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CHARACTERIZING ORGANIZATIONAL LEARNING OVER MULTIPLE PRODUCT GENERATIONS THROUGH ANALYSIS OF PRODUCT DFA METRICS

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Abstract

Traditionally organizational and process learning has been studied in manufacturing situations. In these environments measured data has been available for statistical analysis. The results of this approach have been used in pinpointing process and organisational bottlenecks to be listed for correction. This type of an approach, however, has not been commonly used to develop product development (PD) processes and organisations. In the PD domain, finding the right metrics to measure and the long pulse speed of product development 'products' have often been a prohibiting factor.

We have identified DFA metrics as a set of candidate metrics for use in PD measurement. DFA metrics data, gathered over a number of product generations of mobile phones, is used to show that these metrics can be used to measure organisational and process learning during PD. We discuss the issues and trends seen in the plots of metrics over time. We conclude that analysing the development of DFA metrics over time, it is possible to also identify bottlenecks in PD processes. These identified bottlenecks are possible areas for future product, process and organisation improvement and learning.

Keywords: performance metrics, engineering management, systematic product development, measurement of organizational learning, DFA.

1. Introduction

The past studies of organizational and process learning have been conducted in manufacturing situations. In these environments metrics for product quality, output and yield have been available for statistical analysis. The benefit of this approach has been in the pinpointing of process and organizational bottlenecks to be listed for correction [1]. This type of an approach however has not been commonly used to develop the product development (PD) processes and organizations [2]. This is due to difficulties in finding the right metrics to measure and the low pulse speed of occurrence of PD ‘products’.

In order to measure and benchmark PD projects it is necessary to promote the development of product development metrics. There have been some studies on PD performance. [3] The measures used in these studies have mostly been financial in nature not directly linked to the product and engineering learning in product development. Thus measures relating to directly to the engineering domain are needed to assess the organizational learning in product engineering design.

We have studied DFA metrics and Guidelines and have identified certain key DFA metrics as candidates for use in PD measurement [4][5]. This data of the selected DFA metrics is gathered over a number of product generations of mobile phones. Based on the data, we show that the DFA metrics can be used to measure organizational and process learning in PD. As a result, these metrics can be used as tools for the development of PD organizations and processes in the design of mobile personal electronics products.

We make the hypothesis that DFA metrics are a suitable measure for organizational learning. DFA metrics are intended to help design engineers to assess how well their designs can be assembled. As a result they give a measure, on how good the design is in terms of assembly of the product. DFA metrics are also directed at assessing the product design. Some of the DFA metrics are also indirectly related to the product's cost performance, which is a key measure of product success. Further the DFA metrics provide a comparison metric between successive product generations. This is true to products that have similar properties, functions and features over the product generations. The DFA-index allows for comparison between products that have a larger variance in properties, but it has a slight problem with a subjective parameter in its calculation. For the case of mobile phones we present products, which are quite similar, but some variance is seen in the metrics studied. The subjective parameters have been controlled as far as possible for the DFA-index by defining a standard assumption for the subjective parameter in all the analyzed products.

In this paper we first define the parameters we have used to analyze the products. We then present the results of the analysis and discuss the observations that can be made from the graphs plotting the change of the DFA metrics over time.

2. Metrics

The metrics that need to be defined for assessing learning in PD organisations include the basic DFA metrics of part count, assembly time and DFA-index. To be able to show clear trends in learning, the products need to be grouped so that the features and functions of the compared products are similar enough to allow for direct comparison of the metric. We have identified price category as a tool that enables grouping the products in a way that direct comparison can be carried out. Price category is a good metric since it is a tool the manufacturer uses to select the customer groups that a certain product is marketed to. It is thus independent from value judgements of the analyser. Finally we define the metric of product generation as a tool for identifying the causal order of product families. The metrics are listed in Table 1.

Table 1. Metrics used in the study

Number of parts	N_p	Number of parts in the final assembly of the product
Assembly time	t_a	Assembly time according to DFA-analysis
DFA-index	E_{ma}	Efficiency index of the DFA
Price category	$C_€$	One of three price groups in which the product belongs to
Product generation	L_G	Running number to tell how many "ancestors" the current product has

Number of parts as well as **assembly time** refers to final assembly of parts and subassemblies. For example printed wiring board, bulk parts like connectors, speaker elements, etc. and special components like liquid crystal displays are considered as single components of the final assembly.

