production costs have bad influence to the reliability-functionality balance. Such a close loop competition race is a result of an open market economy and gives very narrow area for experiments and creativity.

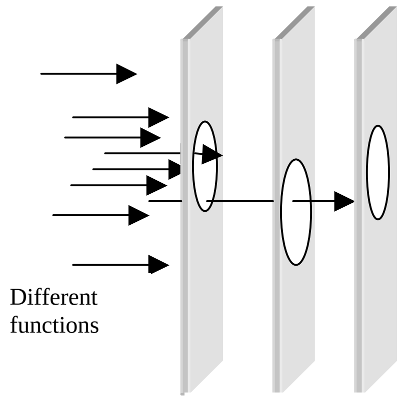

Fig. 1.1 Only some new functions are successful in longer perspective because of shifted market needs.

This paper is part of the work started at year 1996 and resumed in my Doctoral degree thesis. Continuous observation of non-safety critical mechatronic office equipment failures is carried on and here the overall overview is presented.

2. DYNAMICS OF POSITIVE AND NEGATIVE SYNERGY

Concerning quantitative characteristics of the positive synergy their dimensions and scale of evaluation have to be established. In this case, only relative indexes are measured as the change of the ratio of some parameter. Thus, it is suitable to choose some general more or less stable parameter, as the price of equipment is constant (EUR). One can understand that the constant EUR based on the evaluation of the consumer and producer price indexes, is an inaccurate basis. But as the producer price index for EUR has not changed in local market for the same period, the inflation is really negligible. The positive synergy cannot be expressed as a sole universal parameter for the equipment, but as a set of parameters related to the product output parameters such as functionality, operation speed, productivity, energy consumption, weight, starting-up time, need for service etc.

In Fig. 2.1. and 2.2 the growth of functionality with different office equipment models can be seen. The number of functions was determined so that functions comprised in additional equipment are taken with the weight of 0.5. Changes in the cost of functions and a clear sign of increasing positive synergy can also be noticed. Analysis has shown that the synergy index growth during the five year period is 3 on average. In the same way, synergy indexes for other output parameters for office equipment are determined: 1.3 for operation speed, 2 for productivity, 4 for energy consumption at “stand by”, 1.4 for weight and 4 for starting-up time. Based on the dynamics of these index changes it is possible to take these trends into account at a new device design.

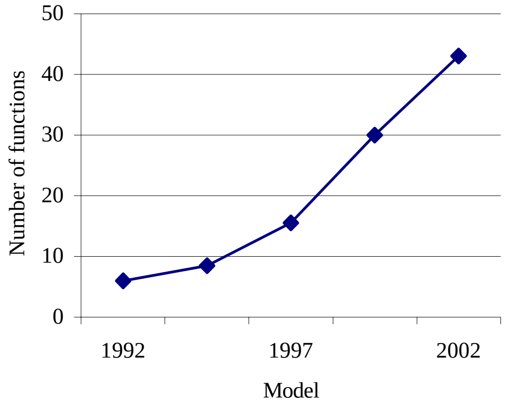

Fig. 2.1 Number of functions

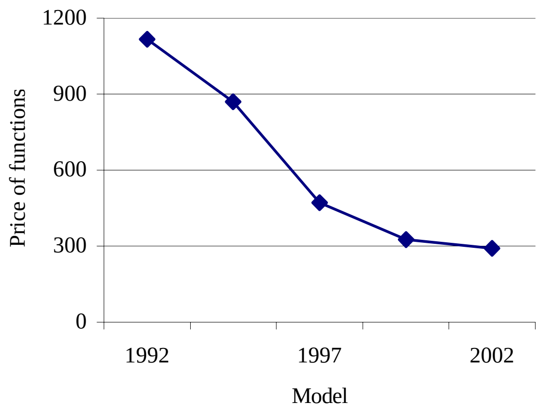

Fig. 2.2 Average price per function

Research and evaluation of negative synergy is based on seven-year service database of non-safety-critical office equipment built up in the framework of this research. The principles of database are described in (Tähemaa, 2002). There are four generations of office machines under profound examination. The first generation consists of devices produced since 1992 with a few modifications until year 2002. The second generation of office machines produced since 1995 until year 2001 has considerable design innovations. Many basic and energy saving functions based on hard- and software have also been added. The third group of equipment from 1997 is fully digital and multifunctional. Based on computer connection, new possibilities and much higher work quality in the medium speed range have been added. The last group is a new digital generation with wider functionality and higher user interface complexity.

