INFORMATION QUALITY FOR OPERATIONS: FRAMEWORK AND MODEL

(Research in Progress - IQ Concepts)

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Abstract: A framework and model of information quality anchored in operations-management theory and based on realistic assumptions. It shows the role of information as a factor in operations, how theories of operations management affect information needs with their respective quality requirements, and how information qualitatively and quantitatively affects models; it identifies the universally necessary use requirements that make information usable and useful at four levels of expectations to make operations effective, ethical, efficient, or both ethical and efficient. Requirements are objectively categorized, ordered, and prioritized for examination in research and practice. It proves the futility of aggregated direct measures of quality and proposes an aggregate that indirectly measures how information, its quality aspects, and properties contribute to the extent that the purpose of operations can be attained.

Key words: Operation factors: their quality aspects, properties, usability, usefulness, and levels of expectations; information use requirements: their taxonomy, ordering, examination priorities; aggregate indirect measure of operational quality

INTRODUCTION

There are many approaches to assessing the quality of information [5, 9, 21, 26, 36, and 37]. One needs a unifying theory that is flexible enough to be embedded in any commonly used operations-management theory and one that objectively measures the impact of information quality on results. Any model derived from such a theory, including the assessment of the quality of factors, must be anchored in defined situations (circumstances) that are viewed through the lens of decision making. The proposed model targets routine operations [9] that sustain us in every-day life and in all other endeavors. Exploration, research, and development require different approaches [12]. A vision of operations with regard to purpose, management philosophy, critical success factors, goals, and the measurement of results are the subject of strategic management.

This paper (a) proposes a framework and model of information quality that is always embedded in and subordinated to the philosophy and theories used to manage operations; (b) presents data and information as factors in operations; (c) provides an overview of the necessary use requirements to classify, order, and prioritize them for research and practical applications; (c) proves that operational quality cannot be directly and summarily assessed objectively; and, instead, (d) proposes an aggregate indirect measure of information quality by measuring how it impacts results.

The suggested model (a) reduces information to discrete patterns of physical states that may represent aspects of reality or its contingencies, (b) reduces informing to developing and spreading such patterns among acting humans and their organizations [10], (c) focuses on aspects of information use, and (d) defines quality as an aggregate of the entire experience of users at all of the touch points related to the use of information (paraphrased from [28]). A touch point may entail one or more quality aspects (dimensions) and requirements determined by users' needs and expectations with regard to necessary and desirable properties of information use.

For brevity, no usual review of literature is provided. The model is presented for challenge, critique, and discussion. For focused reading, key terms in paragraphs are in **bold** font, emphasis is in *italics,* highest emphasis is underlined, and terms accompanied by a definition appear in ***bold italics***.

To analyze operational quality, it is useful to consider its role as a factor in operations. This pertains to all factors in form, such as data (decision-makers' given and available representations), information about their changes, and other elements of knowledge (relationships, rules of reasoning and proceeding) [9]. Their impact on results is the common denominator in assessing operational quality of factors.

INFORMATION AND ITS QUALITY AS A FACTOR IN OPERATIONS [9, p. 13]

There is a ***reality*** with entities such as objects and events of certain properties and relationships among them. Entities can be described by states that are intrinsic to them and by their states relative to other entities. Elements of reality may facilitate or inhibit operations. ***Operations*** are processes that are conducted and/or controlled by acting humans and their organizations; they may include natural processes. Planned operations are triggered depending on opportune situations. They are subject to the competitive, collaborative, and/or adversarial motivated will of participants.

Processes are networks of partially (asymmetric, transitive) ordered closed sets of state transitions or transformations of factors. They may be natural or by design. *Processes by design* require information about their design, factors subject to transformation, energy, means (e.g., *tools, equipment, etc.*), workforce, control, and/or management of their conduct. Meeting their purpose crowns the processes and makes them graph structures as defined in the theory of sets.

A ***factor*** is anything that affects results of operations. To this end, factors must meet some ***requirements*** that may pertain to physical, chemical, biological, or structural aspects as determined by the needs and expectations of significant stakeholders. Factors may be in substance or in form.

