A Method for Key Performance Indicator Assessment in Manufacturing Organizations

Patrick Hester[1]*, Barry Ezell[2], Andrew Collins[2], John Horst[3], and Kaleen Lawsure[2]

[1]Department of Management and Accountancy
University of North Carolina at Asheville
Asheville, NC 28804

[2]Virginia Modeling, Analysis and Simulation Center
Old Dominion University
Suffolk, VA 23435

[3]Engineering Laboratory
National Institute for Standards and Technology (NIST)
Gaithersburg, MA 20899

Abstract: Key Performance Indicators (KPIs) are an essential element of an organization's ability to monitor its strategic health, helping to ensure the strategic goals of the organization are achieved. However, KPI assessment and improvement is often an ad hoc and consultant-driven process rather than one undertaken using scientific principles. This paper outlines the development and subsequent deployment of a method for KPI assessment founded in scholarly literature and balancing practitioner concerns for ease of use. The proposed method draws heavily on organizational stakeholder involvement at varying levels throughout the KPI assessment process, improving current methods by introducing a mathematical foundation based on value-focused thinking. The proposed method allows stakeholders to evaluate the organization's KPIs in an effort to determine organizational performance against predetermined KPI thresholds. The method is demonstrated on a case study and suggestions for future research are offered.

Keyword — Key performance indicators, assessment, performance management, performance measurement, decision analysis

1. INTRODUCTION

Performance measurements, and particularly key performance indicators (KPIs), provide managers and decision-makers with a snapshot of their business operations, specifically how well a business is achieving its goals. There is no shortage of literature pertaining to organizational performance measurement and performance measurement systems. Public and private sector organizations have for several decades acknowledged the importance of measuring their own performance (Behn, 2003; Bourne, Mills, Wilcox, Neely, & Platts, 2000; Gimbert, Bisbe, & Mendoza, 2010; National Performance Review, 1997; Neely, 1999; Wilcox & Bourne, 2003). Researchers have developed many systems and accompanying approaches to meet these measurement needs (Behn, 1995; Bourne, et al., 2000; Bourne, Neely, Platts, & Mills, 2002; Griffin & Page, 1996; Neely, Mills, Platts, Gregory, & Richards, 1996; Rouse & Puterill, 2003). Despite the substantial guidance available in the literature, it is estimated that as many as 70% of such systems fail after they are implemented (Baggett & Hester, 2013; Neely & Bourne, 2000). Why? Deriving KPIs is not a simple accounting task, and it must include a deep understanding of the business or operation to be successful (Meyers & Hester, 2011), including an understanding of the organizational mission and system context. However, traditional methods for KPI assessment and improvement are ad hoc and consultant-driven (e.g., Baroudi, 2010; Marr, 2012; Parmenter, 2010; The KPI Institute, 2013). While these approaches may be appealing from a practitioner perspective (i.e., you can hire a consultant and they provide a list of KPIs), they lack the formal mathematical foundation necessary for a repeatable, generalizable approach to KPI assessment.

The method developed in this paper for KPI assessment draws heavily on organizational stakeholder involvement at varying levels throughout the KPI assessment process, improving current methods by introducing a mathematical foundation based on value-focused thinking. The paper begins with a background on KPI assessment and

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*Corresponding author's e-mail: phester@unca.edu

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manufacturing. It follows with a stakeholder-centric, proposed method for assessing KPIs for a given organization. This method is then demonstrated on a case study. Finally, some conclusions are drawn regarding future use of the method as well as potential method improvements.

2. BACKGROUND

Fraser (2006) considers that KPIs are vital to business success, especially within the manufacturing domain. Thus, it is critical that good and appropriate KPIs are selected for this purpose. The manufacturing industry has seen a resurgence in the United States in recent years, as organizations such as the National Institute of Standards and Technology (NIST) have emphasized the development of smart manufacturing systems and the standardization of procedures used to manage these systems (e.g., Horst and Weiss, 2015). Key performance indicator assessment and improvement is an integral part of the success of these systems, however, due to the emergent nature of smart manufacturing, it is not always obvious what key performance indicators should be used and whether they can effectively measure the performance of these complex systems. Thus, there is a requirement for a measure of the measures, that is, there is a requirement to develop a KPI Assessment Methodology (KAM) that can deal with emergent manufacturing processes. A successful KAM enables an organization to assess the use of KPIs in a way that helps realize basic corporate goals. The main goal of this paper is to develop and demonstrate such a method.

