A metric system for feature and cost control during product development

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Abstract: The use of metrics to control the product development process (PDP) in real time poses a challenge for product development research. To date, control has been limited to the final phase of the project and the literature lacks reliable tools to analyze this process. Considering that manufacturing processes are based on standardization, this paper describes a new system for exerting control during the PDP. The proposed system uses metrics to detect deviations from planned and executed activities, allowing for the implementation of corrections during the development process. The metrics identify whether the deviations lie within acceptable limits, allowing the process to advance to the subsequent production phases. The main purpose is to launch a product that mirrors the features created during the development phase. To illustrate the proposed system, this paper presents an application for controlling the development process of a toy.
Keywords: product development, quality, metrics, toy industry

1. Introduction

During the 80's, production standardization through quality control was intensively discussed, popularizing the statistical process control. Later, regulating norms became a key factor to standardize products and processes designed to compete in a globalized market.

According to Deming, the first step to improve process quality and productivity is to measure and stabilize this process, since improvements can just be made upon steady processes (PATTERSON, 1993). If processes do not present a defined standard, changes are temporary, and any idealized change in the standard may represent waste of work and efforts.

PATTERSON (1993) carried a comparison using a model of process maturity. According to this author, most companies present manufacturing processes focused on the standardization level and activities control. On the other hand, the maturity of the processes concerning product development are on the initial levels, which means that process information are not registered and the execution procedures depend on workers' memory.

As a consequence, companies are currently concerned on registering and standardizing procedures related to product development, in order to measure the performance of the development process. As concluded by Deming, process measurement must follow its standardization. In other words, it is necessary to stabilize processes before proceeding to measurement steps.

Similarly to statistical control principles, which intend to produce with lesser cost and time, development control aims to develop products in a shorter period of time and with lesser costs. When carried at the earlier stages of development, control prevents costs related to bad quality and reduces incurrence of rework.

According to PATTERSON (1993), recognizing an opportunity to develop a new product requires approximately 15% of the work time. The remaining 85% is related to process learning, which is not frequently registered. Modifications in the team's performance without enough knowledge of procedures (or without knowledge concerning the variables to be measured) lead the process to failure. Therefore, development team must be aware about the variables' complexity in order to act in the process.

PAHL & BEITZ (1996) tried to establish process control using check-lists between the phases, called "Quality Gates". Later, with the integrated product development, COOPER (1991) defined the revision of process phases as "Stage-Gates", merging critical points related to integrated product development and concurrent engineering.

Control is usually based on the execution of demanded activities. However, during the development period very little has been done in terms of using metrics to evaluate the deviation of the product to its original idea. Some authors present concepts related to metrics in product development, as VERGANTI (1999); DRIVA et al.(2000); PATTERSON

(1993); GRIFFIN (1993); HARI et al. (2001, 2002) and HAUSER (2002). These authors also present some examples, desired features, and conditions surrounding the use of metrics.

Dense part of literature about metrics brings its computations and applications when the project is already finished. These measures are useful to improve the development model and to compare team and product performance with other projects in the market. However, these measures do not ensure the actual product to be a successful one, since they are related to past events. This condition is similar to establish a manufacture control after product's conclusion, losing the opportunity to correct some undesirable features at the right moment and leading the process to waste and rework.

BAXTER (1998) claims that specifications of product project must be continually assessed to avoid eventual deviations. This procedure allows elimination or modification of products that do not present the desired requirements, avoiding loss of extra resources. The same author argues that quality control during the development of a new product has two functions: i) to guide the development process according to costumers' desires; and ii) to carefully analyze development alternatives, choosing the ones that lead to the goal.

According to HARI et al. (2001), attributes demanded by costumers are an excellent base for metrics' definition. Using the QFD house of quality, the development team may represent demanded quality as a function of critical features of the product, which can consist of metrics. HARI et al. (2001) argue that a measuring system should be able to evaluate the project quality in quantitative terms during the initial phases of the process.

Conversion of demanded quality in terms of product quality features is reported by literature as i) list of attributes (KOTLER, 1997; CRAWFORD & BENEDETTO, 2000); ii) list of requirements (PAHL & BEITZ, 1996); and iii) project specification (BAXTER, 1998).

