INTERNATIONAL DESIGN CONFERENCE - DESIGN 2002
Dubrovnik, May 14 - 17, 2002.

# A REVIEW OF PRODUCT DEVELOPMENT PERFORMANCE METRICS INVESTIGATIONS WITH EMPHASIS ON THE DESIGNER LEVEL

Coelho L.M. Acosta, C.S. Araújo and L.G. Trabassos

*Keywords: Metrics; Product Development Metrics; Performance Measurements*

## 1. Introduction

During the last decade a great progress has been achieved regarding the application of metrics in traditional processes such as manufacturing, accounting, and various other “well behaved” processes. Nevertheless, when the subject is the product development process (also termed “the design process”) the situation is much more complicated due to its creative, multidisciplinary and complex nature.
Regarding metrics in general, the basic reasoning is as follow: first of all a goal and a person (or a team), responsible for guiding the enterprise to the success, must be established. The metrics will help, in this case, to help these individuals to make decisions in order to achieve their goal(s). The remaining question is: Which type of metrics should be used? If you want to measure the product development process effectiveness, you have to use a metric related to the acquaintance of the stated goals. On the other hand, if the interest is mainly on getting a better performance for the business as a whole we must seek metrics that help in the decision process on this matter. Thus, as we shall see along the paper, there are metrics associated to product, project, process, business, R&D, etc, and selecting the most appropriate set of metrics for a given situation in not a straight forward process.
Indeed, with so many metrics presented in the literature, an apparent paradox and problem appears to exist, confronting people involved with the utilization of PD metrics in the practice. That is, even with so many metrics at hand, none of them seem to fit properly to the needs of any PD organization. Whereas researchers in the field of Engineering Design, and regarding to the application of PD tools in general, tend to place the problem on the poor implementation practice employed by practitioners (see for instance Araújo, 2001), others research such as [Stout, 1995] have pointed that, in regarding to PD metrics, we still have to overcome the confusion related to definitions and the aspects of utilization, before being able to propose sets of metrics that have a real chance to win when tried in the practice.
This paper presents a review of much of what have been presented and discussed under the general title of “product development –design- metrics”, with as especial emphasis on the designer level. The study is mainly based on the outstanding literature on the subject (both theoretical and practical), and also on our own industrial experience on the subject of choosing and implementing PD metrics. The final goal is to provide the basis for future research on metrics implementation in industrial contexts.

## 2. Metrics: Concept and Terminology

An unified terminology for the term “metric” is very important not only for researcher but also for practical purposes. The literature presents several meanings for “metric”, and this fact contributes for the existing confusion among writers and practitioners. In general, the nature of the definitions that we found in the literature is strongly biased by their authors´ particular interest on using metrics. The following four definitions were collected from the literature and helps in identifying the implicit conceptual characteristics (key characteristics) behind this term and its usage:

**Def. 1**: "*The role of metrics is to measure how the design complies with its definition*" [Hari 2001].

**Def. 2**: "*Metrics are needed to understand the level of process performance, project performance and product performance. They are needed to set goals and measure the trend and rate of improvement*" [Crow 1997].

**Def. 3**: "*A metric for a process is a performance indicator relating a measure to a target value. A metric evaluates the process entity in that it indicates deviation of the process entity from its target value*"[Ullman et al. 2001].

**Def. 4**: "*We will consider a measure to be a metric if it can be impacted by the efforts of the individual or group with whose incentives we are concerned. Measures that cannot be affected by the efforts of the program team we will call covariates*" [LaFountain 1999].

Based on the definitions above, it is possible to build the following table taking into account key aspects such related to the implicit concept, such as the establishment of goals, concern on variability, decision-making characteristics and human action.

**Table 1. Metrics definition aspects (key characteristics)**

| | Establish – implicitly or explicitly – the need of having a *goal* | Metrics as a *variability* control instrument | Metrics in a *decision making* context | Metrics as an indicator of *human interaction* |
|---|---|---|---|---|
| **Def. 1** | | **X** | | |
| **Def. 2** | **X** | | **X** | |
| **Def. 3** | **X** | | | |
| **Def. 4** | **X** | | **X** | **X** |

## 3. Classifying Metrics

As said in the introduction, the literature discusses metrics associated to *product*, to *process* (of product development), to *project* (*vide* PMI), to *program*, to *business*, to *R&D*, to *computer program*, to *marketing*, to *manufacturing*, to *financial performance*, to *logistic*, and many more. Moreover, there are metrics connected to past events ("Last Quarter Financial Performance – LQFP"), those that indicate present facts or recent events ("*The temperature in this room is 38ºC", "Five bugs were found in this software today*"), or even those related to coming events ("*If we don't finish Luis´ traineeship till the end of the next week, he will not be prepared to integrate our team…*").