NIST is currently identifying KPI assessment best practices in manufacturing, to determine if any should be standardized (Horst and Weiss, 2015; Lawsure, et al., 2015). Any standardization that would occur would happen through a Standards Development Organization (SDO), which conforms to the Voluntary Consensus Standards Organization (VCSO) approach, as approved by the American National Standards Institute (ANSI, 2014). Thus, the process of whether or not standardization is necessary is not in question; rather, what is in question is what the best practices are for such a KAM. The research presented in this paper provides a mechanism, through stakeholder workshops, for both assessing KPIs for a manufacturing process, as well as the suggestion for the improvement of these KPIs in the selected process based on best practices. The intent of this research is to evolve it into a NIST standard for dissemination to the broader manufacturing community.

Horst and Weiss (2015) determined a set of twenty criteria with which a KPI can be measured, namely: aligned (when using different levels of KPI), balanced, standardized, valid, quantifiable, accurate, timely, predictive, actionable, trackable, relevant, correct, complete, unambiguous, automated, buy-in, documented, comparable, understandable, and inexpensive. From these criteria they were able to apply a simple weighted average multi-criteria decision analysis approach to determine KPI effectiveness. The simplicity of this approach was to counter the complexity of other proposed approaches, e.g., Carlucci (2010), which is founded on the complex mathematics of the Analytic Network Process (ANP) and would not be acceptable to industry use. Given its popularity and straightforward nature, we suggest the use of an additive utility model versus more cognitively demanding approaches such as the Analytic Hierarchy Process (Saaty, 1980) or its successor, ANP. The practical focus of the proposed approach is in-line with the Engineering Laboratories' desire to promote ideas that enable industrial competitiveness and not just academic merit. However, there are problems with using such a simple approach, e.g., linearity and normalization considerations. Thus, any proposed approach must balance both academic and practitioner concerns. In other words, it must be scientifically defensible to be generalizable and repeatable, but practitioner-oriented so that it is actually used by organizations rather than ignored.

The approach outlined in the paper uses Horst and Weiss (2015) as a starting point, taking their twenty criteria list as a baseline. However, to avoid issues of linearity and normalization, we use a rank sum method in the criteria weighting calculation and a value function approach to elicit information from the stakeholders without requiring them to perform complicated calculations. From this, we have developed a complete method for KPI scoring, selection, and assessment. The research outlined in this paper remains grounded to practical implementation due to the incorporation of Subject Matter Experts and Stakeholders throughout the development process. The following section outlines the proposed method.

3. METHOD

The proposed KPI assessment methodology (KAM) uses Value Focused Thinking (VFT) (Kenney, 1992) to provide a sound mathematical foundation for KPI assessment. Value functions are often built through subject-matter expertise assignment and have the following form:

$$V(x) = \sum_{m=1}^{n} w_m v_m(x_m) \qquad (1)$$

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where m is the index measure, xm is the level of the mth index measure, vm(xm) is the value of the value function at level xm, and wm is the product of the weights for each level up the hierarchy.

A depiction of the KPI life cycle is shown in Figure 1. This process usually begins with target process identification, then proceeds to KPI definition and continues in a cyclical manner from there.
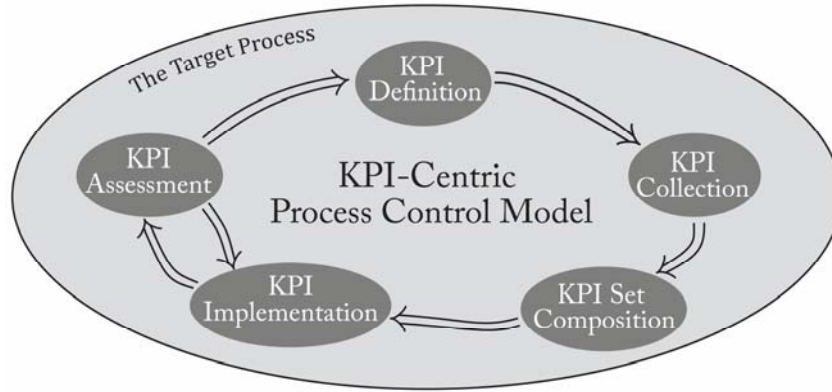
Figure 1: KPI Life Cycle