At this moment, a relevant aspect must be pointed out: the terminology used by current authors. Table 1 compares terms and nomenclature mentioned by AKAO (1990), ULRICH & EPPINGER (2000), ULLMAN (1997), and SUH (1990) with the ones used by this article.

Product features proceed from market and can not necessarily be parameters of the detailed project (specifications of parts of the product). Market can demand, for instance, a product with greater resistance or a silent engine. Such demands will influence the project parameters during the project detailing, after the plan concept approval. During this phase, demanded quality is converted into product features supported by the house of quality, representing the key features concerning product quality and cost.

2. Systematic for developing control

During the product process development, the most important measures to be considered are dimensions of time, cost, and attributes focused on measuring product performance. These three vertices were called "triple restriction" by ROSENENAU (1996), which was after cited in PHILLIPS et al. (1999). PATTERSON (1993) argues that the time to market is a critical variable, but the quality of the product must also be carefully considered. Procedures to measure time and costs are widely reported in literature, since these variables can be easily controlled during the process and measured in a direct way, according to the same author. The quarrel concerns the third vertex: quality measurement.

Quality features can be measured in terms of product functional performance and those guided to costumers. In this article, we propose the utilization of three dimensions during the product development: cost, time and quality.

Market researches can be useful in order to assign product features that will lead to superior performance when compared to competitors' products. These features appear during the phase called "identification of opportunities" and are inserted in the conceptual project. After this, the attributes considered attractive are transformed into product features. At this moment, each project will present a set of variables to be controlled from the conceptual project up to the releasing of the first units. Following the proposed systematic, these variables are controlled using a process of standardized development with delimited marks of process

Table 1. Terminology presented by literature.

Cited by:	Elements		
This article	Demanded quality	Product features	Project parameters
AKAO (1990)	Demanded quality Costumer requirements	Quality features Product features Engineering requirements	Product features Parts features
ULRICH & EPPINGER (2000)	Costumer demand for project	Product specifications, Metrics	-
ULLMAN (1997)	Costumer requirements	Engineering specifications	Project parameters
SUH (1990)	Costumer requirements	Functional requirements	Project parameters

revision (called "checking points"). As a general rule, these marks will identify the best moment for action.

2.1. Definition of product quality features

Concept development is the first activity performed by the development team after the approval of the project. Initially, product features desired by market are identified.

A product considered benchmarking or an idea proposed by the development team might be used as a reference. The main purpose here is to transform quality demanded by customer and ideas generated by the development team into features that the product should present.

2.2. Mathematical formulation of the development process control

In order to make possible control during PDP, a function was developed to measure the three dimensions (cost, time and quality) in a joined way, making possible the measurement of deviation in relation to the idealized features. This function is based on a distance that represents the deviation of a product feature from an ideal situation (in this proposal, Euclidean distance will be adopted for that). It is assumed that each product feature proceeding from the demanded quality must be within a specification interval defined by the development team. The specification interval indicates the acceptable value for this feature. For instance, the desired weight of a product (taking in account norms and taxation) is 10 g, but a value until 11.5 g can be accepted.

2.3. Target deviation measurements

The proposed metrics system is based on distances, considering the deviation of each product feature from the respective target. Literature presents different measurements of distance and proximity. Among these, the Euclidean distance is one of the most used for measuring distance between two points in a *n* dimensional space.

Euclidean distance between points Y^p and Y^0 can be defined as the square root of the sum of square differences between the coordinates that locate each of these points. Alternatively, the square of the Euclidean distance can be used as reported in Equation 1.

$$d\left(Y^p, Y^0\right) = \sum_{i=1}^{n}\left(y_i^p - y_i^0\right)^2 \qquad (1)$$

where:

$d(Y^p, Y^0)$ is zero when the points coincide in the space and will be larger when the distance between these points increase. Considering the problem in question, Y^p represents the position of the set of product features during phase *p*, while Y^0 represents the position of the desired values of these features. Position Y^p is defined by its coordinates in the n-dimensional space ($y^p_1, y^p_2, \ldots, y^p_n$), while the position of the desired values, Y^0, is defined by the coordinates ($y^0_1, y^0_2, \ldots, y^0_n$). Figure 1 illustrates the elements that constitute the proposal of this article.

