INVESTIGATING THE IMPROVEMENT SPACE OF SOFTWARE DEVELOPMENT ORGANISATIONS

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Abstract: Actual results of software process improvement projects happen to be quite disappointing in practice. Although many software development organisations have adopted improvement models such as CMMI, it appears to be difficult to improve software development processes in the right way, e.g. tuned to the actual needs of the organisation and taking into account the environment (e.g. the market) of an organisation. This paper presents a new approach to determine the direction of improvement for an organisation. This approach is based on literature research as well as an empirical investigation among eleven software development organisations in The Netherlands. The results of the research show that software development organisations can be classified and can be positioned on the basis of their internal and external entropy, c.q. the level of (dis)order in the business system and its environment. Based on a possible imbalance between the internal and external entropy, directions for software process improvement can be determined. As such the new approach can complement and improve the application of current software process improvement methodologies, e.g. CMMI.

1 INTRODUCTION

To be competitive in the current economy, more and more software development organisations strive at an improvement of their processes. This is based on convictions that an improvement of their software engineering processes ultimately will lead to an increased quality of the products. Over the last ten years several improvement models have been developed that act as frameworks and tools to improve software development processes (Balla et al, 2001). Models such as the Capability Maturity Model (CMM, CMMI) (SEI, 2006), (Paulk et al, 1993) are being applied increasingly in the software engineering domain. Starting point for process improvements is a so-called process assessment, i.e. an analysis and subsequent determination of the current performance level of the software development process. On the basis of the outcome of an assessment an improvement project can be initiated. However, the actual results of improvement projects are often quite disappointing in practice (Kusters and Trienekens, 2005). Case study reports and success factor investigations offer until now only a limited insight in the way software development organisations can and/or should try to improve their software development processes.

A closer look at assessment and improvement methodologies shows that they are strongly oriented on the internal processes of an organisation. They focus for example on internal organisational factors such as management commitment, on internal human factors such as training, on internal process factors such as project planning, on internal technical factors such as tool support, and on financial factors such as project budgets (SEI, 2006), (Paulk et al, 1993). As a consequence of this internal orientation it can be concluded that current software

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process improvement approaches do not take into account the influence of the environment of a software development organization on the way the software development processes could be improved (Kusters and Trienekens, 2005).

This paper introduces a new approach for software process improvement. This approach uses as kernel concept the distinction between the internal and external entropy of a software development organisation. Entropy is a cybernetic concept that stands for the level of disorder of a system (Boltzman, 2000). The main assumption in this paper is that an organisation should be aware of its own internal and external disorder. Differences between the internal and external disorder should play a role in the process of chosing a direction for process improvement. In this paper the theoretical concepts of internal and external entropy have been made operational. This has been done by an assessment of a selection of well-defined internal and external factors of a software development organisation. Based on an analysis of these internal and external factors the differences between the internal and external entropy, the so-called 'improvement space' of an organisation, is determined. Within its own 'improvement space' an organisation then has to strive at a balance between their internal and external entropy. This should be the main theme for their process improvement activities, and the usage of improvement models such as CMMI should be based on that theme.

This paper deals in chapter 2 with software process improvement, its limitations and the concept of entropy. Chapter 3 focuses on the metrification and quantification of entropy. In chapter 4 the results are presented of an empirical research project in that the entropy of eleven software development organisations has been measured. Finally, in chapter 5 conclusions and recommendations for future research are given.

2 SPI AND THE NECESSITY OF TAKING BOTH INTERNAL AND EXTERNAL ORGANISATIONAL FACTORS AS STARTING POINT

In the software engineering domain, improvement activities are known as Software Process Improvement (SPI). SPI is being defined as:

The measurement-based improvement of the performance of the software development process aimed at delivery in due time, against agreed budgets, and with the required quality.

A well-known and broadly accepted model for the improvement of software development processes is CMM (Capability Maturity Model). CMM prescribes a specific sequence of improvement activities that has to be followed to reach higher levels of software process maturity. CMM and comparable maturity models are used on the one hand to strive at a standardisation of processes and on the other hand to realise a decrease of product failures by eliminating their causes. However, it is questionable whether these improvement models are applicable for each and every organisation. For instance, an organisation that has to deal with an increasing turbulent market, and that has improved its development processes by defining and standardising them in detail, will face difficulties in responding to the dynamic and changing requirements of that market. As a result there will be a ‘mismatch’ between the strengths of the software developing organisation and the needs of the market.

