Flexible and Low-Cost Measurements for Space Software Development - The Measurements Exploration Framework

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Abstract

Verification and validation is an important part of software development and accounts for significant amounts of the costs associated with such a project. For developers of life or mission critical systems, such as software being developed for space applications, a balance must be reached between ensuring the quality of the system by extensive and rigorous testing and reducing costs and allowing the company to compete.

Ensuring the quality of any system starts with a quality development process. To evaluate both the software development process and the product itself, measurements are needed. A balance must be then struck between ensuring the best possible quality of both process and product on the one hand, and reducing the cost of performing requirements on the other.

A number of measurements have already been defined and are being used. For some of these, data collection can be automated as well, further lowering costs associated with implementing them. In practice, however, there may be situations where existing measurements are unsuitable for a variety of reasons.

This paper describes a framework for creating low cost, flexible measurements in areas where initial information is scarce. The framework, called The Measurements Exploration Framework, is aimed in particular at the Space Software development industry and was developed is such an environment.

1. Introduction

Verification and validation is a major part of the costs associated with developing software for space applications, accounting for a significant part of the costs associated with development. To develop good quality products consistently, the software development process itself has to be of a high quality. Measurements are therefore needed to assess both process and product.

Introducing and collecting measurements, however, is expensive. Measurement have to be developed and tailored to the specific situation, data needs to be collected and analyzed, decisions and modification need to be made constantly. A relatively simple measurement, e.g. counting the number of working hours spent on a task, may be costly in terms of the amount of time it takes a developer to collect that data. To reduce costs without compromising quality in any way, measurements have become automated. Indeed, automation of data collection works to reduce the costs associated with collecting the data while, at the same time, increasing the overall quality of the measurement and the data being obtained and the level of confidence in that data. Automated measurements are, however, costly in terms of development time and require specific data to be available in certain formats.

Moreover, existing measurements require certain information to be available before implementation can begin. Information needs need to be clear, available sources of information need to be known and the process needs to be clear. In the case of automated measurements, the information sources need to be known both in terms of the type of information available but also the format in which such in-

formation is found. In practice, it was discovered that there are situations in which all this information does not exist or cannot be collected due to the prohibitive cost.

The requirement for high quality and reliability that are associated with developing software for the space industry leads to a dilemma. On the one hand, implementing measurements without the required knowledge can be a fruitless and extremely costly endeavor. On the other, the requirements on reliability and the high cost of potential failures demand that all parts of the process are assessed from the point of view of quality.

In this context, the need becomes evident for a low cost, high flexibility framework which would enable the information needs and available sources of information to be identified. Of particular importance is ensuring that such a framework could function and provide useful information in situations where little or no initial information is available and where time and resources are limited. This article describes the general principles underlying the workings of such a framework and a practical example of how these principles have been used in practice. The purpose is to provide practitioners with a means of obtaining the required information in situations with minimal information, for the minimum cost.

2. Background

2.1. VAMOS

In this context of increasing importance of both cost saving and high quality, an ongoing collaboration between Swedish universities and aerospace companies seeks to find ways to optimize cost and quality. One result of this collaboration is VAMOS, as described in [5] [4] [3] [1], a verification and validation management and optimization framework.

The VAMOS framework tries to analyze and optimize existing metrics and select from a given set of measurements, those that best fit a certain situation. The determination of the best fit is made according to issues concerning fulfilling the information needs, minimizing cost and minimizing impact on the company's process. While relying on existing measurements, the framework does describe some measurements that can be implemented, if the ones needed are not in place.

The VAMOS framework consists of a number of steps aimed at performing, analyzing and improving measurements. In addition to these steps, a series of additional tools and toolboxes are defined for various purposes.

The Define Phase seeks to collect information about the setting and the process where the framework is expected to work. Since each situation has specific requirements, it is difficult to define a single process or succession of steps than can obtain information for all settings. The solution chosen instead is to provide in the Define phase a toolbox of different methods. They range from informal interviews to the development of prototype measurements to obtain specific information. A methodology is also proposed to allow constant validation of the current understanding of the process against expert knowledge and the situation in the field.