2.4. Scale and procedures during the evaluation

The features used for the conceptual project evaluation can be either directly measured (quantitative) or indirectly measured (qualitative features). Quantitative features can be measured in their original units, while qualitative features must be quantified through a scale.

The scale may use -1 to +1 or 0 to 10 intervals, and the value is attributed according to an ideal condition demanded by the customer. The ideal condition can be considered a fictitious ideal product or a competitor's product, which the company desires to surpass. Usually, the evaluation involves only subjective aspects, and the accuracy of this evaluation will increase with the participation of more than one appraiser.

As a decision rule, all the features must respect their individual limits (acceptance interval). In case of a feature be rejected in relation to the acceptable limit, the PDP will be interrupted and other alternatives for the product must be evaluated. Figure 2 presents the proposed scale.

2.5. Determination of quality deviation

Quality evaluations of the developing product can be obtained through the distance between the planned and the obtained features, denoted by ($d(Y^p, Y^0)$). According to this proposal, measurements of the diverse features are converted into the interval 0 to1, where zero corresponds to the desired value and 1 represents the largest acceptable deviation. If all features are positioned in the alert zone, quality of the project will be poor.

In this context, as a criterion for continuity of the PDP, this proposal establishes that the average evaluation of

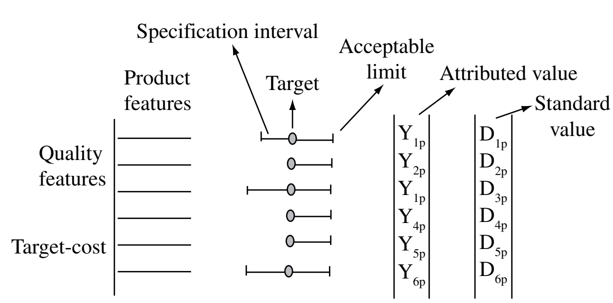

Figure 1. Elements of the proposed systematic.

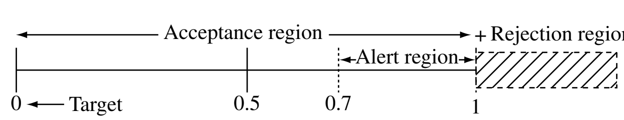

Figure 2. Acceptation criterion of features.

the features, converted into 0 to 1 scale, must be equal or inferior to 0.7. When this condition is satisfied, the project may move forward; otherwise, it must be submitted to reevaluation. Any feature can be converted into the interval 0 to 1 through Equation 2.

$$d_i^p = \frac{|y_i^p - y_i^0|}{|y_i^{\lim} - y_i^0|} \quad (2)$$

where:

d^p_i Standardized deviation, considering the feature i in phase p;

y^p_i Measured or attributed value for feature i in phase p;

y^0_i Target value for quality feature i; and

$y^{\lim}_i$ Acceptance limit for quality feature i.

Quality in phase p can be measured using the square of the distances d^p_i as presented in Equation 3, which is based on the square of the Euclidean distance.

$$Q^p = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{d_i^p}{0.7}\right)^2 \quad (3)$$

where:

Q^p Quality indicator, assessed in phase p; and

n Number of features used during product evaluation.

Distance Q^p is interpreted as follows: *i*) when all the evaluated features present deviation $D^p_i < 0.7$ (measured in scale 0 to 1), Q^p value is smaller than 1.0 (inside of the acceptance limit) and the product is allowed to proceed to the next phase; (*ii*) when all the evaluated features present deviation = 0.7 (measured in scale 0 to 1), Q^p is 1.0 (on the acceptance limit) and the product can proceed to the next phase; (*iii*) if one feature presents $d^p_i > 0.7$ (measured in scale 0 to 1), other features must present their values closer to zero in order to result $Q^p < 1.0$; otherwise, the product will not proceed to the next phase; and (*iv*) if any feature presents deviation larger than 1.0 (measured in scale 0 to 1), the product is not allowed to proceed to the next phase (this situation demands reevaluation of the product or even withdrawal).