The proposed method focuses specifically on Figure 1's KPI assessment step. This KAM is shown in Figure 2. The methodology is broken down into two major phases: 1) KPI Characterization and 2) KPI Alignment and Balance. This paper focuses on Phase 1, and the remainder of this section provides an overview of its 11 steps, as shown in Figure 2. Several elements of Figure 2 require elaboration. Activities include a preparatory activity intended to be executed outside the scope of the facilitator-led stakeholder event (as indicated by a green oval), an individual stakeholder activity (as indicated by a red diamond), a model calculation (as indicated by a white polygon), or a group activity (as indicated by a yellow rectangle). Further, calculations may take place by a web-based FileMaker Pro interface (as indicated by a "W") or via an Excel spreadsheet (as indicated by an "E"). It should be noted that steps 1-4 are expected to be completed prior to steps 5-11, which are typically executed during a 1-2 day, facilitator-led workshop. The facilitator is intended to be an individual that is external to the organization so as to avoid any internal bias.
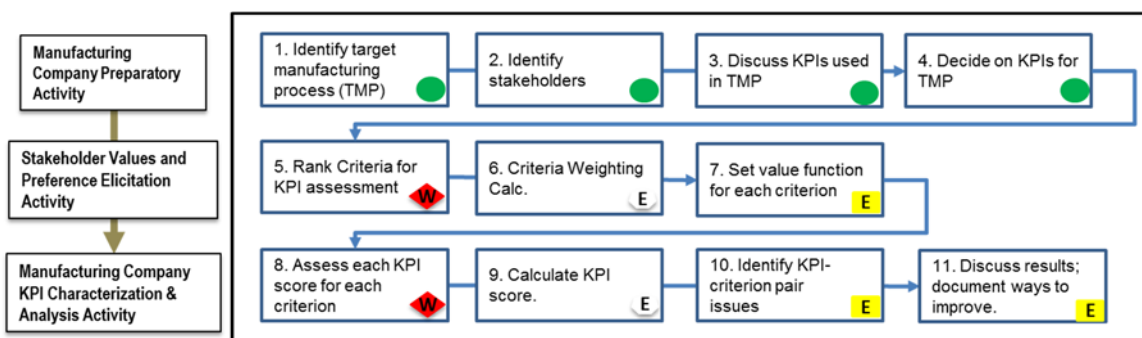
Figure 2: KPI Assessment Methodology

Step 1: Identify target manufacturing process

Problem definition is neither trivial nor straightforward. Vennix (1996) agrees, stating of messy problems:

> *One of the most pervasive characteristics of messy problems is that people hold entirely different views on (a) whether there is a problem, and if they agree there is, and (b) what the problem is. In that sense messy problems are quite intangible and as a result various authors have suggested that there are no objective problems, only situations defined as problems by people. (p. 13)*

Hammond, Keeney, and Raiffa (2002) discuss the importance of problem formulation: "The way you state your

problem frames your decision. It determines the alternatives you consider and the way you evaluate them. Posing the right problem drives everything else" (p. 15).

The focus of this research is on existing manufacturing organizations and processes, where, it may be argued, there is general consensus on the problem (or more specifically, process) being considered. So, it is up to the manufacturing organization, with the help of a facilitator if necessary, to determine a priori, the target manufacturing process (TMP) in question to be examined. Armed with a TMP, we can move to step 2.