The Measurements Options Model and the Company Options Model are tools that allow the evaluation, comparison and selection of different measurements based on a number of criteria. The criteria are related to the cost of implementing and performing the measurement, the impact it is likely to have on the process and the stakeholders and others that are deemed necessary for making an informed decision about the measurements.

2.2. RUAG

RUAG Aerospace Sweden AB, a subsidiary of the Swiss- and German-based company RUAG. It specializes in highly reliable on-board satellite equipment including computer systems, antennas and microwave electronics and adapters and separation systems for space launchers. RUAG Space in Sweden has been active on the space equipment arena since the late 60s and has over the years developed world-class products in the areas of Computers and Data Handling Systems, Antennas, Microwave Electronics, Payload Adapters and Separation Systems, Satellite Structures and Sounding Rocket Guidance Systems. The headquarters and location for design and manufacture of digital electronics, microwave electronics and antennas is in Göteborg, Sweden and employs 320 people (in December 2009). Typically up to five projects are developed simultaneously in varying team sizes of about 10 people. The software projects range from 10 KLOC to 100 KLOC depending on the project and are developed mainly in C but with some low level parts written in assembler.

In terms of development processes, RUAG adopted the Integration Driven Development process. The focus of this process is on the development of software, hardware, testing equipment as separate modules that are then integrated with each other. The system is then seen as the gradual build-up of modules. Often, modules are developed in parallel. A hardware component and the software drivers that control it may be developed at the same time, often with test software and test hardware modules as well.

The Integration Driven Development process is iterative. The first iteration defines all the modules and the relationships between them. As components are developed, they are integrated into the product to provide functionality. Any integration problems or compatibility errors are solved as they are discovered. The Integration Phase is the most important and the longest phase of this process. Issues discovered dur-

ing the Integration Phase may lead to the corrections to the modules and, in more extreme cases, to complete re-design.

3. The Measurements Exploration Framework

3.1. Context

During the implementation of the VAMOS framework at RUAG, it was discovered that certain situations are not suited for implementing existing measurements. For the purposes of this article, the situations where necessary information is unavailable are called "exploratory situations".

A number of measurements are being collected from existing databases. Test-case related measurements are being used to assess progress, requirements related measurements, collected from requirement databases are used to assess the amount of work still to be done. These measurements, however, focus on certain particular aspects and shed little light on the Integration Phase in all its complexity. For example, the software components are influenced to a great extent by the others. As a result, just tracking changes in software version repositories will not capture the full complexity of the situation and will provide little insight in the overall quality of the process.

Exploratory situations are characterized by a general lack of information. The information needs are not defined or ill defined, the available information sources are unknown and the centralized means of collecting information is lacking. This situation raises significant difficulties in implementing any measurement. The unknown information sources make it difficult to start any measurement implementation, while the ill defined information needs may make even a successful implementation irrelevant.

Note that the lack of information that determines the exploratory nature of the situation refers to the lack of information that successfully captures the complexity of the entire process and can be used for assessment and improvement. As stated before, measurements do exist for various components, but an overall evaluation of the Integration Phase based on those would be incomplete.

Introducing measurements in this type of setting is encouraged both by the need to ensure appropriate verification and validation and by the potential cost saving improvements that may be made there.

Obtaining more information about the situation, the information needs and information sources, is an integral part of the Measurements Exploration Framework. The ultimate goal, however, is to implement a set of measurements that fulfill the immediate information needs.

The Measurements Exploration Framework begins by defining the context for the implementation. Known information needs and information sources are identified and form the basis for the first iteration of the implementation. The first iteration seeks to see the extent to which the type of information available currently fulfills the information need and tries to determine the types of that are still needed. These types of information form the basis for a new step. This approach is repeated iteratively until the information needs are deemed to be satisfied. Then the measurements can be said to be stable.

In the initial stages, the focus is more on identifying the types of information that is needed and the types of data sources that can provide such information. Moreover, given the flexible and fluid nature of exploratory settings, the preferred measurements focus on delivering "good enough" information quickly, rather than on providing the most accurate data.