It is therefore possible to classify metrics into two large categories: with respect to their *nature* and to their *usage*.

### 3.1 Classifying metrics with relation to their nature

Goldense [2001] was the first author to classify metrics by looking at their "nature". His classification system is shown in the Table 2. Goldense´s proposal has two important virtues. First, and contrary to most of the authors in this arena, it is not focused on the product (the result), but in the process. The second advantage of his contribution refers to his differentiation among proactive and predictive metrics. Goldense´s key argument is that reactive and predictive metrics have very limited efficiency, and should therefore be avoided as much as possible, always giving place to *proactive* metrics.

### 3.2 Classifying metrics with relation to their usage

The second way to categorise metrics is in respect to their usage. Accordingly we may have:

#### *3.2.1 Metrics associated to the product*

Most of the metrics presented in the literature, and largely used in the industry, are focused on aspects related to the product itself. That is, measuring design by measuring the resultant designing product. In general they are focused on the conformity of the product to their specifications and configurations. Example of this type of metrics include: *Weight*, *range*, *endurance*, compliance between *as designed* and *as contracted* configurations, *Mean Time Between Failure*, *Estimated Operating Cost*, *Noise*

*Level*, metrics that relate the product under development to benchmark products, patterns, regulations, and many more. In summary, product-focused metrics are indicators that help individuals or teams to make decisions in order to achieve the product technical specifications. Key words here include *engineering* and *manufacturing*

**Table 2. Metrics classification respect to its nature (Goldense [2001])**

| | |
|---|---|
| ***Planning*** | *Measures that resulting from fundamental held principles and values, guide corporate and business thinking and decision making in a given company culture. As a result, these measures are often non stated. These values simply "exist".* |
| ***Proactive*** | *Measures that are taken and/or exist and are employed as an analysis and study of product/project opportunity begins but before the product/project is approved for design and development* |
| ***Predictive*** | *Measures that are taken and/or exist and are employed after a project officially begins but before the existence of the first robust physical prototype (both form and function).* |
| ***Reactive*** | *Measures that are taken and/or exist and are employed after the first robust physical prototype exists continuing throughout the life of the product/project until its retirement and/or obsolescence.* |

### *3.2.2 Process Metrics*

In this category we have the metrics that are focused in the characteristics associated to the *process of designing*, not on the product of the designing effort. They included *staffing (hours)* vs. *Plan*, *turnover rate*, *errors per 1,000 lines of code* (KSLOC) [Crow 1997]; *Process cost*, *process time and information quality* [Ullman et al. 2001]; *number of personnel dedicated to the project*, *Concept Review changes*, *Budget*, *Critical Design Review changes*, etc. O´Donnell and Duffy [2001] present a model ($E^2$) where efficiency and effectiveness are connected in order to obtain a measure of the process performance. Haffey and Duffy [2001], make a critical analysis of various process performance measurement (Balanced Scorecard, Business Excellence Model, Integrated Performance Measurement and Performance Pyramid) and its reading may help anyone who wants to determine process metrics. Hales [1987] provides a list of 103 factors that influence the engineering design process where it is possible to identify some candidates for metrics, including *clarity of corporate strategic objectives*; *incentive to innovation*; *level of communication*, *commitment and enthusiasm*; *technology and energy resources available*; and various others. Key words for this categorization are: *People* and *design*.

Metrics associated to product and to the process are the most commonly found in the literature and the practice of PD. Other types of metrics discussed in the literature are:

- **Project Metrics**: Number of product changes, Number of engineer changing orders, non conformity notes, reliability growth, use of QFD and/or DFX concepts [LaFoutaine 1999]; degree of technological innovation; etc.. The key word here is quality.
- **Program Metrics**: Unit Production Cost, schedule performance, Financial performance. Key words: Logistic, Planning and organisation.
- **Business Metrics**: Breakeven time, percent of revenue from products developed in last 3 years, proposal win percentage, development cycle time trend. Key words here are Market, Finance and Strategy.

## 4. Aspects Related to the Use of Metrics

As found by many of the authors that looked at this subject with more detail, metrics alone are useless, unless you have a goal against which your metrics will be confronted! This is the starting point.