Step 2: Identify stakeholders

Stakeholder identification is part of a larger process known as stakeholder analysis. Hester and Adams (2013) offer a succinct introduction to stakeholder analysis:

Stakeholder analysis was first explored by Freeman (1984) as a methodology to assist business organization leadership with their strategic management functions. Stakeholder analysis has since expanded beyond the corporate arena. Stakeholders exist at the center of any complex problem solving effort and holistic consideration of them is a key element of analyzing a problem systemically. Stakeholders are the customers, users, clients, suppliers, employees, regulators, and team members of a system. They fund a system, design it, build it, operate it, maintain it, and dispose of it. Each stakeholder contributes their own value-added perspective, as described by the systems principle known as complementarity. (p. 337)

Hester and Adams (2014) introduce the notion of stakeholder identification: "The first step necessary for stakeholder analysis is arguably the most straightforward, that is, identifying the stakeholders relevant to the problem being analyzed" (p. 82). A quandary exists, however. "We must have some notion of our problem before we can brainstorm who might be relevant to the problem solving process, however, we need those very stakeholders to help us clearly formulate (and later reformulate) our problem" (Hester and Adams, 2014, p. 82). Thus, steps 1 and 2 must operate in concert with one another. The key for stakeholder identification is to ensure a broad range of perspectives is incorporated into any KPI assessment approach. This prevents a unilateral perspective and encourages complementary viewpoints are taken into account. It is assumed that stakeholders are identified prior to undertaking a workshop.

Step 3: Discuss KPIs used in TMP and Step 4: Decide on KPIs for TMP

Our empirical results have shown that manufacturing organizations typically have a set of KPIs in house that they currently measure. However, as previously discussed, the relative merit of a given KPI will certainly differ depending on an individual's perspective (i.e., line worker vs. vice president). Thus, it is important that KPIs currently being used are identified, as well as a (potentially) smaller list of retained KPIs to be examined is agreed upon by the stakeholders chosen in step 2.

Step 5: Rank criteria for KPI assessment

Step 5 is the first workshop step to be undertaken. Using a rank sum method, each of the criteria is ranked numerically in descending order, e.g. a one is assigned to the most important criteria, a two to the second-most important, etc., by each of the stakeholders. The criteria that are used in the method are their definitions are found in Table 1. Notice that this list is a reduction of the original 20 criteria identified by Horst and Weiss (2015).

Table 1: KPI Criteria and Definitions (Adapted from Horst and Weiss, 2015)

Criterion	Definition
Quantifiable	The degree to which the KPI's value can be numerically specified.
Relevant	The degree to which the KPI enables performance improvement in the target operation.
Predictive	The degree to which the KPI is able to predict non-steady-state operations and is accompanied by a record of the past performance values for analysis and feedback control.
Standardized	The degree to which a standard for the KPI exists and that standard is correct, complete, and unambiguous; also, the more broad the scope of the standard, the better, for example, plant-wide is good, corporate-wide is better, and industry-wide is best.
Verified	The degree to which the KPI can be shown to be true and correct with respect to an accepted standard and has been correctly implemented Note: The verified criterion is zero if no standard exists, but this is an indication that a KPI used

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	without a standard can be a costly problem
Accurate	The degree to which the measured value of the KPI is close to the true value.
Timely	The degree to which the KPI is computed and accessible in real-time, where real-time depends on the operational context, and real-time means the updated KPI is accessible close enough in time to the occurrence of the event triggering a change in any metric affecting the KPI.
Traceable	The degree to which the steps to fix a problem are known, documented, and accessible, where the particular problem is indicated by values or temporal trends of the KPI.
Independent	The degree to which the KPI collection, transfer, computation, implementation, and reporting are performed independently from process stakeholders.
Actionable	The degree to which a team responsible for the KPI has the ability and authority to improve the actual value of the KPI within their own process.
Buy-in	The degree to which the team responsible for the target operation are willing to support the use of the KPI and perform the tasks necessary to achieve target values for the KPI.
Understandable	The degree to which the meaning of the KPI is comprehended by team members and management, particularly with respect to corporate goals.
Documented	The degree to which the documented instructions for implementation of a KPI are up-to-date, correct, and complete, including instructions on how to compute the KPI, what measurements are necessary for its computation, and what actions to take for different KPI values.
Inexpensive	The degree to which the cost of measuring, computing, and reporting the KPI is low.