3.2. Goals

The framework has two goals.

On a low level, it seeks to provide practitioners with a low-cost, highly flexible measurement that is suitable for low-information environments. This provides an immediate benefit to the company, in addition to its contribution to the other goals.

At a high level, the frameworks seeks to define the information needs, available information sources and process details and enable a more detailed knowledge of the setting in question. As this goes on, the setting becomes better known and less "exploratory" in nature and allows other approaches to become possible as well.

3.3. Essential Notions

The Measurements Exploration Framework relies on a number of notions. To fully understand the framework, its intention and purpose and its applicability, it is important to clearly define the meaning of these notions.

Information Need.

The information needs describes the information that is needed in a given context. This includes type of information that is needed, the way it will be used, the level of accuracy required, the priority level, impact on the overall decision-making process and any other attribute that impacts on the data collection process.

For example, if information about delays is needed, it is important to know what level of accuracy (to within 1 man-hour or 1 man-day) is the information required to have and how quickly the information is needed (expected delays may play a significant role in daily planning sessions, so they will need to be available for those meetings). In addition, it may be important to note that such information may have a significant impact on the planning for that day and high priority may be due to the consequences of faulty planning. The fact that this information will be collected

to improve the planning process and not to evaluate personnel or departments may have a significant impact on data collection, so it should be mentioned as well.

Each stakeholder in a process may have a different set of information needs, depending on their view of the context in question. Defining the information needs of each set is the responsibility of that stake-holder, though researchers and consultants may provide assistance. It is, however, important that each stake-holder is responsible for deciding if the information he/she is provided with fulfills their information needs and, if not, what type of additional information is required.

Information Availability.

This concept defines the information that exists in a certain environments and that can be collected by means of some measurement.

Information may be stored in documents and artifacts. Examples of this type of information include: lines of code, faults found in reviews and code inspections, requirements and requirement stability, etc. This type of information is easiest to collect and is the main focus for measurements.

A lot of information, however, may exist in a setting and not be recorded. Causes for delays are usually discussed in detail, problems encountered with modules and libraries may be the subject of meetings and discussions. Once such discussions are concluded, if such information is not recorded, it is lost.

Thus, information that is present in the system is considered ”available” if it is already being collected or if it may be collected in a practical manner.

Exploratory Setting.

This notion describes a particular context where information needs and availability are not clearly defined. Once investigations start, and information becomes available, the stake-holders perception of the setting may change and, with it, their information needs may change as well.

The initial stages of an investigation into an exploratory setting are characterized by a high level of instability. The information needs identified lead to measurements being introduced. New measurements provide new information and, as new information becomes available, the perception of the system changes, as do the information needs.

The instability of the information needs leads to certain challenges in working in an exploratory setting. The instability of the information needs leads to a more fluid selection of measurements. Measurements may be introduced on short notice to fulfill newly identified information needs. Conversely, existing measurements may be removed, sometimes soon after introduction, as the information needs associated with them may become outdated or irrelevant, or the measurements themselves may be deemed insufficient.

This type of unstable environment favors measurements with certain attributes. Cost, in terms of both time expenditure and the effect implementation would have on the existing process is a major factor in measurement selection. Since measurements may be abandoned soon after introduction, the focus is towards low-cost measurements that have a low impact on the process already in place. The speed at which the measurement can provide results is also an important factor. Measurements that offer quick results may be evaluated sooner. Evaluation may lead to abandoning a measurement, thus saving the cost of collecting irrelevant data, or it may lead to an increased level of confidence in the measurement. The combination of these factors ensures that resources are funneled towards relevant areas and measurements, while allowing newly discovered information needs to be quickly and cheaply investigated.

Note that accuracy is not an important factor in this type of setting. The focus on speed in providing results and low measurement cost entails a reduction of accuracy. In addition to this factor, early measurements may be based on inherently inaccurate information sources or on sources whose accuracy is unknown. If the accuracy of the data source is in question, the accuracy of the measurement looses its importance.