- ***Factors in substance*** must be transported to where they are needed. They entail the first three known Ms (material, machinery, and manpower), products, services, energy, or means of warfare with their respective *properties* (specific states of their respective quality dimensions).
- ***Factors in form*** can be observed, communicated, and/or transported. They may symbolically represent reality or its contingencies (possibilities), including methods. They are patterns of physical states that may represent *existing objects* or *events* that *occurred,* their *properties*, and other elements of knowledge (e.g., *relationships, rules of reasoning, and rules of proceeding*). The accuracy of the representation is the outcome of the quality control of their mapping.

Factors may be available or not yet available. Unavailable factors are not part of this view. Available factors in substance are considered ***resources***, those in form, ***data***. Not-yet-available factors must still be acquired or delivered. They are either routine or non-routine.

- ***Routine factors*** are known by type and their role; if in form, they are the to-be-acquired ***routine information*** for routine decision making.
- ***Non-routine factors*** are still unknown or unrecognized but of potential significance, such as new materials, tools, or devices. If *in form* (inventions, patents, methods, algorithms, programs, etc.), they constitute ***non-routine information*** of a strategic and/or exploratory nature that requires different approaches [12], which are not the subject of this paper.

Commonly, data are not distinguished from information, which may be the label for any factor in form.

THE FRAMEWORK AND MODEL – ASSUMPTIONS AND DEFINITIONS

A fruitful framework needs a solid point of reference, a frame of reference, and a unit for measuring results [4, pp. 5-8]. The framework is defined from the ***praxiological*** perspective (theory of human conduct or actions)—its fundamental triad: effectiveness, ethics, and efficiency [11]. The presented operational framework and model are based on the following assumptions and definitions:

Assumption GA1: The **main purpose** (e.g., *profit, unconditional surrender, saved lives, etc.*) of routine operations serves as the main ***point of reference*** and is measurable or at least detectable**.** In existing organizations, it may be a critical success factor (e.g., *cash flow, net income, retained earnings, return on equity, net present value, etc.*) that is articulated within a framework of the theory of managing such operations; for instance, the Theory of Constraints (TOC) [13, 15] proposed by [16] as the theory for operations management, Management by Constraints (MBC) [33], Management by Criticalities (MBCII) [33], Hierarchical Balanced Criticalities (HBC) [33], the Theory of Swift Even Flow, or the Theory of Performance Frontiers [29]. Purpose depends on the philosophy that guides strategic management of organizations. Merits of these theories are not discussed here. TOC has appeal for many practitioners because it covers a broad spectrum of business operations and nonprofit organizations within infinite loops of ongoing improvements that also include one-time projects or campaigns; hence, TOC examples will illustrate the concept.

Assumption GA2: ***Managers*** are the main **driving force** and **observers (**including mechanical or other types of sensors serving them). They participate as **interested agents** (as viewed by John Dewey [21]) and act within specific circumstances—frames of reference.

Definition GD1: A ***Frame of reference*** describes, according to the available knowledge, the circumstances of operations by

- **SN—**a set of states of nature **sn ∈ SN—independent variables** of significant materiality or impact on operations—factors beyond the control of decision makers (e.g., *weather conditions*)
- **DV—**a set of states **dv ∈ DV** of **dependent variables** of significant materiality or impact on operations—under the control of the decision maker (e.g., *to use or not to use* a toll road by truckers)
- adopted **criteria** of effectiveness, ethics, and/or economy of operations

Assumption GA3: A unit of the adopted **measure of results** of operations $\mathbf{M_{RO}}$ serves as a ***yardstick*** derived from the missions of business organizations, public administrations, or military operations.

Definition GD2: Measure of results—$\mathbf{M_{RO}}$ pertains to the **extent to which the main purpose P** has been attained (effectiveness) as a function of all (universal quantification ∀) **variables SN** and **DV,** formally $\forall$ **sn ∈ SN, dv ∈ DV:** $M_{RO} = M_{RO}(P, SN, DV)$. When decomposing the organization into subunits and assessing their local performance, one needs a cohesive system of measures that directly contribute to the measure of the overall performance.

Assumption GA4: Operations O can be decomposed into a network of **elementary tasks t ∈ T (closed set of all tasks)** with related **clusters cf(t)** of **elementary factors f ∈** $\mathbf{F_O(T)}$ required for each respective task as practiced with PERT [24], formally ∀ **t ∈ T,** n = cardinality of |T| : $F_O(T) = cf(t_1) \cup cf(t_2) \ldots \cup cf(t_n) = \bigcup cf(t)$.