The **DFA-index** is a metrics that is obtained by dividing the theoretical minimum assembly time by the actual assembly time. If a part is considered to be assembled optimally its assembly time is three seconds. Optimal operation means assembly of fully symmetrical part without handling, insertion or fastening difficulties. The DFA-index can be calculated with equation (1).

$$E_{ma} = \frac{N_{\min} t_a}{t_{ma}} \tag{1}$$

where N_{min} is the theoretical minimum number of parts defined subjectively by the analyst, t_a is the assembly time of an optimal assembly operation and t_{ma} is the estimated assembly time of the product. [6]

In this paper products are divided into three **price categories**. In the first category (low) the current prices of mobile phones are below 300€, in the third category (high) they are over 800€. The second category (medium) is between the first and the third. The price limits between the categories have changed during the years. The most important factor in categorization is the targeted customer group. It is assumed that same type of customer would have bought a product from the same category.

Product generation describes the cumulative development work during the product history. There are altogether 10 product generations between the years 1989 and 2001. A new generation has started when for example a new network, technology or product platform has been presented.

3. Method of Study

The study of DFA metrics is conducted trough DFA teardown analysis of 16 products from 10 successive product generations. All the mobile phones in the study were produced by the same manufacturer. The Products have been analysed after market launch, by persons that do not belong to the product development organisation. The authors carried out about half of the analyses. The necessary parts criteria in the analyses done previously were been updated to be the same in all analyses.

The DFA metrics were obtained from the analysis using methods described by Boothroyd and Dewhurst [6]. The methods were translated into a computer based calculation application to enable speedy processing. Price category and product generation were determined from the product placement of the mobile phone manufacturer and by counting the successive product releases.

The analysis results were plotted to show the trends in metric development over the successive product generations. Products in different price categories are plotted separately to allow for direct comparison of the metrics. DFA-indexes of the different categories are also plotted together to show similar trends. The comparison can be done between the price categories because the DFA-index is designed to allow comparison of non-similar products.

4. Results

The results of the analysis show a distinct learning curve, where the product design according to the metrics improves over successive product launches. The plots also show that after the initial improvement a slight trend of metrics erosion takes place. The curves also show some ripples. We also elaborate on the causes of metrics erosion and the ripple effects. The elaborations are based on an understanding of the activities in the PD organization and business environment of the products in the study.

In the early years of product releases there was only one category of phones. The segmentation of products into price categories starts with the third product generation. The plots include the first product generations and the changes due to category are visible from 1993 onwards with the medium category and 1994 onwards with the high category.