Once more and more information on an exploratory setting is collected, systematized and made available, it ceases to be an exploratory setting. As information needs and sets of measurements stabilize, there is less of a need for quick, flexible responses to emerging situations and more for accuracy and automation in terms of data collection. This transformation is, however, outside of the scope of application for the Measurement Exploration Framework.

Burden of Decision.

This notion describes the responsibility of making certain decisions and, as a results, ensuring their implementation and owning their results. The stake-holder that carries the burden of decision will be provided with all relevant information and pertinent advice, but is ultimately, uniquely responsible for the implementation of the framework, as well as the appropriate use of any results to emerge from this implementation.

As an example, the Measurements Exploration Framework relies on the principle of placing the burden of decision with the company where the framework is being implemented. This enables the company to focus on items that it finds of interest. In practical terms, it means that decision makers in the company select an owner for the measurement. That person is responsible for the major decisions such as prioritizing information needs, deciding the set of measurements, accepting or rejecting new measurements and modifications to existing measurements and so on.

3.4. Overview of the Measurements Exploration Framework

The exploratory nature of the context has determined a particular structure of this framework. The fluid nature of the information needs and of the available information has lead to a separation of concerns between different components of the framework. This enables the same thinking and overall approach to be used in varying circumstances. The components are as follows:

Information Needs Elicitation and Evaluation.

The information needs and context information in such an exploratory setting are quite flexible and fluid. As a result, any sort of elicitation process would have to be performed repeatedly. Moreover, the initial information available to any elicitation method is likely to change, as is the focus of subsequent efforts. As a result, what is needed is a toolbox of different methods, focusing on different aspects, with different initial requirements and suitable for different situations. When the Framework for the Management and Optimization of Verification and Validation Activities, known as VAMOS, was described in [5] and [4] and implemented in [3] such a toolbox was defined. The solution, thus, was to reuse the Define Step of that Framework with some minor alterations. Rather than being an initial step, as in [5] and [4], or a permanent process running in parallel, as in [3], it is now an integral part of the framework. The tools within can be used at any time they are deemed suitable in the running of the Measurements Exploration Framework, although the need for such tools is most evident in the Information Needs Analysis and Reevaluation phase, as we shall see later.

While the Define Step is the toolkit used for developing and the initial validation of the framework, it is important to note that any toolkit is suitable, provided it offers the required insight into the information needs, information availability and the context factors that will influence the understanding of the setting at an acceptable cost. As guidelines for selecting an appropriate toolkit as well as the appropriate tools, note that in an exploratory settings the cost incurred for measuring a certain aspect and the speed with which data becomes available to decision makers are more important than accuracy. Due to the fluid nature of the setting, very accurate data might become outdated, obsolete or irrelevant quite quickly.

Separating this component from the rest of the framework enables already existing resources to be used as much as possible and more suitable tools to be incorporated when needed. It is, however, of the utmost importance that a component providing this type of data is available.

Decision Support.

Since the Measurements Exploration Framework means to shift the burden of decision to the company, it is of utmost importance to provide decision makers with proper decision support tools. During the development of the Framework, such decision support was provided by the Company Measurements Options component of the VAMOS framework [3]. That tool offers the ability to classify all available measurements in terms of factors such as: accuracy, the information goals they seek to achieve, the level of effort needed to implement and perform them, the degree of process change required and others that might be relevant to decision makers. Moreover, it can be expanded to include other factors that may have been overlooked or that are relevant in a given situation.

Methods that are thought most suitable, given the context and the requirements, are selected and are presented to decision makers. The purpose is to allow the stakeholders to make an informed decision about what is most suitable in their context, for their purposes and within their strategy and goals.

This component was separated as a result of the focus the framework has on shifting the burden of decision towards the companies. Other mechanisms for providing decision support than the one presented here are possible. Nevertheless, the underlying goal of allowing the major decisions to be made within the company is a major factor of this framework and should be supported by any replacement decision mechanism.

Measurement Implementation and Evaluation.

New measurements, aimed both at determining the information needs and later at satisfying those needs, have to be implemented and evaluated throughout the activity of this framework. As a result, this component has a central role in the activity of the framework and it will be discussed in greater detail.

