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Robust Design Impact Metrics: Measuring the effect of implementing and using Robust Design

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Robust Design, Effects Measurement, Design Process, Design Metrics

Abstract

Measuring the performance of an organisation's product development process can be challenging due to the limited use of metrics in R&D. An organisation considering whether to use Robust Design as an integrated part of their development process may find it difficult to define whether it is relevant, and afterwards measure the effect of having implemented it. This publication identifies and evaluates Robust Design-related metrics and finds that 2 metrics are especially useful: 1) Relative amount of R&D Resources spent after Design Verification and 2) Number of 'change notes' after Design Verification. The metrics have been applied in a case company to test the assumptions made during the evaluation. It is concluded that the metrics are useful and relevant, but further work is necessary to make a proper overview and categorisation of different types of robustness related metrics.

1. Introduction & Delimitation

Organisations constantly strive to optimise their operations in general, including their product development process. To do this, metrics are used to monitor and benchmark performance over time, against competitors, between projects, etc. Production companies typically consist of a number of different departments with different responsibilities such as *production*, *product development*, *quality assurance*, *sales*, etc. It is the impression of the authors, that there is a notable difference in the use of performance metrics between departments. For example, in *production*, performance is measured using metrics such as *production yield*, *process capability*, and *customer complaint rate*, whereas in product development the equivalent metrics either do not exist or are not used. This makes it challenging to measure the performance of a product development department in general.

This contribution is delimited to focus on the measurement of performance related to the implementation and use of Robust Design. Robust Design is a paradigm focused on designing products with a functional performance that is insensitive to variation and noise. As a further delimitation, a distinction is made between *design metrics* and *management metrics*. The former refers to the embedded metrics of the individual Robust Design Methods, such as the Risk Priority Number (Failure Mode and Effects Analysis) and Signal-to-noise Ratio, whereas the latter refers to the overall metrics related to the use of the paradigm. In other words, the pur-

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pose of a design metric is to measure the impact of a change to the design (within a project), where a management metric is to measure the impact of a change to a processes/procedures (across projects). This contribution focuses on the management metrics. More specifically, it would be valuable to have metrics to measure:

1. **The relevance of Robust Design.** Before applying Robust Design, it is beneficial to know the current level of performance in order to evaluate whether Robust Design is a relevant methodology to implement.
2. **The effect of Robust Design.** Implementation of Robust Design (or any other methods), requires resources such as training, change management, documentation etc. Ideally, a positive effect should be seen after the change has been introduced, such as depicted in Figure 1. This data can be used to evaluate the benefits of the implementation.

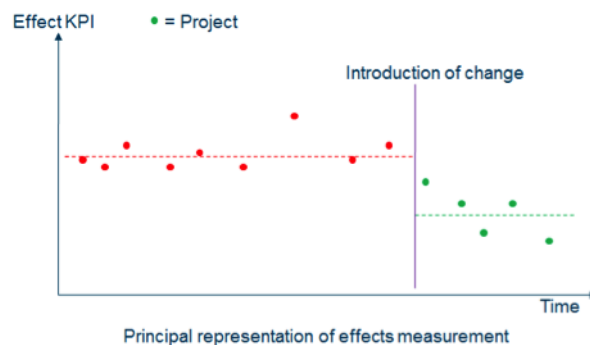


Figure 1 – A principal example illustrating how a performance metric can be used to visualise the effects of implementing a change in the development process.

Summing up, there is need to measure performance of product development in general and of the use and implementation of Robust Design in particular.

The next section introduces some requirements for selecting suitable impact metrics for robust design. The following section then lists, evaluates and selects suitable metrics. Before the concluding section, the results of five case studies are described using the selected metrics (four cases before and one after robust design implementation).

2. Requirements for Robust Design Impact metrics

A simple method, depicted in Figure 2, was used to identify and evaluate the metrics. Based on experience and case descriptions from literature, a list was made of parameters that are typically affected by using Robust Design, such as scrap, lead time etc. For each parameter, the corresponding metric was identified, e.g. scrap being measured by the metric *First Time Yield*. The metrics were passed through a filter of requirements (see below for a detailed description) that had to be fulfilled. The remaining metrics were then evaluated against a list of criteria that would be valuable for the metrics to fulfil. In the end, a shortlist of relevant Robust Design metrics was created. To test the validity of the results, 4 historical case projects were selected and the metrics were applied to these.