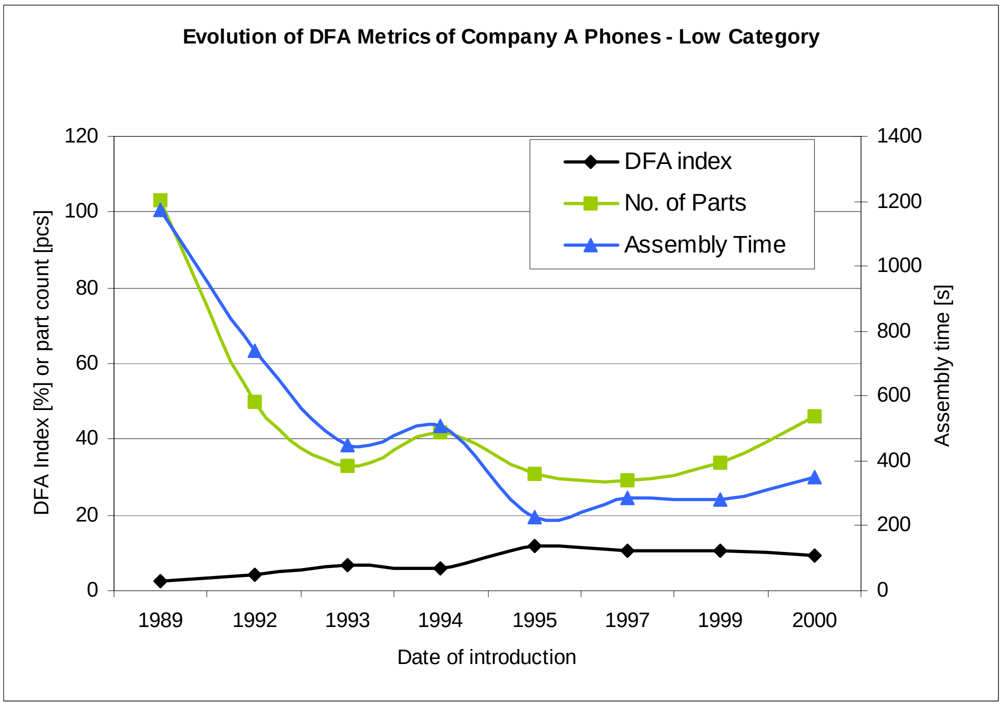

Figure 1. Evolution of low-end category mobile phone DFA metrics over successive product generations.

For the Low category, shown in figure 1, the first five years show a continuous improvement in DFA metrics. A bump in the curve in 1994 is induced by the introduction of the first phone from a new PD center. After reaching the level of about 12 % in assembly efficiency index in 1995, the metrics show no specific trend in DFA metrics. After 1995 the DFA metrics depend on the mechanical additional features chosen for the specific model.

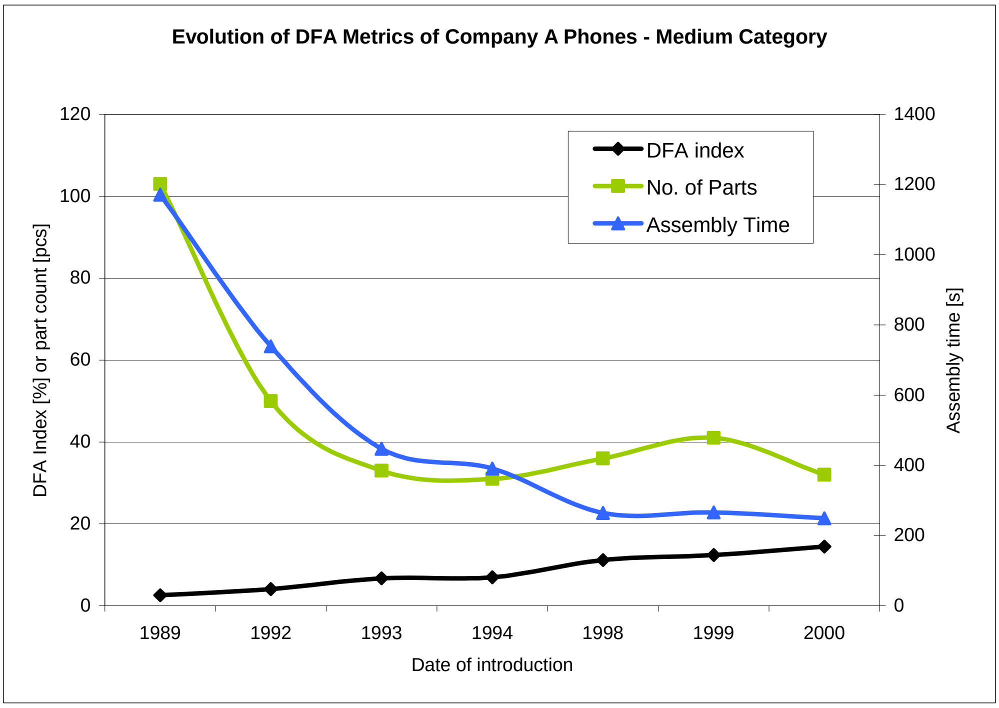

Figure 2. Evolution of medium category mobile phone DFA metrics over successive product generations.

Medium category, shown in figure 2, separates from low category in 1993. In the medium category, the improvement in assembly efficiency index is relatively smooth trough the whole period of time. In late 90's, additional features increased the number of parts, but assembly time did not increase in the same ratio. Products designed at a number of PD centers each with a slightly different product development culture and level of experience can explain some variation in the metrics from 1994 to 2001.