3.5. Steps of the Measurements Exploration Framework

The goal of this framework, as stated before, is to provide as much information as possible in an exploratory setting. The end result will be both a clearer understanding of the context itself and a set of measurements that satisfy the information needs. Later steps can include automating the measurement process and other improvements, but those are outside of the scope of this paper. This goal is achieved by an iterative process. The steps of this process are identified and explained below.

Information Need Analysis and Reevaluation.

This step is concerned with identifying and evaluating information needs. During the first run the immediate information needs are identified. Once this is done, the first model of the information needs can be created. This model

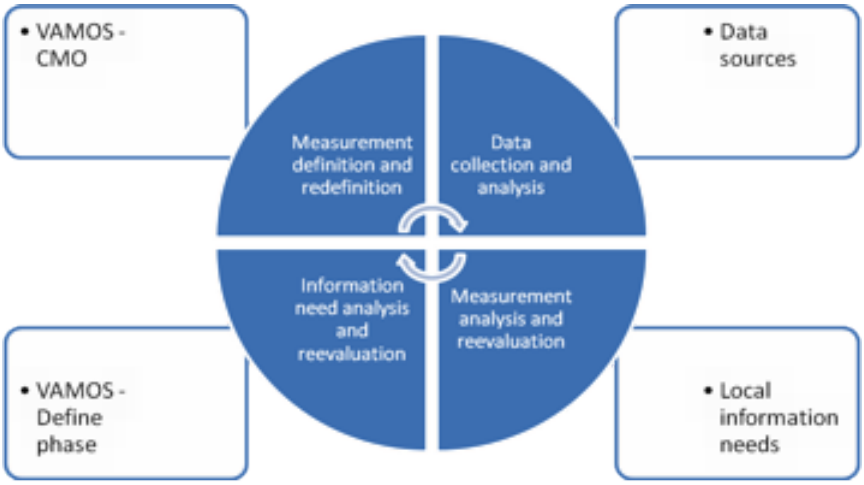

Figure 1. The Measurements Exploratory Framework

will serve as the basis for both the following steps and for further models. This model includes, in addition to the information needs identified thus far, the information sources identified, a model of the process being used, and any other information deemed useful to the correct application of the framework.

In subsequent steps the model created is analyzed with respect to the new information becoming available. The additional information may shed new light on existing information needs, helping to clarify and define them further, or rendering them obsolete. Alternatively, existing, but previously unknown, information needs may come to light and will have to be incorporated into the model. Another possibility is that new information needs will arise, as the information becoming available may lead the research into completely new directions.

This step defines what the company goals are, how they reflect in the information required and what priority is assigned to each item of information. This step requires input from the Information Needs Elicitation and Evaluation component, since that toolbox should provide most of the needed information. As stated earlier, the Define phase component of the VAMOS framework was used for the purposes of developing and evaluating this framework. The need for that component to offer low cost tools that provide quick results becomes evident, since these tools will have to be used extensively with each iteration.

Measurement Definition and Redefinition.

Once the information needs have been identified and established, at least for the current iteration, measurements have to be defined to satisfy them. At this stage existing measurements are evaluated and modified or removed as needed and new measurements can also be introduced. It is important to note that measurement definition is done in accordance to the entire model developed at the previous step. Information availability and process considerations influence the choice and the analysis. The focus, however, is on satisfying the information needs that have been identified.

The choice of new measurements is based on the information needs identified in the previous step as well as direct input from decision makers within the company. This is where the decision support component enables the company to take an active part in selecting the measurement. During the development of this framework, the Company Measurements Options component of the VAMOS framework was used [3]. The emphasis on providing useful and accurate information and allowing the company to make an informed decision made that component ideal for the task.

Measurements can also be developed at this stage, to address specific issues. If established methods do exist, they can be slimmed down to reduce cost and increase response time. If that is not possible, ad-hoc measurements can be developed and implemented and, if successful, these measurements can be later replaced or refined.