2.6. Determination of cost deviation

In order to measure the cost dimension, we propose the comparison between estimated cost in phase p and target cost through Equation 4.

$$C^p = \frac{C^{p\$} - C^{target}}{C^{lim} - C^{target}}, if\ C^{p\$} > C^{target} \text{ or} \quad (4)$$

$$C^p = 0, if\ C^{p\$} \leq C^{target}$$

where:

C^p Product cost in phase p, using the scale 0 to 1;

$C^{p\$}$ Product cost in phase p;

C^{target} Target cost, determined in the conceptual project; and

C^{lim} Acceptance limit for cost, defined to ensure a competitive product.

2.7. Quality-cost evaluation

A global evaluation regarding quality and cost can be obtained from the Euclidean distance combining the performances of the dimensions quality and cost.

Similarly to previous conditions, it is not desirable both quality and cost to be beyond the acceptance limit. As a continuity criterion of PDP, this proposal assumes that the average of these indicators must be equal or inferior to 0.7. When this condition is satisfied, the project can move forward; otherwise, it must be submitted to reevaluation. Consider the Equation 5:

$$Des^p = \frac{1}{2}\left\{\left(\frac{Q^p}{0.7}\right)^2 + \left(\frac{C^p}{0.7}\right)^2\right\} \quad (5)$$

where:

Des^P represents product performance in phase p considering quality and cost. It can assume the following values: i) if quality and cost value are smaller than 0.7, Des^P is smaller than 1.0 (inside of the acceptance limit) and the product is allowed to proceed to the next phase; ii) if quality and cost are equal to 0.7, than Des^P is 1.0 (on the acceptance limit) and the product can proceed to the next phase; iii) if one of the dimensions (quality or cost) is larger than 0.7, the other dimension must be capable to balance the situation in order to result $Des^P < 1.0$. Otherwise, the product will not proceed to the next phase; and iv) if quality or cost present deviation larger than 1.0, the product will not proceed to the next phase. Figure 3 brings an example of the trajectory of Des^P for each phase of the PDP.

2.8. PDP control graph

Quality performance, cost, and scheduling of the PDP can be evaluated using a unique graph suggested by the authors of this article, called Control Graph of the PDP. Figure 3 presents an example.

In this example, we are considering five phases of evaluation. The horizontal axis of the control graph is a time line, indicating the deadline of each stage. The vertical

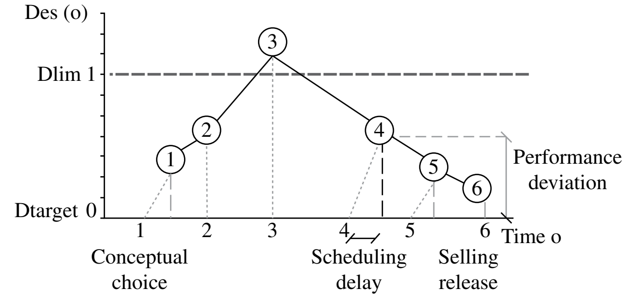

Figure 3. Process control using quality and cost performances.

axis reports the values of Des^P. For each evaluation point, measurements of quality and cost are obtained, generating a value of Des^P (represented by numbered points delimited by a circle in the graph). The ideal performance is zero, indicating that there is no deviation in relation to target. Deviations of observed values of Quality and/or Cost in relation to planned ones are measured in the vertical axis. The control graph also presents deviations in the scheduling using the difference between the stipulated time and the control moment of the PDP. This deviation is visualized by the angle formed between the dotted line and the horizontal axis.

The first evaluation of the example (circle "1" in Figure 3) shows that the project was inside of the acceptance limit, but it was late considering its schedule. In the second evaluation, the project continued inside of the acceptance limit and the initial delay was recovered. In the third evaluation, the development period remains adequate (without delay), but the project exceed the decision limit, signalizing the necessity of larger efforts from the team (major product reevaluation). Phases 4 and 5 show that the project effectively improved, since these points have approached to the target (improvement in the product quality and/or cost). However, the project presented some delay in relation to the original schedule.

The following section presents a practical example where the proposed metrics was used for the development of a new toy.

3. Example of development control of a new child tricycle

3.1. Definition of control points

Toy industry is characterized by short development cycles (around 6 to 12 months) and frequent launchings and modifications in existing products. The product in question is a new child tricycle, requiring peculiar modeling procedures, platform, and equipments for its manufacturing. Figure 4 brings the phases of the PDP and the control points analyzed during the development of this product.