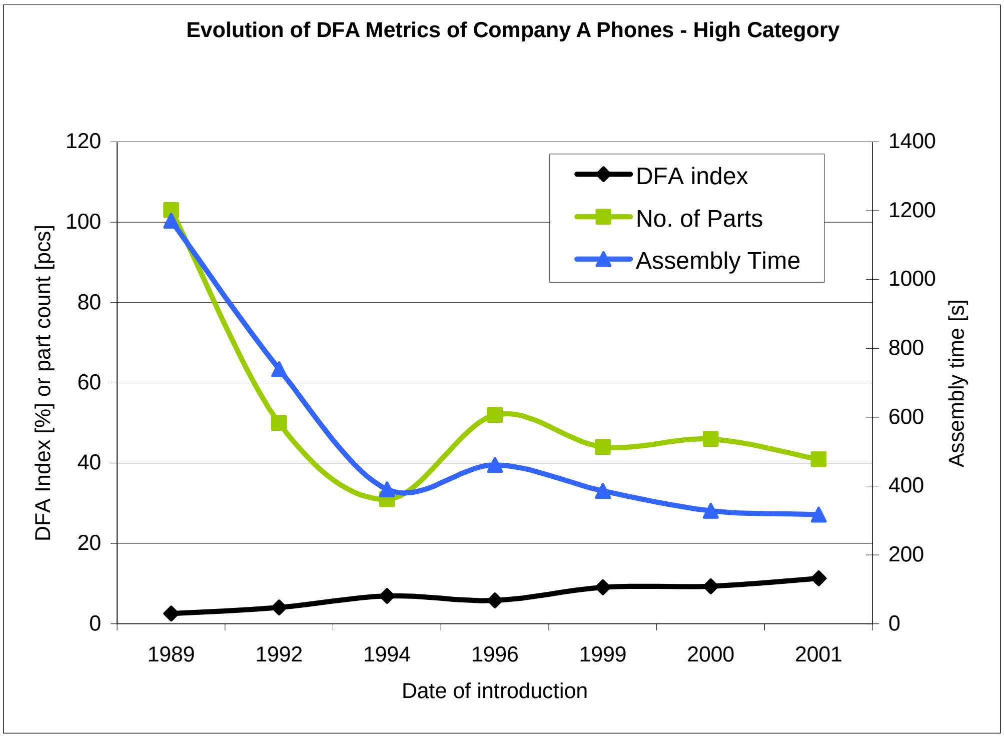

Figure 3. Evolution of high-end mobile phone DFA metrics over successive product generations.

High category, in figure 3, is presented for the first time in 1994. To the next model, the DFA metrics show an improvement. After that the metrics again show slightly worse values, but remain on a level better than in the medium category. The divergence of the curves for the number of parts and for assembly time indicates that the metrics are not dependent on each other. Improvements in the design that don't affect part count but reduce the assembly time are evident.

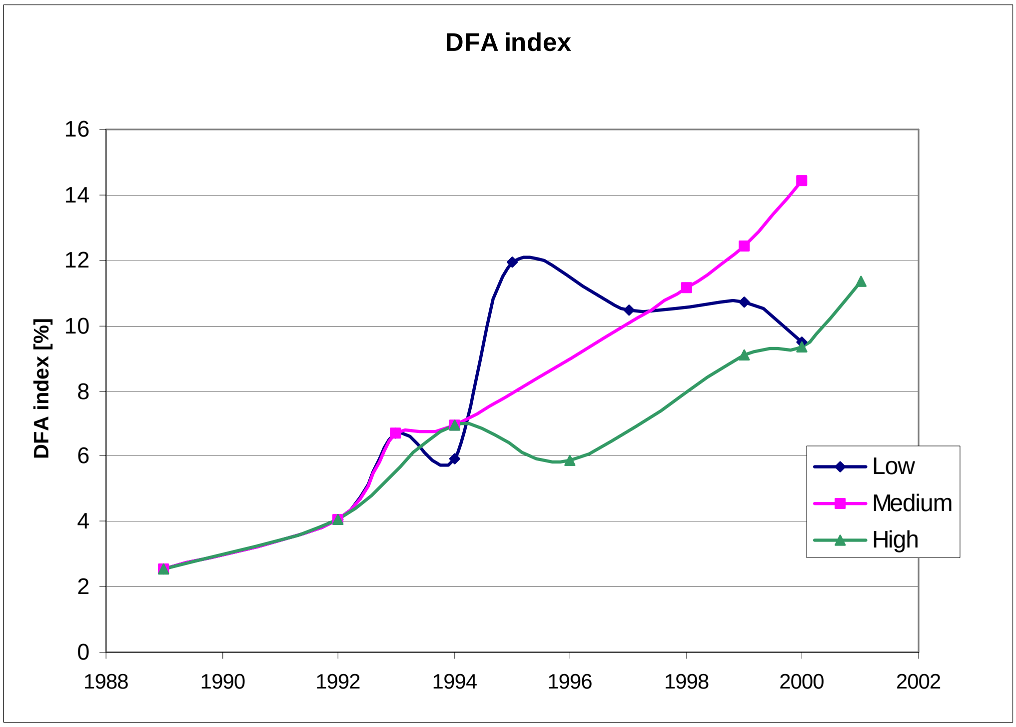

Figure 4. Evolution of mobile phone DFA-index over successive product generations of three product categories.