2.1 Description of the requirements and criteria

There are certain requirements and criteria that the design metrics ideally fulfil in order to be useful as performance metrics.

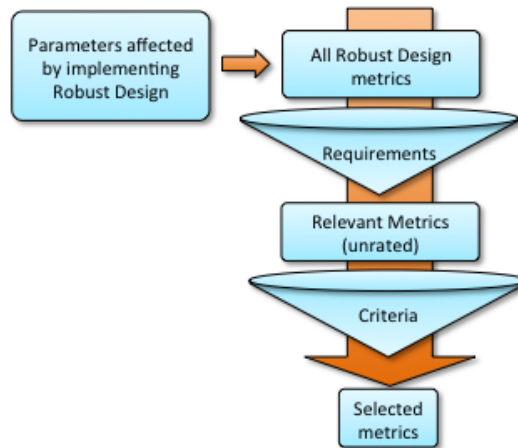


Figure 2 - A visual representation of the method applied for identifying and evaluating Robust Design Metrics

Requirements (Must-haves)

1. **Accuracy.** The quality and accuracy of the data must be trustworthy. Inaccurate data can lead to wrong conclusions. It should be noted that the act of measuring itself, can affect accuracy, either by attracting focus to a certain problem area (Hawthorne Effect) or by inducing a certain behaviour, e.g. including multiple design changes on the same Change Note, to minimise the number of Change Notes being registered.
2. **Relevance.** Data should be of relevance to what we are trying to measure – in this case Robust Design. Irrelevant data can mislead users. An obvious example is using the number of new product introductions as a metric, since this is not closely related to Robust Design (it has stronger correlation to other factors than robust design).
3. **Objectivity.** Metrics should be based on objective data only, as opposed to personal impressions and gut-feeling.
4. **Correct incentives.** Certain metrics can create unwanted incentives, which should be avoided. An actual example of this, from the case company described later, is the measurement of production drawings being 'submitted on time'. This created a strong incentive to register drawings as 'completed', although the quality of the drawings was questionable, which led to many subsequent drawing revisions. As a rule of thumb, any of the so-called *activity based metrics*, which simply measure whether a certain activity has been carried out, is prone to create unwanted incentives. Instead, the metrics should measure the performance related to the activity.
5. **Comparable across projects different in size and type.** The product portfolio in a company may range from complex systems to minor accessories, which means the metrics have to either be unaffected by the complexity of the product they relate to or be *indexable* such that a fair comparison can be made between different products.

Criteria (Nice-to-haves)

1. **Easy to gather data.** The cost and effort of collecting, analysing and storing metrics should be low, since the majority of any optimisation initiative should focus on the actual improvement and less on the measurement of the improvement.
2. **Access to historical data.** Often, the interest for implementing a metric is being able to compare the performance after a change, e.g. a new development process, with the historical performance. Therefore, it is beneficial if it is possible to derive the historical data for the metrics.

- 3. Motivate action.** An impact metric should measure a meaningful impact that could influence or motivate action. It is also beneficial if the metric can indicate the type and extent of action to be taken. Generally speaking, the further removed from cost/profit the less influential the metric is. In this sense, scrap rate is a more meaningful metric than number of specified dimensions or number of over-constraints in an interface.

The decision on how well the identified metrics met the requirements and criteria was made by the authors along with a quality manager and a technology manager from the case company – with an inherent risk that the results to some extent were biased by the experiences of this company.

3. Evaluation and Selection of Potential Metrics

3.1 Parameters affected by Robust Design

Based on experience and descriptions in literature, e.g. Krogstie, Ebro & Howard (2014), the known effects of Robust Design implementation, as well as more broad quality engineering metrics (Buchheim, 2000) were identified in Table 1. For each of the effects, corresponding metrics were identified and held up against the requirements listed in the previous section.