Examples of other factors in the environment of an organisation that can influence its behaviour are changing governmental and legal factors. However, these types of external factors are until now not addressed by software process improvement methodologies. This paper proposes that both internal and external factors should be taken into account during a process assessment and they have to play a role in the determination of process improvement activities.

In order to make external and internal factors applicable to process assessment, the concept of external and internal entropy is introduced.. Entropy is a concept with that the internal and external situation of a system can be expressed (Boltzman, 2000). A low entropy means a high level of order, or structure and stability, in a system. A high entropy means a low, or even chaotic, level. Table 1 gives some examples of characteristics of organisations with high and low internal and external entropies. These rather abstract characteristics are used as a basis for making the concept of entropy more operational.

Based on this type of characteristics, organisations can be considered as dynamic entities that are continuously moving and changing, and that have to strive at a balance between their internal and external entropy. For instance, in case a market is very dynamic, and a company in that market is, as a consequence, faced with a high external entropy, this company then has to be able to respond quick and adequately to the market, and in other words should be flexible.

Table 1: Some examples of characteristics of organisations with high and low entropies.

High external entropy	Low external entropy
Environment is unstable and unpredictable	Environment is stable and predictable
Standardisation is less important than flexibility	Flexibility is less important than standardisation
High internal entropy	Low Internal entropy
Flexibility is more important than standardisation	Flexibility is less important than standardisation
Organisational processes are often executed in a chaotic way	Organisational processes are executed in a formal and predictable way.

To increase its own flexibility, an organisation could be forced then to increase its internal entropy so that it becomes able to respond to the (dynamic) market. Such an organisation has to drop for example certain standardisation rules and has to increase the level of decisional freedom of employees in the development processes. The dropping of standardisation rules and the increasing of decisional freedom of employees should become main themes for software process improvement in this type of organisations.

3 MEASURING ENTROPY

To be able to use the concept of internal and external entropy in a practical way it is necessary to make entropy measurable. In accordance with (Boltzmann, 2000) entropy is based on the number of states that a system can have. In order to make entropy operational we link the state of a system to basic size variables. Of course this link has to be validated in practice and elaborated further, but in this paper organisations are considered to be business systems, consisting of interrelated components. The entropy of such a business system increases with:

- an increasing number of components;
- an increasing number of interactions between the components;
- an increasing number of changes in the environment.

From the above we derive that two concepts are playing a central role in the determination of entropy, respectively complexity and dynamics. These two concepts can be described as follows:

- complexity is a measure of the number of interacting components;
- dynamics is a measure of the amount of changes over time.

3.1 Entropy and Its Relations to Complexity and Dynamics

Entropy can be made measurable by using the concepts of complexity and dynamics. In principle, measuring is the linking of a value to a parameter, by positioning the parameter on a measurement scale. From the four types of measurement scales: ratio, interval, ordinal and nominal, only the ordinal scale applies for the measurement of the concepts of complexity and dynamics (and subsequently for the measurement of entropy). The ordinal scale offers the possibility to position a parameter on a measurement scale with values low, average, and high. In our research we have chosen to measure complexity and dynamics by using a four value measurement scale with the levels: low, average-low, average-high and high.

Table 2: Levels of complexity.

Complexity	Definition
Low	Almost all parameters have a low score
Average-Low	Most parameters have a low score
Average-High	Most parameters have a high score
High	Almost all parameters have a high score

Measuring complexity is executed via a number of business system characteristics, such as the number of employees per business function, the number of functions per department, the number of departments in the organisation, etc. Based on numbers for these parameters, organisations can be classified. For example the number of employees can be used to classify an organisation as small (1-9), average-small (10-99), average large (100-999) or large (1000+).

Similarly the dynamics of a business system can be measured. For example a classification can be derived on the basis of the number of process changes per time-frame. To determine the number of changes of a specific parameter, such as employees, information is needed on the input, the output, and the current number of the employees. Other parameters are for instance departments, products, customers, suppliers, competitors etc.

Consequently a total score for entropy can be calculated by combining the scores for dynamics and complexity, see table 3.