To analyse the dynamics of failures it is necessary to look at the reliability in the time context during the three classical periods of equipment life cycle – infant mortality, useful life and wear-out (Rao,1992). Analysis of the completed database shows that the moral and physical lifetime of mechatronic office equipment is roughly 4-5 years at the medium intensity of continuous use with some exceptions of course. On average, the first year could be treated as infant mortality period, the next 2-3 years as useful life and the last year as wear-out period. Analysis of databank shows that the amount of adjusting/cleaning is an independent constant, mainly depending on the environmental conditions and copy paper quality for one certain generation. During this service operation, usually the mirrors and copy-glass are to be cleaned, the original or copy paper positioning and exposure settings to be adjusted, etc. The normally replaceable details and broken parts (without customer’s faults), listed in the group “mechanical failure”, show a significant growth with time as the time to replace the parts is on arrival. Some electronic components have a certain lifetime and that is the reason why the number of electronic failures is growing at old equipment too. Better electronic component quality is proved by reduce of electronic failures at latest generations. Software failures clear up mostly in the infant mortality period, and they are removed by updating the software.

During two latest generations we have full set of data from infant mortality period until useful lifetime period. The older models lack infant mortality failure data and that is because only useful lifetime failure data from the older generation has been shown. Anyway, it is interesting to observe the personality of failure data distribution of each generation shown in Fig. 2.3 to 2.8.

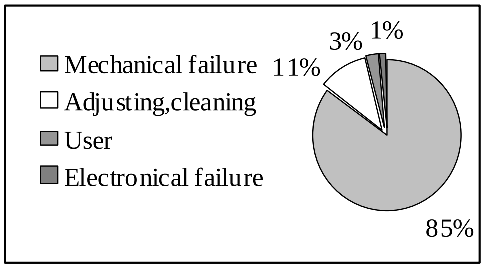

Fig.2.3 Failure distribution of the model from 1992…2002

As one can see, purely mechanical problems are dominating. This is understandable, taking into account, the long stabilization period of this model.

In next generation lot of functionality was based on the integration of electronics, mechanics and software. Deficiency of experience and inapt integration is the reason of growth of negative synergy (12 % failures are based in inapt integration).

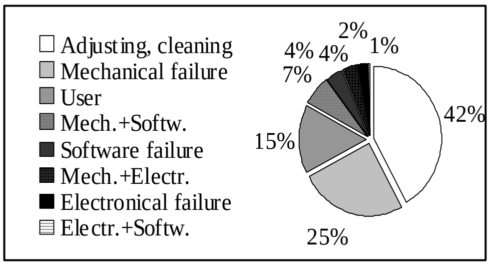

Fig. 2.4 Failure distribution of the model from 1995…2001

Digital solution in office equipment was a long step forward in reliability-functionality relationship. A lot of possibilities based on computer connection have been added, and much higher work quality in the medium speed range model is also possible. Next two figures show the change of failure distribution inside of one generation, figure 2.5 shows the distribution at very first months of model existence and figure 2.6 goes on with distribution one year later.

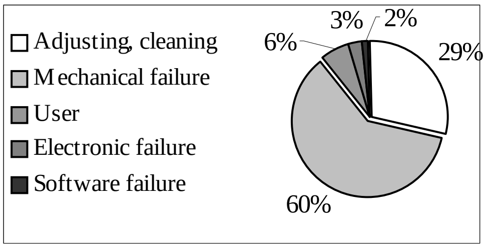

Fig. 2.5 Failure distribution of the model from 1997…2003 at infant mortality period

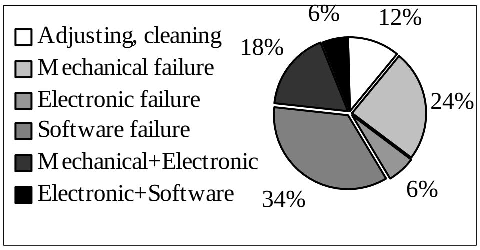

Fig. 2.6 Failure distribution of the model from 1997…2003 at useful life period

From there on it is more difficult to understand is the reason of the error the observed device or computer system. One is clear – the importance of start-up training of user-operator plays now greater role then years ago. The latest data show that the man-machine interface errors dominate during infant mortality period of the newest generation. Other combined error types recede, which shows the growth of experience of product developers.

Figure 2.7 shows the infant mortality period failure distribution of the latest model. User errors are the reason of service action in almost 1/3 cases, seems that the user himself can improve the reliability by studying the procedure of work and principia of equipment.

Fig. 2.8 proves that most users are able to learn. The mechanics, as the weakest link in devices with movable parts, proves the rule again by showing 60% in failure distribution.