Table 1 – Known effects of Robust Design implementation benchmarked against the identified requirements: 1) Accuracy, 2) Relevance, 3) Objectivity, and 4) Correct incentives

What will change	Metric	Fulfilment of requirements	
Time to market will become shorter	Manhours pr. project	<input checked="" type="checkbox"/> Relevant <input checked="" type="checkbox"/> Objective <input checked="" type="checkbox"/> Incentive <input type="checkbox"/> Comparable	<ul style="list-style-type: none"> • Large and small projects are not comparable. • Accuracy is low due to unclear definition of when a project is started, eg. if pilot projects come before the actual project and in the case of platform architecture (projects may only develop variant solutions). • Meta-metric that can be affected by other and more dominant changes than RD
R&D Expenses pr. project	R&D Costs	<input checked="" type="checkbox"/> Relevant <input checked="" type="checkbox"/> Objective <input checked="" type="checkbox"/> Incentive <input type="checkbox"/> Comparable	
Fewer and less demanding specifications on drawings	# of specifications IT-grade (Tolerance level) of specification	<input checked="" type="checkbox"/> Relevant <input checked="" type="checkbox"/> Objective <input type="checkbox"/> Incentive <input type="checkbox"/> Comparable	The quality and information level of drawings are strongly dependant on the operator and can change dramatically e.g. due to the introduction of GD&T

Fewer late design changes	# of change notes	<input checked="" type="checkbox"/> Relevant <input checked="" type="checkbox"/> Objective <input checked="" type="checkbox"/> Incentive <input checked="" type="checkbox"/> Comparable	Fulfil all requirements, although care should be taken regarding accuracy, since systems for logging change notes can be tweaked, e.g. by logging multiple design changes on the same change note.
Increased predictability in project execution	# of milestones being delayed (measured against project plan at previous milestone)	<input checked="" type="checkbox"/> Relevant <input checked="" type="checkbox"/> Objective <input checked="" type="checkbox"/> Incentive <input checked="" type="checkbox"/> Comparable	Care should be taken about accuracy, because project plans typically change over time, making it difficult to exactly define a 'delay'
	R&D resources used in late stage design	<input checked="" type="checkbox"/> Relevant <input checked="" type="checkbox"/> Objective <input checked="" type="checkbox"/> Incentive <input checked="" type="checkbox"/> Comparable	Fulfil all requirements, although accuracy could be affected by the definition of late-stage design. In the case company, the late stage was defined as all activities coming after the Design Verification Milestone
Shorter ramp-up time	Weeks between <i>Design Verification</i> and <i>Product Launch</i> milestones	<input checked="" type="checkbox"/> Relevant <input checked="" type="checkbox"/> Objective <input checked="" type="checkbox"/> Incentive <input checked="" type="checkbox"/> Comparable	Fulfil all requirements
Fewer recalls and customer complaints	Customer Complaint Rate	<input type="checkbox"/> Relevant <input checked="" type="checkbox"/> Objective <input checked="" type="checkbox"/> Incentive <input type="checkbox"/> Comparable	Robustness related issues often occur when variation is increased, which could happen over time. An example of this is automobile recalls. Using customer complaints as a metric would require data from the entire lifetime of the product, which would strongly complicate data gathering. Furthermore, many companies have very low complaint rates e.g. due to effective quality assurance procedures.
Fewer quality issues in production	First-time yield (FTY)	<input type="checkbox"/> Relevant <input checked="" type="checkbox"/> Objective <input checked="" type="checkbox"/> Incentive <input type="checkbox"/> Comparable	Difficult to make comparisons between different types of products. Yield can be attributed to other things than the product, e.g. issues with the production equipment.
Increased predictability in project execution and product launch	# of milestones/launches on time	<input checked="" type="checkbox"/> Relevant <input type="checkbox"/> Objective <input checked="" type="checkbox"/> Incentive <input type="checkbox"/> Comparable	Lack of access to historical data Project plans are constantly changed – unclear which version of the plan should be used. Difficult to compare small and large projects.
Reduced variation in functional performance (Quality Loss)	?	<input type="checkbox"/> Relevant <input type="checkbox"/> Objective <input type="checkbox"/> Incentive <input type="checkbox"/> Comparable	An accurate and absolute metric was not identified to describe the variation in functional performance of a product.

Evaluation of metrics against criteria

The metrics that fulfilled the requirements were then evaluated against the criteria listed in the Method-section, and the results were collected in Table 2.

Table 2 - Evaluation of how well the relevant metrics meet the criteria for good Robust Design Metrics.