By the end of each phase, product features (subdivided in quality features) and the target-cost were converted into the standard scale. Then the product was evaluated using the metrics system proposed in this article. The stages of development control of a new tricycle are described in the following section.

3.2. Definition of product features

Quality features and target-cost were defined based on strategic meetings held by company's management. Table 2 brings the conversion of the demands into quality features.

Using a benchmarking product (tricycle for children up to 3 years), we defined the target values and the specification interval for the product features as presented in Table 3.

For this example, the evaluation of the qualitative features used a 5 points scale (where 5 means superior quality compare to competitor and 1 means inferior). The quantitative features, as weight and injected global area, were measured using appropriate units. In addition, one of the goals during the conceptual phase is to satisfy the product target-cost, which is defined by the financial team of the company.

The estimated cost, when compared with the target-cost in the initial phases, has become more accurate after improvements over product dimensions and features.

3.3. PDP Control Graph

According to Figure 4, control process of a developing product requires 6 steps of evaluation, each of them considered as an important point for the development of a new toy. Measurements in these steps can be collected

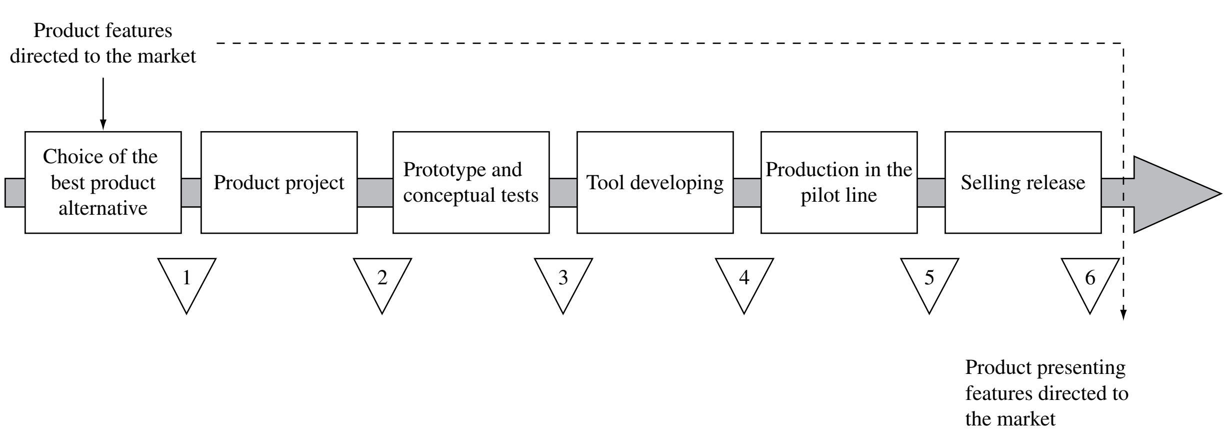

Figure 4. PDP phases and control points for the toy development case.

Table 2. Conversion of demanded features into quality features.

Demand	Quality features	Measurement unit
To seem resistant	Robust appearance	Scale 1 to 5
To accommodate the child	Anatomic appearance	Scale 1 to 5
Attractive and happy	Lively colors (with brightness)	Scale 1 to 5
To avoid fallings	Secure appearance	Scale 1 to 5
To be different and modern	Attractive Design (rounded trends)	Scale 1 to 5
Good finishing	Absence of sharp edges and hidden injection points	Scale 1 to 5
Present attractive	Superior attractiveness in relation to competitors	Scale 1 to 5
Do not break easily	Physical robustness	Weight (Kg)
Satisfy the norm	Tricycle weight	Kg
Satisfy the norm/platform	Tricycle height	mm
Satisfy the norm/platform	Tricycle length	mm
Satisfy the norm/platform	Tricycle width	mm

Table 3. Performance evaluation during the choice of the best product configuration.