Step 6: Criteria Weighting Calculation

Once all of the criteria have been ranked, it is advatangeous to translate these rankings into weights for use in further calculations. There are many mechanisms for generating weights, including equal weighting, rank order methods, Simple Multi-Attribute Ranking Technique (Edwards, 1971, 1977), and swing weighting (see, e.g., Clemen and Reilly, 2001). The authors advocate the use of the rank sum method, as shown in Eq 2 below, for its simplicity.

$$w_i = \frac{K + 1 - r_i}{\sum_{j=1}^{K} K + 1 - r_j} \tag{2}$$

where r_i is the rank of the ith criterion, K is the total number of criteria, and w_i is the normalized ratio scale weight of the ith criteria. Results of Eq. 2 can be averaged across stakeholders to create a comprehensive evaluation of each criterion's importance. A sample set of stakeholder group weights is shown in Figure 3 below.
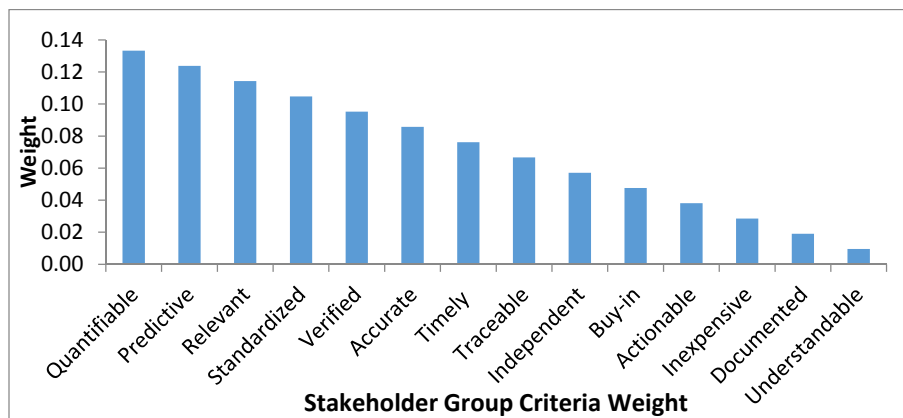

Figure 3: Sample Group Criteria Weights

Step 7:Set value function for each criterion

This task begins by fully documenting each measure. A common framework similar to Ezell (2007) should be used to develop value functions, as shown in Figure 4. It is necessary to account for whether the measure is natural or constructed scale and if the measure is direct or proxy.
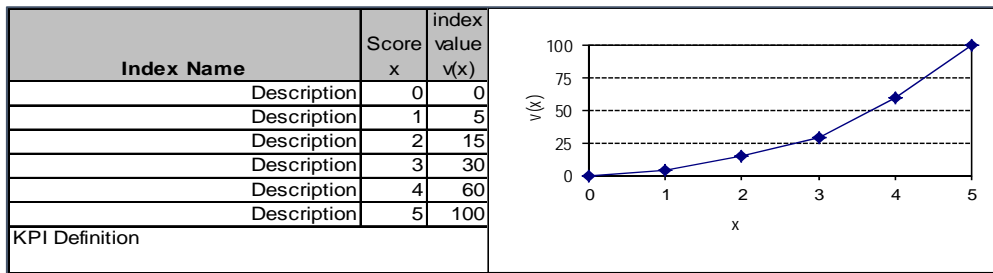
Figure 4: Example Value Function

Step 8: Assess each KPI score for each criterion

A KPI score is a measure of the effectiveness of each candidate KPI for a given manufacturing process. Using the value functions generated in Step 7, each stakeholder independently generates their own rating of each KPI against each criterion. The selection of scores for each KPI with respect to each criterion can be a time consuming activity and may result in decision fatigue (Baumeister & Tierney, 2011). This adds further credence to the importance of properly selecting KPIs earlier in the process.