Metrics	Criteria					
	Ease of gathering data		Access to historical data		Motivate action	
# of Change Notes	+	Already stored in Product Data Management (PDM) System	+	Simple lookup in PDM-system	+	Costs and inconvenience of reworking inventory, notifying suppliers, etc. is typically obvious
# of delayed milestones	+	Simple metric to gather on-the-fly	-	Risk of ambiguous historical data	?	It is not given that the consequences of milestone delays are apparent to all
% of R&D resources used after Design Verification	+	Merging milestone dates with time registration	+	Milestone dates are typically maintained in PDM-systems	+	Wrong use of experienced R&D resources and cumbersome firefighting
Weeks btw. Design Verification and Product Launch	+	Simple metric found in PDM system	+	Simple metric found in PDM system	-	Not necessarily a problem to have a long ramp-up, if only it is predictable

Summing up, two metrics were found to be particularly useful as Robust Design Metrics, namely the **% of R&D resources used after Design Verification** and **# of Change Notes**.

4. Case Results

The identified metrics were used in the case company, to validate the results. Four recent projects were chosen as historical case projects, that could act as a benchmark by which future projects could be measured.

Gathering data for the metric *% of R&D resources used after Design Verification*, was done by collecting project time registrations for the case projects, as well as the historical milestone dates, from the company's PDM system. Combining the two data sets, it was simple to calculate the absolute and relative use of R&D resources for each phase of the project. The data is represented in Figure 3. The company had expressed, that for an ideal project, the R&D expenditure after the Design Verification milestone would be limited, as the project would gradually be handed over to the production department. More precisely, it was expressed that after Design Verification only a further 20-25% expenditure would be experienced in an ideal project. As the figure shows, only 1 of the 4 projects (Project A) stayed remotely close to this target, whereas the 3 other case projects all experienced that more than half of the total R&D expenditure was used after the Design Verification Milestone. In the Introduction, it was mentioned that metrics could be used to evaluate the relevance of Robust Design.

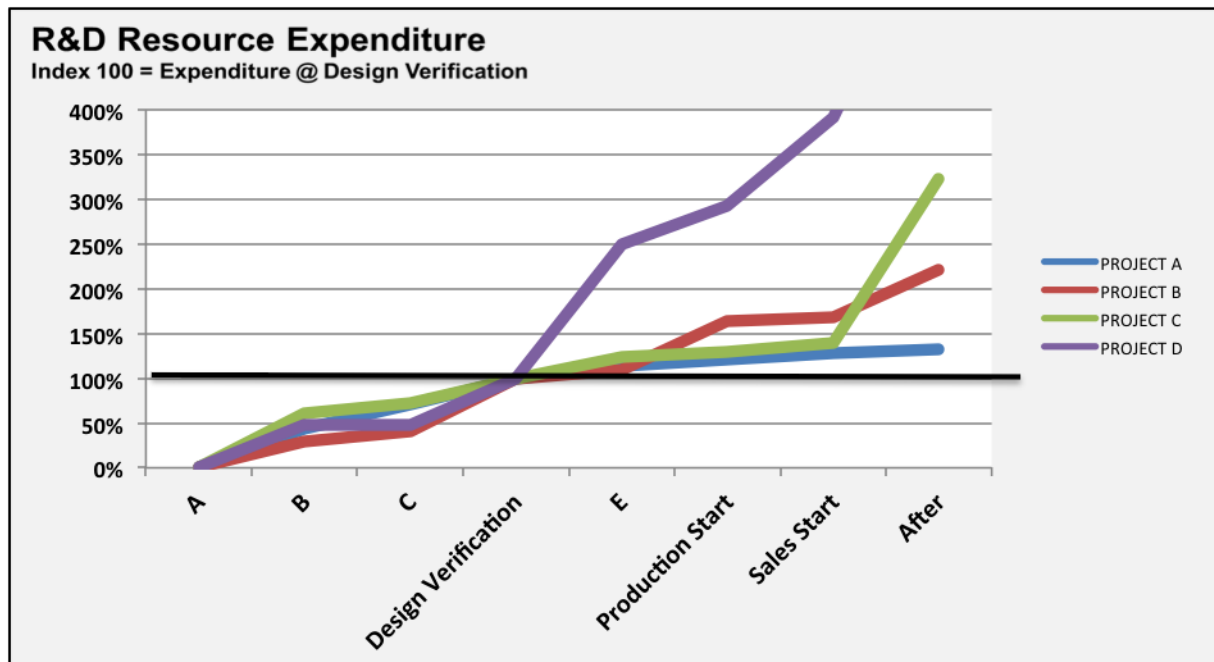


Figure 3 - R&D Resource Expenditure during project phases. Ideally, after Design Verification, R&D expenditure should be limited. It turned out that 3 out of the 4 projects had more than half of their total expenditure after Design Verification.