		Product features	Target	Acceptable limit	Yi			Standardized deviation		
					A	B	C	A	B	C
Quality features	Qualitative	**Visual robustness**	5	3	5	4	3	**0.00**	0.50	1.00
		Anatomical appearance	5	4	4	5	4	**1.00**	0.00	1.00
		Alive colors (with brightness)	5	4	5	4	4	**0.00**	1.00	1.00
		Security	5	4	4	4	4	**1.00**	1.00	1.00
		Attractive Design	5	4	4	4	4	**1.00**	1.00	1.00
		Good Finishing	5	3	4	4	4	**0.50**	0.50	0.50
		Superior attractive in relation to competitors	5	4	5	5	5	**0.00**	0.00	0.00
	Quantitative	**Physical robustness**	20 Kg	18	19	19	19	**0.50**	0.50	0.50
		Global weight	620 g	680	620	680	640	**0.00**	1.00	0.33
		Height	220 mm	260	238	240	235	**0.45**	0.50	0.38
		Length	470 mm	490	470	470	470	**0.00**	0.00	0.00
		Width	300 mm	320	300	310	300	**0.00**	0.50	0.00
PDP	control	**Target-cost**	R$ 10	14	12	10	14	**-**	-	-
		Quality metric (Q^P)	0	1	-	-	-	**0.630**	0.893	0.978
		Cost index (C^P)	0	1	-	-	-	**0.500**	0.000	1.000
		Global performance (Des^P)	0	1	-	-	-	**0.660**	0.813	1.997

either before the "gate" (allowing correctional procedures) or during the "gate" moment.

The first step consists on choosing the best alternative or configuration of product and is performed when several alternatives of project are transformed into product alternatives. Usage of sketches can be helpful at this step.

In this study, quality features and target-cost were analyzed during the evaluation of alternatives. At this moment, it was defined the first point of feature evaluation (which was established during the conceptual development). For that, Des^P was calculated for each alternative, assisting the choice of the best concept by the development team. The performance of the chosen concept will be represented in the control graph.

According to Table 3, alternative *A* presented the best performance (Des^P = 0.66), being chosen for the next development stage. Table 3 also presents desirable features pointed out by researches and experiences in the area, as *anatomical appearance* and *security*.

The maximum value 5 (superior level in the considered scale) was chosen as the target for all the qualitative features. The acceptable limit was defined in accordance with the strategic product planning, which was performed during the "opportunity identification" phase. Considering the example of this study, *robust appearance* and *good finishing* present larger tolerance, since "3" was the consensus for the acceptable limit.

The specifications for quantitative features (Physical robustness, Global weight, Height, Length, and Width) were defined in order to satisfy norms, storage of the product, final costs and features demanded by customer. Table 4 brings the results of the performance evaluation for the 6 points.

After that, the first point is plotted in the control graph, according to Figure 5. The control limit is 1 and is represented by the red line in the graph. In the same figure, the numbered point in the horizontal axis shows the latest date in the planning scheduling, while the point in the interior of the graph shows the instant that measurement was effectively performed. The difference between these points in the horizontal axis represents the delay time.

Similarly to traditional quality control graphs, points related to remaining evaluations are added in the control graph in accordance to process development evolution. In addition, deviation points between the planned and the measured (indicated by Des^P) are highlighted in real time, allowing the adoption of corrective actions.

The second evaluation starts after the project is detailed. In this phase, technical modifications may influence the product conception. For instance, material specification may imply major deviations in some features. In this case, quality evaluation using the proposed metrics will expose the mentioned deviations. The development team must be aware of changes that could bring time or cost reductions, but these changes should not modify the product conception.

Remaining evaluations are performed similarly. The third evaluation refers to prototype and conceptual tests. In this study, engineering, marketing, and production areas performed the control of quality features immediately after the development of first prototype. The prototype is usually the first physical representation of the product to be developed. Its evaluation is conducted by the internal team, and conceptual tests require costumer's opinion. The results of these two analyses may demand changes in the values attributed in previous evaluations. Once again, the development team is urged to suggest improvements concerning quality, but without compromising the cost of the product.