Figure 5: KPI Criteria Characterization
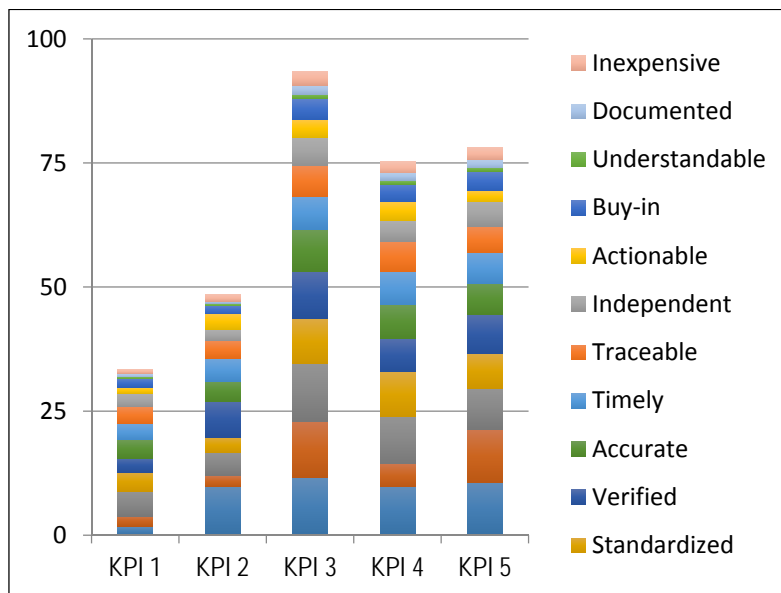
Step 9: Calculate KPI score

Once all of the stakeholders have scored the KPI-criterion pairs individually, each KPI is assigned a score by each participant (this is done automatically via Excel based on already-collected information). This score is determined using Eq. 3:

$$v_{ik} = \frac{\sum_{j=1}^{M} \overline{w_j} \, \overline{v_{ijk}}}{\sum_{j=1}^{M} \overline{w_j}} \tag{3}$$

where M is the number of criteria, v_{ik} is the ith KPI score from the kth stakeholder. v_{ijk} is the ith KPI score, from the kth stakeholder, for the jth effectiveness criterion. The stakeholder average weight of the jth criterion is given by $\overline{w_j}$. Completion of this step can be visually demonstrated using a stacked bar chart similar to that shown in Figure 5.

Step 10: Identify KPI-criterion pair issues and Step 11: Discuss results; document ways to improve

These steps call for a discussion between the stakeholder to determine whether any of the results shown in a graphic such as Figure 5 appears anomalous or problematic. For example, stakeholders, faced with Figure 5, maybe troubled by KPI 1's poor performance relative to the others. At this point, we may wish to document that KPI 1's performance is a concern, but more investigation is necessary. This is because the KPIs do not exist in a bubble. They operate in a set and they are tied to strategic objectives. In this manner, they require further investigation, pursued in Phase 2 of the KAM. While more advanced methods exist (Collins, Hester, Ezell, and Horst, 2016), a general heuristic that the authors suggest employing as a starting point is to suggest improvement where the greatest deviation exists between a KPI-criterion pair and its ideal (i.e., there is the most room for improvement).

4. CASE STUDY

In early 2015, the authors conducted a workshop with a leading chemical manufacturing company to assess a environment, health and safety process they employed as well as to test out the KAM. This case study provides highlights of this engagement. The scope of the initial engagement covered the tasks outlined in Phase 1 of the KAM.

Step 1: Identify target manufacturing process

The company was interested in assessing an internal process they had focused on environmental, safety, and health. The process was identified as business-critical for the organization.

Step 2: Identify stakeholders

The manufacturing company identified five stakeholders to participate from varied levels of the organization's hierarchy. These included the site manager, EH&S superintendent, a process engineer, engineering manager, and the production manager.

Step 3: Discuss KPIs used in TMP and Step 4: Decide on KPIs for TMP

The organization pre-selected 12 KPIs for assessment based on the current execution of the process in question and current KPI tracking. After discussion, the stakeholders retained these 12 KPIs.

Step 5: Rank criteria for KPI assessment

Each of the five stakeholders individually assessed the relative importance of the criteria.

Step 6: Criteria Weighting Calculation

Eq. 2 was used to convert the raw rankings of the five individuals into a comprehensive weight for each of the criteria. These weights are shown in Table 2 in descending order of weight.