There are three main aspects concerning metrics that should be looked at: Control of variability, strategic alignment and the decision-making process.

**Variability -** The focus of variability should be on the subject we deal with. If our attention is placed on the product technical specifications (a metric related to the *product*), then it seems to be a good idea to control the product variability. However, if we are looking at metrics related to the business as a whole, variability is something not to be controlled. Sometimes it is imperative. "Some would agree that the purpose of controlling the development processes is to prevent variability. After all, we have all been deeply indoctrinated to believe that variability is the business equivalent of the Ebola virus: any variability is evil, an no effort to eradicate it is too extreme. This is a dangerous sloppy way to think about control. In fact, there is a purpose for control, but it has nothing to do with variability. In business we use control system for one purpose: to make money – there is no other reason to control a project" [Reinertsen 2001]

**Alignment -** Authors have demonstrated the wish to build sets of product development process metrics strongly linked to the company strategic goals. An interesting example of such class of efforts is provided by Haffey and Duffy [2001], who describe four main aspects to evaluate the performance of measurements systems for product development processes. They are: Definition of Goals, Composition of Metrics, Overall and Sub-level Index and Relational structures. They divide *Definition of Goals* into four topics: *Alignment*, *Congruency*, *Constrains and Contributors to Success* and *Learning*, where *alignment* means the consideration that must be given to "how high-level organisational objectives will be viewed at the process level and how they will effect (i.e. contribute or constrain) upon the specific goals and objectives of development functions and visa versa"

**Decision Making Process -** Many authors agree that metrics are a valuable instrument to support the decision making process [Reinertsen 2001, Stout 1995, Hauser 2001, Ullman et al. 2001, Hari et al 2001, Goldense 2001]. This aspect have been considered as a key point in several works about the subject and deserves an especial attention when building up a set of metrics.

## 5. Building a Set of Metrics

Once established an understanding about metrics definition, classification and purpose, it is now possible to investigate the processes discussed by author that are necessary in order to build a set of effective metrics. Ullman et al [2001] proposes and explain four step to build it:

1. Document the existing Product Development Process.
2. Construct The Process Measurement Matrix
3. Identify the sub processes with greatest impact on successful execution of the Product Development Process.
4. Create quantitative metrics by developing measurements of the critical sub process attributes and relating the measurements to target values.

The need of process mapping and documentation is also stated by Crow [1997] and is the basis for its management. Crow summarises four criteria for effective metrics:

1. Keep them simple;
2. Keep them to a minimum;
3. Based them on business objectives and the business process – avoid those that cause dysfunctional behaviour; and
4. Avoid metrics that require significant additional data collection.

Hari et al. [2001], relate the problems that arise when people try to modify metrics from manufacturing to design process. Nevertheless, he indicates five basic aspects to build a set of metrics:

1. Attention to value of the design product as perceived by costumer;
2. Metrics must be specific for each project and for each process;
3. Metrics should reflect the competitive positioning in the market;
4. The feedback time for metrics must be as short as possible; and
5. Metrics should be available and be based on reliable data.

From the industry point of view the key word is *alignment* as show in the Harley Davidson case cited at Metrics Handbook [The Management Roundtable, Chicago, September 2001]: "Having been with the company for thirty-one years, Harley-Davidson director of program management and contract operation Kisk Trucker has seen the best of times and the worst of times. Ask him what internal factors best account for the motorcycle maker's movement from near death to double-digit growth for the last several years and he'll talk to you about a simplified, high-performance organizational structure and a set of clear *metrics derived from one key goal*: **To be ready for launch at the right time**". The *italics* are ours to emphasize the need for an strategic alignment. In the other hand, the absence of it may be the cause of many problems as those occurred in the TBG (The Bell Group) case, also referred in Metrics Handbook: "*Difficulties began to appear as openness and empowerment led to an unbalanced concentration on culture for its own sake at the expense of strategic focus*".

## 6. Industry Experience

Due to the increasing interest of most of the industrial sectors (specially the top management of these industries) on themes such *BSC* and *KPI*, we have seem lately a real rush towards the establishment and the utilization of metrics at all enterprise processes and levels, including the product development (design) process. Thus, many congresses, seminars and meetings have been called in the last years (E.g., The Management Round Table´ special series about *PD Metrics*), with strong industrial attendance.

The TBG case is particularly interesting when applying the BSC four dimension merged with the TOC (Theory of Constrains) five steps. The Metrics Handbook brings the case description: "The combination of BSC with TOC provides a means by which TBG avoids a measurement-for-measurement-sake mentality, and generates an environment where metrics provide a coherent strategic focus that delivers business results". Cases of metrics implementation at industry are also related in Ullman et al. [2001], Stout [1995], LaFountaine [1999] and at the Metrics Handbook.