For this same evaluation, Figure 6 shows that cost strongly increased and arrived at the boundary value. This situation pushed global performance beyond the acceptable limit (arriving at Des^P = 1.27), indicating that the project needed revision (possibility of cancellation was another alternative at this time). The team promoted a major revision

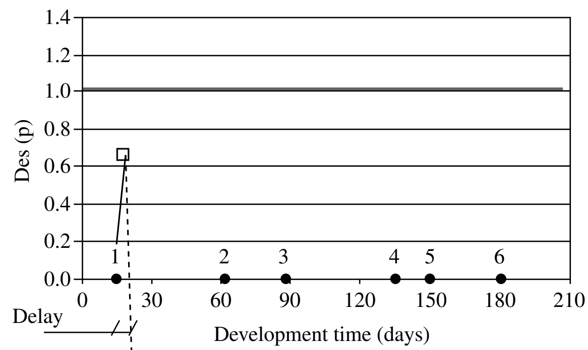

Figure 5. Control graph of performance evaluation after the choice of the best alternative.

Table 4. Performance evaluation for the considered phases.

	Evaluation phases: 1 to 6									
Product features	**Target**	**Acceptable limit**	Y_i	$d_{(i,1)}$	$d_{(i,2)}$	$d_{(i,3)}$	$d_{(i,4)}$	$d_{(i,5)}$	$d_{(i,6)}$
Visual robustness	5	3	5	0.00	0.00	0.00	0.00	0.00	0.00
Anatomical appearance	5	4	4	1.00	1.00	0.50	1.00	0.50	0.50
Alive colors (with brightness)	5	4	5	0.00	0.00	0.00	0.00	0.00	0.00
Security	5	4	4	1.00	1.00	1.00	1.00	0.75	0.75
Attractive Design	5	4	4	1.00	1.00	1.00	1.00	1.00	1.00
Good Finishing	5	3	4	0.50	0.50	0.50	0.50	0.50	0.50
Superior attractive in relation to competitors	5	4	5	0.00	0.00	0.00	0.00	0.00	0.50
Physical robustness	20 Kg	18	19	0.50	0.50	0.50	0.50	0.50	0.50
Global weight	620 g	680	620	0.00	0.00	0.00	0.40	0.40	0.40
Height	220 mm	260	236	0.40	0.40	0.40	0.40	0.40	0.65
Length	470 mm	490	490	0.00	0.00	0.00	0.70	0.70	0.70
Width	300 mm	320	300	0.00	0.00	0.00	0.00	0.00	0.00
Target-cost	R$ 10	14	11	0.25	0.25	1.00	0.5		0.5
Quality metrics (Q^p)	0	1		0.62	0.62	0.49	0.73	0.53	0.62
Cost index (C^p)	0	1		0.25	0.25	1	0.5	0.5	0.5
Global performance (Des^p)	0	1		0.46	0.46	1.27	0.80	0.54	0.65
Delay (days)	0	30		2	2	2	22	10	7

and brought the global performance back to acceptable limit, deciding to move forward.

During the fourth evaluation, tool developing, drawing of product parts and final product were compared, involving project and production departments. In this phase, some critical items were evaluated, as i) the point submitted to the strongest effort during the use; ii) fragility of the parts; and iii) good finishing and assembly of the components, among others. Some modifications have taken place in order to adjust the project to the initial concept.

This evaluation presented a great delay, which is illustrated in Figure 6 (point 4). According to the project team, this fact is justified by several problems of communication among production-engineering-tool departments. There are two main explanations for this delay: i) there were several modifications in tool development until it was considered adequate for manufacturing; and ii) slow liberation of resources from the top management to tool development.

The Fifth Evaluation (point 5 in Figure 6) refers to production in pilot line. During production test procedures (consisting of production planning, layout, physical infrastructure, and installed capacity), temporal data and machines were compared with the executed ones.

Tests performed in a pilot line certify product manufacturability and the attendance of features idealized during conceptual development. After the approval of pilot lot and conclusion of marketing and sales plans, resources were allocated for production in large scale and launching. According to Figure 6, this phase also presented undesirable delay, which can be estimated by the difference between the fifth round point (located over the horizontal axis) and the projection of the fifth square point (inside the graph) over the same axis.

The last evaluation consists of selling release, which is conducted after production approval. In this phase, activities concerning media and marketing planning, conferences of packing and availability of materials are performed. New and more accurate calculations are executed, helping management to make decisions in issues related to sales and costs.