3.2 Entropy and Its Relations with Business System Aspects

To determine the internal and external entropy of a software development organisation a questionnaire has been developed. This questionnaire is based on the following structure. First the concept of business system has been subdivided in the three aspects of Market, Organisation and Factory. Subsequently these aspects have been elaborated. Respectively:

Market has as sub aspects: products, design and architecture; Organisation has as sub-aspects: processes and structure; and Factory has as sub aspects: people, resources and technology. The objective is that for each of the three aspects (and sub aspects) the complexity and dynamics can be determined. Table 4 summarises the basic structure of the questionnaire. By using the questionnaire, information is gathered about the (sub)aspects and subsequently about the complexity and the dynamics.

On that basis the internal entropy (business system aspect Organisation and Factory) and the external entropy (business system aspect Market) can be determined. To illustrate the questionnaire and its questions, in table 5 an example is given of a question that addresses the complexity of the Market.

The questions about the business system aspect Market, lead to scores with that the external entropy can be determined. The questions about the business system aspects Organisation and Factory lead to scores on which basis the internal entropy can be determined.

Table 3: Determination of entropy on the basis of measurements of complexity and dynamics.

Entropy		Complexity			
		Low	Average-Low	Average-High	High
Dynamics	Low	Low	Low	Average-Low	Average-Low
	Average-Low	Low	Average-Low	Average-Low	Average-High
	Average-High	Average-Low	Average-High	Average-High	High
	High	Average-High	Average-High	High	High

Table 4: (Sub)aspect of Market, Organisation and Factory.

		Sub aspect	Complexity	Dynamics
External entropy	Market	Product, Design, Architecture		
Internal entropy	Organisation	Process and Structure		
	Factory	People, Resources and Technology		

Table 5: Example of a question about the complexity of the Market.

COMPLEXITY (of market on the basis of the aspects product, design and architecture)
How many parties are involved in the development of the software products (e.g. as supplier of sub-architectures, -designs and/or components)
Quantification: How large is the involvement of third parties? - percentage components delivered? - number of external parties that contributes to an architecture and/or design? - amount of time that external parties contribute?
What is the average effort that external parties contribute? - average number of employees per external party /number of employees intern - total number of employees of external parties /total number of employees in the project

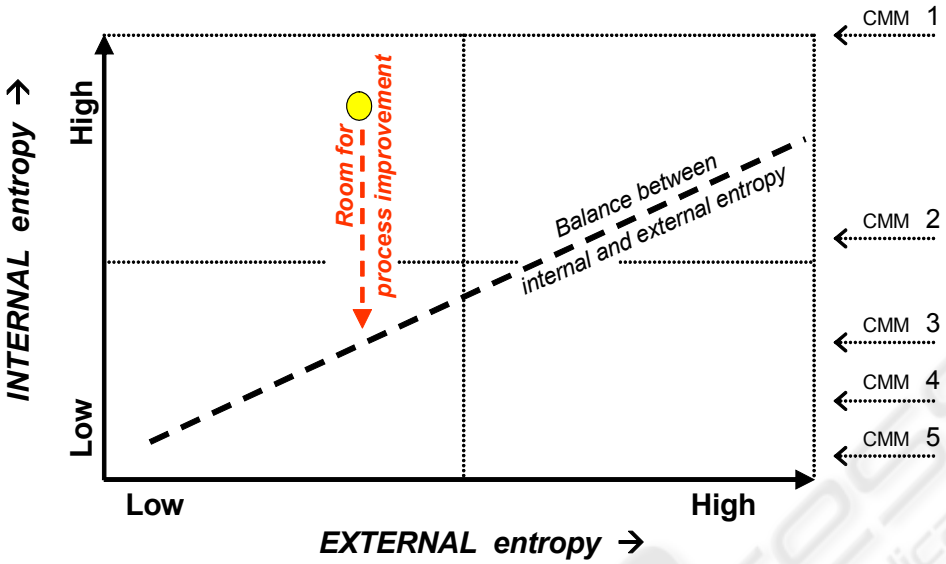

Figure 1: Space for improvement for software development organisations.

By comparing the scores of the external entropy and the internal entropy it becomes possible to position organisations in a two-dimensional matrix, see Figure 1.