The second metric, # of Change Notes, was collected by making a simple query in the company's PDM system. This generated a report with 800 Change Notes, with a short description of what the problem was and what had been changed. A group consisting of the author, two quality managers and a technology manager categorised the change notes. First, they were categorised into software, hardware and mechanical issues and afterwards, the mechanical issues were subcategorised into structural failures, usability, tolerance issues etc. This procedure took app. 4 hours. The results are shown in Figure 4.

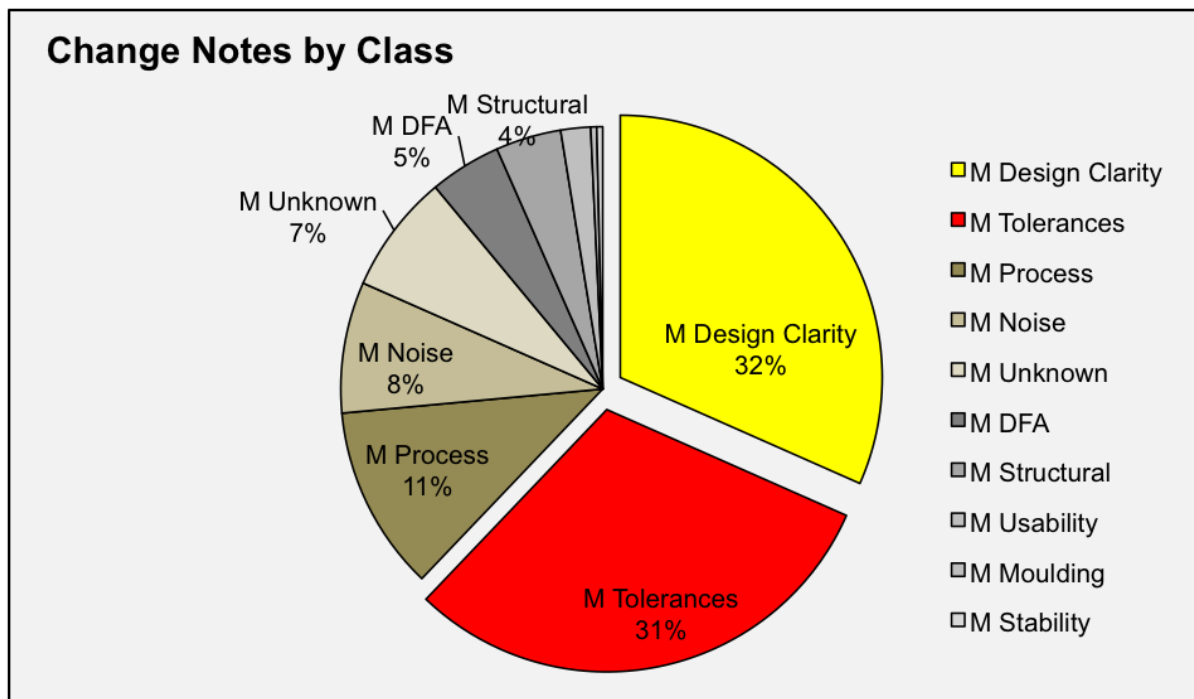


Figure 4 - Mechanical Change Notes subcategorised into various issue-types. 63% of the change notes were related to tolerance and so-called Design Clarity issues.

The first classification showed that 65% of the total number of change notes was related to mechanical issues. Out of these, a total of 63% were related to issues regarding *design clarity* and *tolerances*, which includes parts conflicting, functionality being outside specifications, suppliers not being able to meet tight tolerances etc.