The accuracy of the measurements being developed is not as high as that of existing and established measurements. This is mostly due to the focus on low cost and on the high speed of development and data collection. This is to be expected, since accurate measurements involve additional costs and reduced flexibility and adaptability to changing situations. The focus on exploratory settings, however, means that information being provided by these measurements, however lacking in accuracy, are nonetheless the best information available and a significant improvement on the previously obscure situation.

It is important to note that this step favors measurements that focus on low cost and fast response times. Getting in-

formation back quickly and with as little modification as possible to the existing process is more important than increased accuracy. This is mostly due to the volatile nature of the exploratory setting. The next iteration might redefine the information needs and render a measurement useless. It is therefore important that as few resources as possible are spent, and therefore wasted, on measurements that may be rendered obsolete.

Data Collection and Analysis.

Based on the information obtained regarding information sources and the measurements selected, data is collected and analyzed. At this stage the analysis focuses on the degree to which the data provided by a measurement is in accordance with what was expected. The information collected at this stage forms the basis for the analyses that will be later performed on the measurements and on the information needs.

Measurement Analysis and Reevaluation.

The information collected at the previous step is now used to analyze the performance of the measurements themselves and the degree to which the measurements provide the information needed.

The analyses performed at the data, measurement and information need levels may overlap to a considerable extent. The purpose of all these analyses is to determine how appropriate the measurements were for providing the needed information, while at the same time determining if the information needs themselves are still relevant. This overarching analysis is broken down into steps for the purposes of clarification. It is important to note that these steps can, and most often will be, concurrent.

As more information becomes available, information needs change an a new iteration can begin. The iterations are meant to be quite short, since the goal is to obtain the needed information as quickly as possible.

After a number of iterations, most of the information is already known and the models of information needs, availability and process stabilize. With the stabilization of the information needs, fewer fundamental changes are brought. The set of measurements to be implemented also stabilizes and the measurement changes begin to focus on accuracy and, if at all possible, on automation. At this time, it can be said that the setting is no longer ”exploratory”, since information about it is available. Once this stage is achieved, the activity of this framework ends. Certain components may remain in place, particularly those relating to decision support for the company, but the overall goal can be said to have been achieved.

The Measurements Exploration Framework aims to be a complement, not a replacement, to other measurement approaches. It is meant to be used under certain circumstances, when there is little information available, situations where existing measurements cannot be applied or don't perform as well. Once the information needs and information sources are identified and validated, the measurements developed with the framework can be replaced by other approaches, depending on the situation. Thus, the MEF is an initial step in investigating a low-information environment. It enables practitioners to get initial information at low cost and, based on the information, make the best decisions on how to proceed.

4. Evaluation

The evaluation of the Measurements Exploration Framework is still ongoing, and more information should become available, as the framework is being used.

A preliminary evaluation has already been made, based on an implementation of the framework and has yielded useful and encouraging results. The prototype implementation was made in a hither-to unexplored and unmeasured part of the development process: the Integration Phase. This particular Phase of development was chosen for analysis for a variety of reasons.

Importance.

The Integration Phase is the longest phase and the main component of Integration Driven development. It is, therefore, of central importance to the company.

Complexity.

The Integration Phase is where hardware, software, test hardware, test software and test cases, all components that were developed separately, are combined to build and test the final product. Often modifications have to be made, as a result of testing activities or for other reasons. Such modifications, in turn, bring about further changes and more modifications. The complexity of the phase is further increased by the interaction between different departments.

Information Deficit.

As mentioned before, the Integration Phase is a complex stage where different departments interact. This means that there was little centralized information available. Moreover, different IT systems and different processes made the phase even harder to navigate.

Time Constraints.

Due to the nature of the Integration Phase, it is often the case that time is at a premium. Late changes in any of the components ripple through the entire phase and cause further delays. As a side-effect, the process allows relatively little time for data collection, while the costs associated with process change are unacceptable.

As a result of all these issues, the Integration Phase was deemed an ”exploratory setting” and the decision was taken to apply the MEF to obtain more information, to determine and define the information needs and to implement measurements that can begin to address the needs thus identified.

The Define Step of the VAMOS framework [3] was used as the Information Needs Elicitation and Evaluation component. The Company Measurements Options, CMO [3], filled the decision support role.