A difference between the internal and external entropy shows, what we would like to call, the 'improvement space'. The concept of 'improvement space' indicates that it is possible to strive at a balance between internal and external entropy. The larger the distance an organisation has to the balance-line, the larger the space for improvement is, see Figure 1.

In Figure 1 the balance-line is represented by the dotted black line. The position of this balance-line is currently based on the usage of the data collected (i.e. the eleven companies). This means that we assume that on the average these companies have a 'certain' balance between internal and external entropy. It has to be emphasised that this is just a first step to determine the balance-line. Further research, and preferably more data, is needed to determine the balance-line more precisely.

The yellow bullet represents an organisation with a particular distance to the balance-line. This organisation has a relatively high level of internal entropy and a relatively low level of external entropy. Such an organisation should emphasise in its software process activities a decrease of its internal entropy, for example by striving at a certain level of standardisation of its processes. By doing so, the internal entropy will decrease until a balance is reached. Rather intuitively, on the vertical dimension to the right of Figure 1, the CMM-levels are given. Notice that on CMM5, which is the highest maturity level, the internal entropy is extremely low. This means that a software development organisation has an extremely high level of internal organisational order.

4 RESULTS OF THE RESEARCH: SPACE FOR IMPROVEMENT FOR SOFTWARE DEVELOPMENT ORGANISATIONS

The questionnaire has been applied in an empirical research project in that eleven software development organisations in The Netherlands have been visited for the execution of interviews. In each organisation both a responsible person for software process improvement and a representative product manager have been interviewed. The software process improvement experts, with a strong internal orientation, had more than five years experience in the field. The product managers, with a strong orientation on the environment (or: external Market factors) of the organisation had about 10-15 years of relevant experience. The structured interviews took about 2 hours per interview. The results, answers to the questions, have been elaborated and have subsequently been reviewed by the interviewed persons.

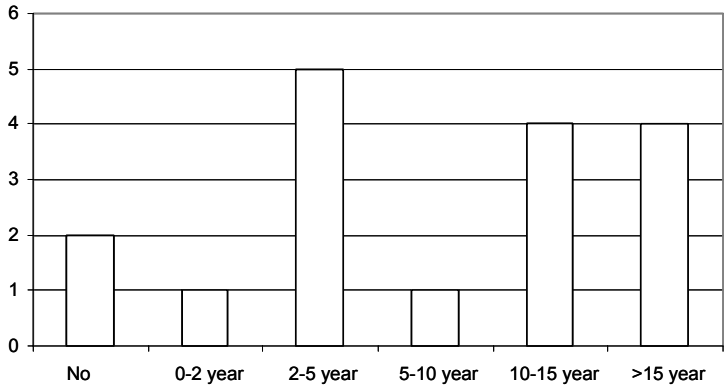

Figure 2: Experiences with Software Process Improvement.

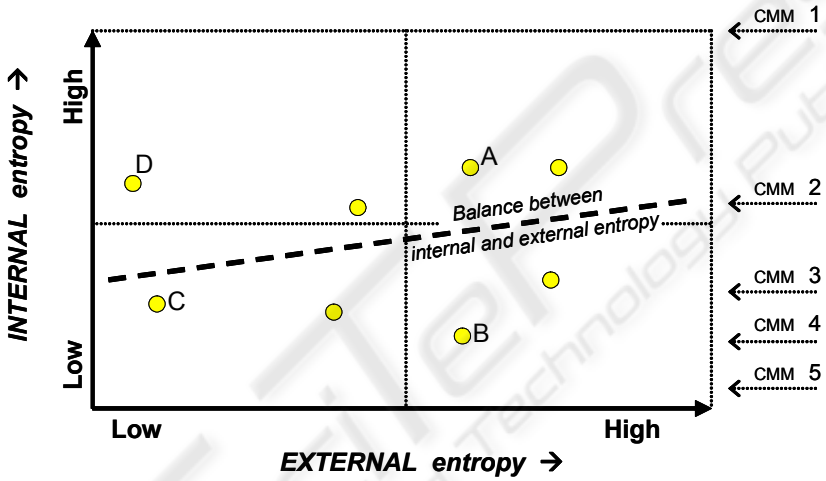

Figure 3: Positioning of software development organisations on the basis of their internal and external entropy scores.