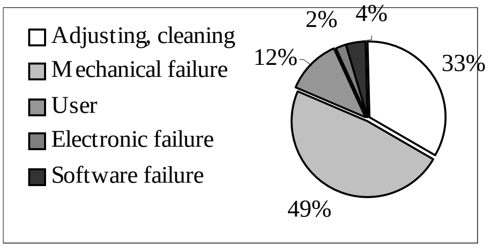

Fig. 2.7 Failure distribution of the model from 2002… at infant mortality period

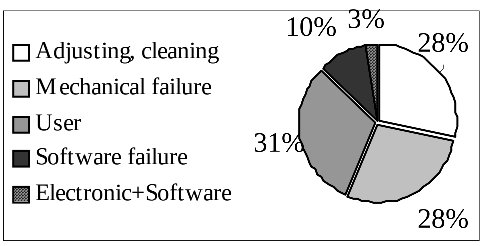

Fig. 2.8 Failure distribution of the model from 2002… at useful life period

By analysing those different failure distributions we can pick the right direction in product development and in general product support policy as well.

It is impossible to have universal database of such a failure distributions and it is difficult to transmit data from one database to another similar database as well. Current office equipment database is collected manually and lot of time was wasted to process service action description sheets. To improve reliability at infant mortality period of office equipment the worldwide systematized database would be the powerful tool. Unfortunately the common "easy-to-use" service activities managing tool is still missing in software market. Most known software brands as "Oracle", "Microsoft", "Baan" and so on offer perfect business software for production and distribution but not for service activities.

3. UNUSED FUNCTIONALITY

Multifunctionality of modern office equipment offers us more then 40 different built-in document editing functions and the number of those possibilities is still growing. Same trend is also known in other mechatronic and electronic product groups. Many of such functions are useful only in case they become widely used and standardized. Lot of functions are based on the legislation and regulations of different laws and safety norms. Every product must have those "so called" required functions. Other functions, related with price and reliability, are the levers of competition on the market. As seen in figure 1.1 the far-sighted developer makes rules and creates standards for the future. Unused function is worse than missing function because it confuses user and reduces reliability.

By investigating frequency of functions in use we mention that only 50% of whole functionality is in active use in average. It means that curve shown in figure 2.2 is not going down as we optimistically predicated. Real reason of such an expanded functionality is to suit for each customer requirements without having big number of different models on the market.

Caused by huge number of functions the user menu on the operation panel or display should be distributed between many levels. First level – main menu must give sufficient overview what kind of functions is collected under this title. It could be possible to find right function if the total amount of functions is less then 40 (it takes approximately 1 hour to test and remember them) but the number still grows! It seems that it is easier to be jet plane pilot then work with office equipment.

To hide unused functionality, operation panel menu customisation could be good idea. The process of customisation should be easy enough or directed by superuser. So software based overfunctionality, which enlarges volume of man-machine conflicts, is possible to reduce. Overfunctionality based on mechanics is not so easy task to eliminate. Unused mechanical parts have predisposition to collect dust and dirt, elastic parts can change their shape and bearings start to creak. Fortunately the concept of integration and positive synergy can help us in this hopeless situation. As all mechanical movements are already controlled by software it is easy to observe the length of rest-cycle of different parts and units. Without considerable loss of energy it is possible to start movements at quiescent parts to avoid their damages.

We still have the problem why we mast pay for the functions we do not use. The answer is short – almost all functions are somehow designed to create benefit, user must learn to employ whole power of device.

4. CONCLUSION

In last year mechatronic industry has shown highly integrated approach at product development. Low level of negative synergy is proof of success in development methodology. The overall reliability level of non safety critical office equipment is not the issue of the current work but we can clearly feel that nowadays complex devices have higher reliability than years ago. The only "but" is that the level of user skills must be higher as well.

There exist two types of pioneers, those who are generating new functionality and those who start to use them. Both of them are important for the progress of technology. Short product life cycle gives a possibility rapidly eliminate bootless trends by natural selection. Short development time and experience-based development makes new-comers difficult to entry into the market. Environmental conditions seems to be the only brakes to regulate competition race, functionality based in software development can save the resources and avoid inept pollution of nature.

Author of current work wants to point out that it is easy to manipulate with reliability and price relationship in marketing process so wider attention should be paid for finding out real values.

5. REFERENCES

Buur J., (1990), "A Theoretical Approach to Mechatronic Design", Institute of Engineering Design, Technical University of Denmark, Lyngby.

S. Ashley. Getting a Hold on Mechatronics. ASME, 1997.

Tähemaa T. Assurance of Synergy and Competitive Dependability at Non-Safety-Critical Mechatronic Systems Design, Doctoral degree thesis, Tallinn 2002

International Financial Statistics. IMF, Washington, October, 2001.

S.S.Rao. Reliability-Based Design, School of Mechanical Engineering, Purdue University, 1992.

6. CORRESPONDING ADDRESS

PhD. Toivo Tähemaa
TTU, Department of Machinery,
Ehitajate tee 5, 19086 Tallinn, Estonia
Phone: +372 50 91918
Fax: +372 6300 503
E-mail: toivo@overall.ee