## 7. Some insights about metrics

"Effective metrics have these three characteristics: They are part of something bigger, support the kind of behaviour you are trying to Foster, and facilitate good business decision making, helping you get answers to critical questions" [Tom Kendrick (HP Project Management Consultant) in The Metrics Handbook].

"Metrics alone is useless. Metric is a piece of a control system. The selection of a metric is a crucial decision in the design of such a system" [Reinertsen 2001].

"Reactive metrics tell you where you have been and not where you are going, unless you use them to close the learning loop." Goldense [2001]

"…three major factor where identified that adversely impacted the effectiveness of the decision-making process: misalignment between the individuals with the decision-making authority and those with responsibility for the eventual decisions; requirements misunderstandings; and inadequate information feedback between the decision-makers and either the designers or costumers" [Stout 1995]

"High-level strategic goals or objectives need to be decomposed into process specific objectives, providing the ability to relate and align process specific performance measures with the needs and strategic direction or focus of the organisation, and in turn providing the ability to link company objectives to daily activities and decision making activities" [Haffey and Duffy 2001]

## 8. Discussion

During this study we confirmed that there exists, in fact, a real need for a set of metrics to be used in the product development process, specially those ones applied to the level of the designing activities. We do believe that the suggested steps on section 5 may help on building such set of metrics. In respect to the metrics definition, we believe that it is possible to define metrics as those indicators that help us (individuals or teams) to make decisions in order to achieve our goal. Goals and decision making process where identified as key factors on selecting effective metrics. As we saw, metrics may be classified in respect to its nature and usage. Moreover, the great challenge is to obtain prescriptive metrics to monitor the product development process. It was not possible, until now, to identify a set of metrics that fit with this objective and may be collected and easy analysed by the engineering staff.

Based on the insights from this investigation, a long term research project with this focus has been set, and will be reported in the coming International Design Conference series.

## References

*Araújo C.S., "Acquisition of Product Development Tools in Industry: A Theoretical Contribution". PD Thesis. Technical University of Denmark. Department of Mechanical Engineering, Lyngby, DK, 2001.*

*Reinertsen D.G., "Wanted: Control System for Product Development", Product Development Metrics Handbook – What Every Manager Needs to Know About Measuring Product Development, 2001, pp 6-7.*

*Stout, T.M., "The role of Product Development Metrics for Making Design Decisions in the Defence Aerospace Industry", ,M.S. Thesis, Massachusetts Institute of Technology, 1995.*

*Lindley M.W., Muranami M., Ullman D.G., "A Metrics Methodology Developed in Cooperation with Industry", Proceedings ICED 01 (Design Management – Process and Information Issues), Glasgow UK, 2001, pp 545-552.*

*Hari A., Weiss M. P., Zonnenshain A., "Design Quality Metrics Used As a Quantitative Tool for the Conceptual Design of a New Product", Proceedings ICED 01 (Design Methods for Performance and Sustainability), Glasgow UK, 2001, pp 413-420.*

*Goldense, B. L.; "Proactive and Predictive R&D Metrics", Product Development and R&D Metrics – Quantifying and Justifying Product Portfolio Decisions, Pre-Conference Workshop, Chicago, 2001.*

*O´Donnell F.J., Duffy A.H.B., "A Performance Management at Design Activity Level", Proceedings ICED 01 (Design Management – Process and Information Issues), Glasgow UK, 2001, pp 537-544.*

*LaFountain, B.D.,"An Empirical Exploration of Metrics for Product Development Teams", M.S. Thesis, Massachusetts Institute of Technology,1999.*

*Crow K.,"Product Development Metrics", DRM Associates, 1997*

*Hales C., "Analysis of the Engineering Design Process in an Industrial Context", Gants Hill Publications, Hants, UK, 1987.*

*Haffey M.K.D., Duffy A.H.B., "Process Performance Measurement Support: A Critical Analysis", Proceedings ICED 01 (Design Management – Process and Information Issues), Glasgow UK, 2001, pp 561-568.*

Luis Marcelo C. Acosta
Embraer Aerospace AS
Av. Brigadeiro Faria Lima, 2170, 12227-901 – São José dos Campos – SP – Brazil
Tel.: +(55 12) 3927 3458
Email: luis.acosta@embraer.com.br