The research has lead to a number of results. In the introduction of the interview sessions the interviewed persons have been asked to answer some more general questions. One of these questions was to describe the level of experience with software process improvement of the organisation. In section 4.1 we present first these experience levels. In section 4.2 we will present the entropy scores of the interviewed organisations.

4.1 Experience with Process Improvement

Answers to questions regarding the experience with software process improvement have lead to Figure 2. In total 17 persons could answer this question, see Figure 2. From this it appeared to be that about 80% of the visited organisations had experience with SPI

4.2 Positioning Organisations on the Basis of their Entropy Scores

Based on answers from the questions regarding the complexity and the dynamics of the three aspects Market, Organisation and Factory, the internal and external entropy could be determined. The following Figure 3 shows selected results.

Based on the above mentioned scores for the business system characteristics of the software development organisations, their scores for the internal and external entropy could be determined.

These scores have then been used to position each software development organisation in the internal/external entropy balance Figure, see Figure 3.

Table 6: Characteristics of Organisation A.

Organisation A	Complexity	Motivation	Dynamics	Motivation
Market	H	Various products for various markets	H	Product portfolio changes rapidly
Organisation	H	Many interrelations with suppliers	H	Many changes in collaborative processes
Factory	H	Large diversity in resources and people (skills)	H	Emerging new technologies

Table 7: Characteristics of Organisation B.

Organisation B	Complexity	Motivation	Dynamics	Motivation
Market	H	Complex product portfolio	HH	High pressure of market which asks for lead time reduction in combination with innovative products
Organisation	L	Rather rigid formal matrix organisation	L	Stable structure and standardised processes
Factory	L	High level of standardisation	HH	Many job changes, fast emerging technologies.

Table 8: Characteristics of Organisation C.

Organisation C	Complexity	Motivation	Dynamics	Motivation
Market	L	Stable and mature market with restricted product portfolio	L	Long lead time per product
Organisation	M	High level of maturity of business processes	LL	Rather stable processes, only few changes per time interval
Factory	H	High level of standardisation of all resources is a necessity	L	Few changes in resources to be applied

Table 9: Characteristics of Organisation D.

Organisation D	Complexity	Motivation	Dynamics	Motivation
Market	L	Limited product portfolio, relatively low complexity of design and architecture	M	Influence of customers on product portfolio increases.
Organisation	L	Flat, formal organisation	HH	Many reorganisations necessary due to market pressure
Factory	H	Low level of standardisation	H	Allocation of (new types of) resources in the business processes is emerging

From the four tables 6, 7, 8 and 9 it can be concluded that organisations can have totally different characteristics regarding their internal/external entropy balance. As a consequence different organisations should follow rather different directions regarding the improvement of their software development processes. For example, it is possible that an organisation wants to strive at a decrease of its internal entropy by means of a standardisation of its development processes. By doing so, this organisation can reach a more balanced internal/external entropy situation. Of course it is also possible that an organisation wants to influence its external entropy by focusing on new emerging markets (i.e. increasing its external entropy) or by focusing on existing stable markets (i.e. decreasing its external entropy). The final objective of these 'improvement directions' or 'improvement themes' is a more balanced situation regarding the internal and external entropy of the software development organisation.

5 CONCLUSIONS

This paper presents the hypothesis that software development organisations can be classified and can

be positioned on the basis of their internal and external entropy. Based on empirical research in eleven organisations the concept of entropy has proven to be fruitful for the characterisation of both the internal business system and its (external) environment. By using these internal and external characteristics, a possible imbalance can be determined for an organisation and a direction for improvement can be pointed out.

In this paper the characteristics of selected software development organisations have been determined on the basis of questionnaires that have been used in formal structured interviews. The concepts and terminology used has lead to positive reactions of the interviewed practitioners. The research results show that software development organisations can have quite different internal/external entropy characteristics, and this can lead to quite different software process improvement directions. Although the results gained are interesting we realise that further research is needed to validate the assumptions and constructs made. In particular we will investigate further the measurability of the internal and external entropy on the basis of the concepts of complexity and dynamics. Other main issues in our near-future research are the more precise determination of the entropy balance-line, and also the determination of the relation between CMM-levels and the internal/external entropy levels, which is currently still intuitively assumed. The final result at that we aim at, is a method (a.o. systematic analysis) and tool (i.e. automated questionnaire), to determine the improvement space of software development organisations that strive at efficient and effective software process improvement.

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