5. Discussion & Conclusion

Two metrics have been selected as being useful for measuring the relevance and effect of applying Robust Design in an organisation. They were selected by first listing metrics related to robust design and then evaluating these against a set of requirements and criteria.

The metrics, *% of R&D expenditure used after Design Verification* and *# of Change Notes*, have been tested in a case company that had struggled to keep deadlines and launch dates. The metrics acted as an eye-opener to the case company and put quantitative data on what already existed as a gut-feeling; the issues were primarily mechanical and they were discovered in the late design phases, i.e. after design verification. This indicates that implementing Robust Design in the case company could be relevant, since one of the main foci of Robust Design is to reduce issues & failures related to variation, which is often first discovered during ramp-up, when the production volume is increased.

One notable limitation of the metrics is the role that non-robustness related reliability issues can have. For example, not having materials delivered on time, materials being delivered but out of spec, miscalculating engineering properties leading to unintended functionality (such as poor stress estimations) or overlooked safety or usability concerns that arrive late. All of these issues would have an effect on the chosen metric and are not robustness related. Therefore, a project may have prevented misplaced R&D resources through use of robust design, however, this may be overshadowed by the late R&D resources required to solve catastrophic reliability/safety issues like those mentioned above.

The process of using R&D metrics in general (and not just related to Robust Design) was welcomed by the case company and rather than just being used for measuring the effect of Robust Design, which was the initial intent, it ended up also being used to support the need for a change in the development process.

The case company has now installed a series of Robust Design Methods, and a follow-up case study will be conducted to measure the effects of Robust Design. The first project, making use of the principles of Kinematic Design and Design Clarity (Christensen et al, 2012) has been conducted, and benchmarked against the other projects in Figure 5. Although one project is not sufficient to make any conclusions, it is included here to show the principle of how the metric can be applied.

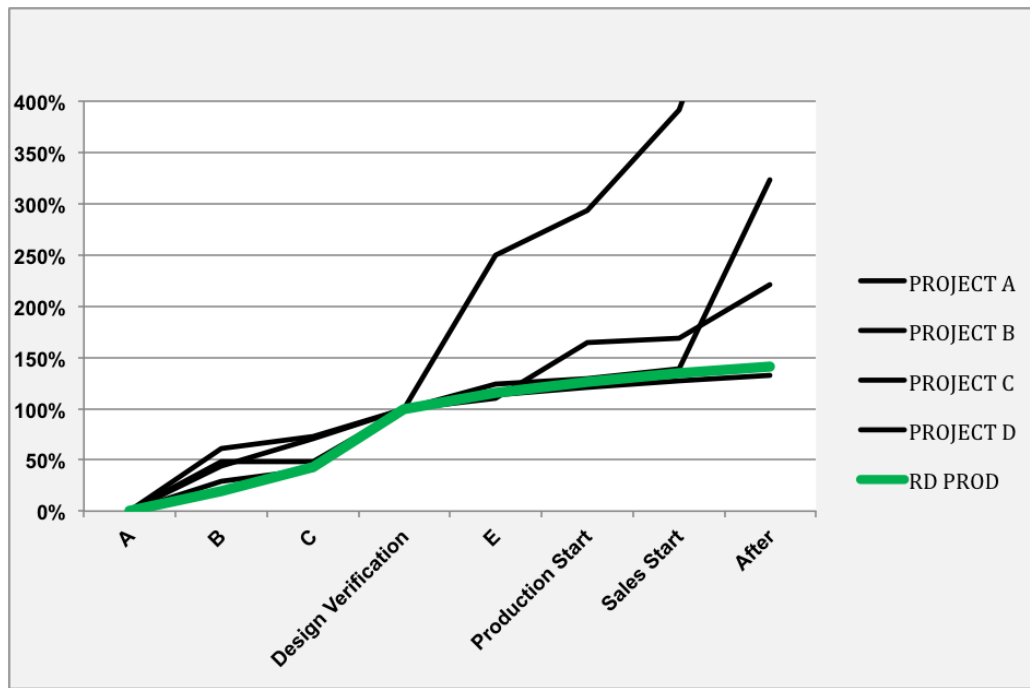


Figure 5 - Followup measurement of R&D expenditure after Design Verification.
The black lines are historical projects, whereas the green line is the first project using Robust Design Methods.

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