In this phase, a final verification concerning product quality and cost is performed, allowing product launching. At the same time, the final metrics have to be computed. The next evaluations (which are beyond PDP scope) are related to product performance in the market, evaluation of customers' satisfaction and attendance of management's goals.

Figure 7 presents the final control graph. Numbers 1 to 6 indicate the latest time for conclusion of each evaluation, while the horizontal axis expresses the required development time (in days). The angle formed between the round numbered points and the squared points (inside the graph) represents the delay in days during the entire project. In this case, initial estimated time for conclusion was 180 days, but the real time demanded was 198 days.

According to the final control graph (presented in Figure 7), it is observed that the development process presented acceptable deviations until phase 2. In phase 3 a major reevaluation was necessary in order to bring the project back to the acceptable zone.

Following the analysis, there was a delay in evaluation 4 caused by alterations performed over the product project after the evaluation 3. Evaluations 5 and 6 indicated that the delay was partially recovered, as well as some improvement in the global performance index was verified.

A set of final indicators related to project performance can be computed: i) quality index of product features $Q^p = 0.62$; ii) index of attendance of target-cost $C^p = 0.5$; and iii) index of global performance $Des^p = 0.67$. The total delay in relation to the latest date was 18 days. These parameters can be either used as project indicators describing quality, cost and time or as base information for project management of further similar projects.

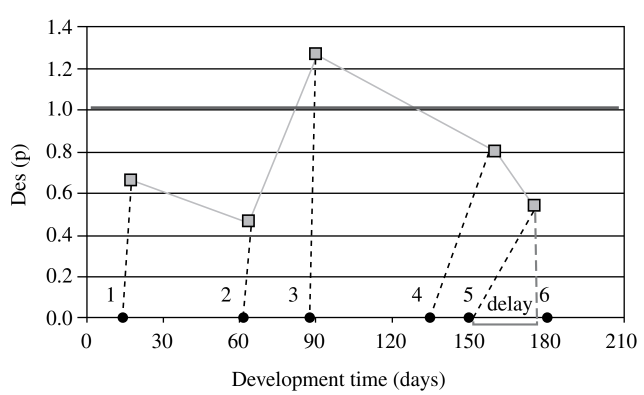

Figure 6. Control graph of product performance during the pilot line phase.

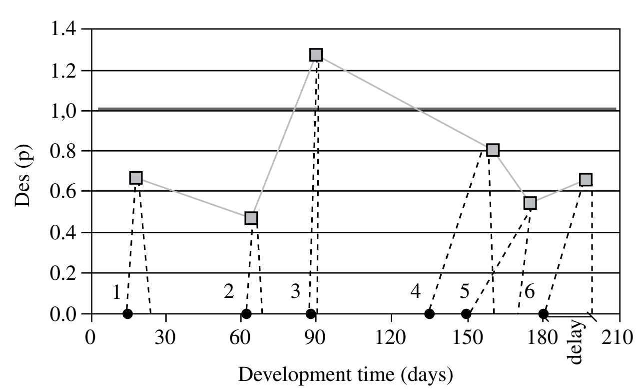

Figure 7. Final Control Graph for the tricycle.

4. Conclusion

At the first stages of the PDP, product demanded features are known. This knowledge comes from market research or from information consolidated during strategic meetings. After the conceptual development, however, the product is submitted to several adjustments concerning materials, dimensions, and production techniques. These adjustments can be useful in order to fit the product to physical and technological constrains. However, they also can lead to substantial deviations compared to the initial demanded features. In this way, appropriate methods are necessary for process control during the PDP.

Among several control techniques available for that purpose, the documentation between the departments and the method called "stage-gates" are the most divulgated. In this article, we presented a complementary form of control based on metrics that measures the deviations from the original idea (the one that satisfies market desires). The proposed metrics combine deviation relative to quality and cost in a unique measurement.

The application of such control system on product features and cost demands accurate planning. At first, the team must realize the advantages brought by the use of scales and metrics. Some of these advantages are the identification of problems concerning important issues (avoiding brainstorming for urgent solutions) and process control in real time, which reduces the costs of rework due to immature decisions. Metrics also prevent the releasing of inappropriate products (i.e. products with features not desirable by customers).

The use of software containing a routine for metrics calculation might facilitate the application of the PDP control, turning the evaluations accessible to all correlated areas.

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