Table 2: Criteria Weights

Criterion	Weight	Criterion	Weight
Understandable	13.73%	Standardized	6.86%
Quantifiable	12.75%	Documented	5.88%
Actionable	11.76%	Predictive	4.90%
Relevant	8.82%	Traceable	3.92%
Accurate	8.82%	Verified	2.94%
Timely	8.82%	Independent	1.96%
Buy-in	7.84%	Inexpensive	0.98%

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Step 7: Set value function for each criterion

In this particular case, the stakeholders generated one value function and decided to use it for all criteria. This value function is shown in Figure 7.
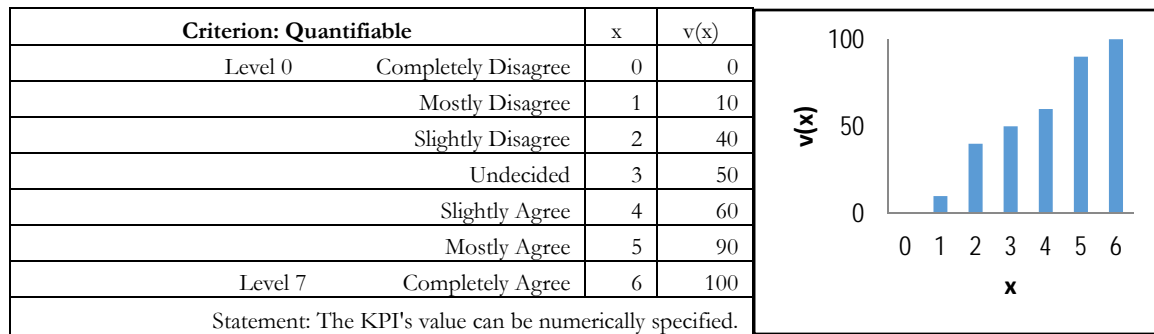
Criterion: Quantifiable		x	v(x)
Level 0	Completely Disagree	0	0
	Mostly Disagree	1	10
	Slightly Disagree	2	40
	Undecided	3	50
	Slightly Agree	4	60
	Mostly Agree	5	90
Level 7	Completely Agree	6	100
Statement: The KPI's value can be numerically specified.			

Figure 7: Standard Criterion Value Function

Step 8: Assess each KPI score for each criterion

Each stakeholder used the value function shown in Figure 7 to assess each KPI's relative success in addressing each of the criteria. This required 14 criteria * 12 KPIs = 168 ratings for each stakeholder.

Step 9: Calculate KPI score

Using Eq. 3, KPI scores were calculated. Table 3 shows these scores, averaged across the stakeholders. The bottom row represents the cumulative total for each KPI.

Table 3: KPI Criteria Scores

Criterion/KPI	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	IDEAL
Quantifiable	12.7	11.7	9.8	10.4	10.0	10.6	9.8	8.5	9.8	8.1	6.4	1.7	12.7
Predictive	1.6	2.3	2.3	2.4	2.2	2.1	2.0	2.2	3.3	3.3	2.2	1.9	4.9
Relevant	7.4	7.4	5.4	6.0	6.5	6.6	6.9	6.8	6.0	5.6	6.3	3.2	8.8
Standardized	5.8	5.6	4.6	3.8	2.7	1.5	3.4	3.9	3.5	4.2	3.1	1.5	6.9
Verified	2.5	2.4	2.4	1.8	1.3	1.7	1.5	1.3	1.5	1.6	1.2	0.6	2.9
Accurate	7.4	6.8	7.1	6.8	5.7	4.9	4.0	4.7	4.7	4.4	5.4	0.7	8.8
Timely	7.2	7.2	5.7	5.0	5.4	6.2	5.6	4.9	5.3	5.4	5.3	1.9	8.8
Traceable	3.3	3.2	2.4	2.4	2.4	2.6	2.5	1.8	1.8	2.2	2.3	0.2	3.9
Independent	1.1	1.1	0.8	1.0	0.8	1.0	1.0	0.9	0.9	0.9	1.2	0.9	2.0
Buy-in	5.9	5.9	5.8	5.2	5.6	4.3	4.3	4.1	3.5	4.8	3.8	1.4	7.8
Actionable	8.6	8.4	7.8	8.2	8.0	8.0	7.8	7.8	8.4	6.7	6.7	2.7	11.8
Inexpensive	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.6	0.3	0.5	0.5	0.5	1.0
Documented	4.8	4.8	4.9	3.7	4.4	3.7	4.4	4.7	2.3	3.5	3.8	1.2	5.9
Understandable	11.4	11.4	11.4	11.2	10.1	10.8	10.8	11.0	10.3	10.1	7.3	4.6	13.7
Total	**80.2**	**78.7**	**70.9**	**68.6**	**65.7**	**64.5**	**64.5**	**63.1**	**61.7**	**61.2**	**55.5**	**23.1**	**100.0**