When plotting the DFA-indexes on the same graph, figure 4, it can be noted that the products have improved over time. The general trend is an increased index value, which signifies a better design. The jump in the low-end category in 1994 is due to the introduction of automated assembly. In successive product generations product miniaturization eroded the learning effect in the low category.

5. Discussion

The general trend in the plots of all the categories is toward an improving product. A measurably improved product from product generation to product generation signifies organizational learning over product generations.

The learning effect may not always be visible in the immediately consecutive product generation. We believe that this is a result from the time it takes for feedback from the previous generation to reach the designers. In many cases and because of overlapping PD of products the feedback of learning's from one generation come too late to influence the early stages of the design in the next. The implementation of learning thus skips one product generation to be implemented in the next. This delayed feedback produces a ripple effect in the flatter parts of the curves. Some of the ripples after 1998 can also be explained by further segmentation in the industry. New product price categories were introduced between the defined low, medium and high categories used in this study. The product demands in these categories vary slightly from the true low, mid and high categories and as a result the measured values are not totally consistent within the price categories. Additionally the production volumes of mobile phones have varied considerably during the time frame of the study. Manufacturing volumes have an effect on the manufacturing technologies and processes, which have different capabilities that are reflected on the design and the DFA metrics.

The ripples in the flat parts of curves of part count and assembly time, are rather small and do not obscure the observation that significant product improvement is seen during the first three product generations after which the curves flatten out. This is consistent with the theories of learning. [7]. The DFA-index shows a trend of continuous improvement, which suggests that it may be a better indication of post third generation learning than part count and assembly time. However, one must remember that in calculating the DFA-index the assessment of what are necessary parts is subjective and must be carefully controlled to allow for a fair comparison between products.

There are also trends in product design that counter the effect of learning. Trends such the continuing increase of product complexity with the addition of features and rise in product quality demands, in addition to the ripple effect described previously, make seeing the effects of organizational learning in the measured metrics difficult beyond the third product generations. The shifting trends produce a moving baseline for PD measurement, which is not forbidding for analysis but must be acknowledged.

DFA metrics is usable to show learning, but noise from special demands on individual products and process changes is significant. This makes identifying trends beyond the third product generation difficult. Also during the period of analysis some now product design centres started to design products the new design units did not have all the hereditary product understanding available and thus products from these tend to have slightly worse metric values that the more experienced design centres.

In the mobile phone industry, a smaller and cheaper product typifies better design. Part count and assembly time directly affect these factors. The less parts there are the less space they take and the less time it takes to assemble them. Labour costs per product are directly dependent on the time used to make each product. Thus number of parts and assembly time are good measures of better design. They can be used to measure the success of the PD in the case of an individual product.

What the DFA metrics do not measure directly is the customer acceptance, financial success or quality performance of the product. As a result they need to be used in conjunction with other measures to produce a holistic picture on the linkages of engineering design performance on company level success. Loch, Stein and Terwiesch ha proposed some metrics that can be used to help produce this holistic picture. [3]

6. Conclusions

The motivation for the use of DFA metrics for the measurement of PD arise from the wide spread use of DFA. The basic metrics of: part count, assembly time and DFA Index provide a well known and with some exceptions a stable benchmark for different products. Measuring PD from its results, the launched products, enables comparison of PD processes utilized in different organizations and design cultures. The metrics can be used as a comparative measure of PD proficiency. Using the product as a tool to measure PD also allows for a direct link between measured PD proficiency and the product success. This helps managers promote the PD culture and organizations that produce successful products.

Studying and analyzing the DFA metrics show the learning and performance of PD organizations. Understanding the PD teams in question and comparing its to the measured metrics to those of other teams can provide valuable information on what indeed are the best practices for PD of a given product. In addition to this experience has shown that the measurement of the quality of PD as such drives its embetterment. The difficulty has been in finding the right metrics.

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