Due to time and resource constraints, the current implementation sought to identify and address only one key information need. That key information need was deemed to be the early identification of potential delays. Due to the complex and interconnected nature of the Integration Phase, delays in one department have a ripple effect on the entire project. Early identification of delays can enable the company to re-deploy resources to compensate for the delays or minimize their effect.

4.1. The Measurement

Description and Final Form.

The solution was the development of an ad-hoc measurement that allowed for the measurement of delays identified up to the present. The conclusions would be drawn by the Integration Responsible, who was also the owner and main stakeholder of the measurement. To minimize impact on the process, and the costs associated with it, data collection was performed during some of the daily status meetings. Data collection was to be performed twice a week, but the framework was robust enough to allow for missing data points. The robustness proved useful as the amount of work did not allow for data collection at certain times.

The measurement consisted of a method of recording delays and a classification, albeit coarse-grained, to record the probable causes of the delays. Once the measurement was implemented, three iterations were needed to refine the classification and to provide the appropriate manual to use the classification.

The classification used by the stabilized measurement is presented below.

- Specifications are contradicting or incomplete.
- Specifications are changed.
- Incomplete or incorrect manuals (includes incomplete, inaccurate or unintelligible information).
- HW problems
- SW problems
- Timesharing, unavailability of resources (personnel, equipment, other departments, licenses, etc.)
- Planning problems for known work.
- Planning problems for new technologies
- Infrastructure problems

Results and Analysis.

From a Data Collection and Analysis perspective, the results fulfilled the expectations imposed by the measurement definition. The focus on low cost and fast response time yielded a simple, light-weight measurement that provided results immediately after collection. Data handling and interpretation was minimal, further ensuring a low cost. Data accuracy was limited, both due to the focus on light weight and due to the particular conditions of the measurement, i.e. the inherent inaccuracy of performing delay estimates on ongoing work. The data yielded was, however, deemed useful for the course of daily operations and decision making, so it can be regarded as an operational success.

From a Measurement Analysis and Evaluation perspective, the results were a useful first step. The measurement selected and implemented was successful in addressing the information need previously identified. In addition, more information was obtained about the Integration Phase and new information needs were identified and defined.

On the issue of Information Need Analysis and Reevaluation, the measurement confirmed the usefulness of the information need previously identified. Early identification of delays was confirmed as useful information. Moreover, several potential information needs were identified, mostly as specific areas where little information is available and potential improvements may be achieved.

Overall the results fulfilled the expectations, both in operational terms and in terms of the functioning of the framework. Since the framework is an iterative process, more work is needed before the set of information needs stabilizes and a clear set of measurements can be proposed. Nonetheless, this is an encouraging first step in addition to being a useful contribution to the company's development process.

5. Future Work

The first item, in terms of future work, is to achieve a better validation of the framework. Further iterations will be performed in the current setting, to both validate and refine the current version. In addition, implementing the framework in other companies and settings will help show its usefulness

6. Conclusions

While not yet fully evaluated and validated, the Measurements Exploration Framework has been applied successfully and has yielded useful results. The focus on low-information environments is meant to help companies that have few or no measurements in place, as well as those companies that have changed their development process and are not quite sure how to proceed in the new situation.

Focusing on situations where information is unavailable forces certain compromises to be made. Measurement accuracy is sacrificed in favor of low cost and flexibility, as well as the ability to quickly implement and obtain information. The type of setting, however, means that this trade-off is worthwhile, saving time and resources that would be wasted implementing more complex, and potentially useless, measurements. Moreover, if increased accuracy is needed, the framework can point towards the types of measurement that is needed, offers a first, albeit unsatisfactory, example of such a measurements and help define and clarify information need.

As an overall conclusion, the framework presented above seeks to allow practitioners and companies to investigate low-information, "exploratory" settings. This leads to certain trade-offs, sacrificing accuracy in favor of low cost and quick response times. A further focus in on shifting the burden of decision toward the company and allowing stakeholders to take ownership of the resulting measurements. Partial validation of the underlying ideas behind the framework was achieved, although we cannot say that the framework has been validated until further results become available.

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