Step 10: Identify KPI-criterion pair issues and Step 11: Discuss results; document ways to improve

A number of KPI-criterion pairs were determined to be insufficient at this stage, based on their deviation from the potential ideal score they could achieve. The top 20 potential KPI Improvement scores for the KPI-criterion pairs as ranked by greatest difference between the scored value and the ideal value, in the context of the target manufacturing process, are shown in Table 4. This list serves as an initial starting point for further investigation and for targeting of resources in improving KPI and overall organizational performance.

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Table 4: Suggested Improvements

KPI	Criterion	Improvement Score	KPI	Criterion	Improvement Score
11	Understandable	6.4	5	Standardized	4.2
11	Quantifiable	6.3	8	Accurate	4.1
6	Standardized	5.4	9	Accurate	4.1
10	Actionable	5.1	11	Buy-in	4.0
11	Actionable	5.1	8	Actionable	4.0
7	Accurate	4.8	7	Actionable	4.0
10	Quantifiable	4.6	6	Accurate	3.9
10	Accurate	4.4	8	Timely	3.9
9	Buy-in	4.3	3	Actionable	3.9
8	Quantifiable	4.2	4	Timely	3.8

5. CASE STUDY FINDINGS

In addition to the numeric results of the case study, several qualitative findings were also generated during deployment of the KAM. They are summarized in the following four recommendations made by the authors to the client:

1. Starting with the highest scoring KPI-criterion pair in Table 4, improve the performance of the KPI in terms of the criterion in the context of the examined TMP. Once it is improved as much as possible, move on to the next KPI-criterion pair in Table 4. Continue until all KPI-criterion pairs have been addressed or all organizational resources (i.e., personnel or available funds) are exhausted.

2. Once the organization has made the suggested improvements, conduct a follow-up workshop to examine the effect of improvements. Rescore criterion weights and KPI criterion scores, compute KPI scores and KPI improvement scores, and measure the improvement from KPI scores from the first workshop.

3. If the resultant improvement is determined at the second workshop to be insufficient, determine a new set of KPI-criterion pairs for improvement and repeat Steps 1-3.

4. Additionally, conduct a follow-up workshop to address Phase 2 of the KAM; that is, to explore KPI Alignment and Balance. This workshop will include assessment of current KPI relevance and existence of a balanced set of KPIs, KPI alignment to strategic objectives, and possibilities for reduction or (if necessary) introduction of KPIs.

Each of these findings is generalizable and is applicable to any usage of the proposed methodology by any stakeholder as a path forward once an initial workshop has been conducted. The generalizability is based on the mathematical foundation of value focused thinking on which the approach is founded. Thus, while an organization's individual results may be different, the findings presented in this section can be applied to any set of results generated using the proposed methodology. In general, understanding what KPI-criterion pairs should be improved and where resources should be focused assists organizations in achieving their strategic goals, the achievement of which is being monitored by the very same KPIs.

6. CONCLUSIONS

This paper presented a straightforward method for assessing KPI performance for a manufacturing organization. This method attempted to balance practitioner concerns (i.e., ease of use) with a proper mathematical grounding for validity. The proposed method has two phases: 1) KPI Characterization and 2) KPI Alignment and Balance, with this paper focused on the development of Phase 1. A leading manufacturing organization partook in an exercise to demonstrate the Phase 1 method and this paper reports the results of that investigation. The authors have begun developing methods in support of Phase 2, i.e., Collins, Hester, Ezell, and Horst (2016), and it is the intent of the authors to explore further case studies to give additional validity to the proposed method. Future enhancements should include additional software support and advanced analytics for improvement recommendations.

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