Definition GD3: ***E is a set of entities*** (e.g., *factors, information, data, quality aspect,* or *properties*—states of qualities**)** ***e ∈ E*** that causes **materially significant** state transition in the situation and its model.

Definition GD4: ***Materiality M(e)*** of situation-specific ***use of entity e*** $\in$ ***E*** is measured by the difference in the measure of results $\mathbf{M_{RO}}$**,** when operations are conducted with and without the entity **e,** formally $\forall$ **e** $\in$ **E :** $\boldsymbol{M(e) = M_{RO}(E) - M_{RO}(E - e)}$**.**

Definition GD5: ***Materiality M(e) is significant*** if the absolute **(| |)** difference of results of operations $\mathbf{M_{RO}}$**,** when conducted with and without them, is not less than the ***threshold of significance*****—**the minimal increment $\mathbf{s_{min}(\Delta M_{RO})}$ of materiality **M(e)** under the policy of decision makers, formally $\boldsymbol{|M(e) = M_{RO}(E) - M_{RO}(E - e)| \geq s_{min}(\Delta M_{RO})}$. In operations, it provides sufficient reason to give entity **e** its due consideration. Of course, the set $\mathbf{F_O(T)}$ of elementary factors of operations **O** in Assumption GA4 is a subset of the set **E** of materially significant entities.

Assumption GA5: ***Postulate of teleological perspectivism*** [24] and ***restricted relativity*** [4, p13] ***of assessments***. Aspects are assessed equally unless the purpose and frame of reference change. When change occurs, even physically identical entities may be assessed differently by decision makers. Restricted relativity limits the model to local operations, e.g., where our astronomical time still makes sense.

Assumption GA6: ***Decision makers,*** when making decisions, employ mainly rational or rule-following choices [23] with bounded rationality (Kotarbinski-Simon problem of unattainability of perfect rationality [32, 20, and 35]) and prevention of irrational or unacceptable choices (e.g., *unauthorized trade, access to or movement of nuclear warheads*). Various criteria may be used, such as net income after taxes, retained earnings, payback period, return on investment, return on equity, cost effectiveness, or the possibility of international sanctions or even military action.

Assumption GA7: The model distinguishes four basic levels of expectations with regard to the conduct of operations: **effective, ethical, efficient**, or both **ethical and efficient.**

- ***Effectiveness*** of operations is measured by the extent that they attain their purpose: (a) a real number (e.g., net income); (b) a binary variable, if indivisible; or (c) a fraction between one and zero or in percentage points between 0 and 100%, if divisible. Exclusive use of effectiveness implies that operations are conducted with an all-out effort, regardless of costs, as in special operations or acts of terror.
- ***Ethics*** in operations may be defined by ethical standards or requirements that should be met (e.g., *in business* [18, 27] or the *military code of conduct*).
- ***Efficiency*** measures the economy of operations as the ratio of the output to the input of a process.

All of the above require identification of the significant (see Definition GD5) operational factors that affect the decision situation, the way decisions are implemented, and the results of operations.

Quality of operation factors – Assumptions and Definitions

Initial definitions regarding quality are general and are based on the Aristotelian approach to *quality* as something that enables one to distinguish and define objects. Other needs and expectations will be added later.

Definition QD1: ***Quality Q*** is an infinite multidimensional space of theoretically possible quality aspects q (dimensions or attributes) of distinctive characteristics, $\boldsymbol{Q = q_1 \times q_2 \times \ldots \times q_i, \ldots \times q_\infty}$, where i – is an ordinal number.

Definition QD2: ***Distinguishing quality—*** $\boldsymbol{Q_D(F)}$ *of a class F of factors f* $\in$ *F* (e.g., *aerial pictures, vectors, messages*) is a finite multidimensional space of the **necessary** (e.g., *resolution, precision, length*) quality aspects $nq_i(F)$ of cardinality $k = |nq(F)|$: $\boldsymbol{Q_D(F) = nq_1(F) \times nq_2(F) \ldots \times nq_i(F) \ldots \times nq_k(F)}$

Assumption QA1: ***Monitoring quality focuses on significant factors***, which implies that factors $f \in F$ are a subset of significant entities $e \in E$ (see Definition GD5), formally $\mathbf{F \subset E}$.

Definition QD3: ***Quality of a specific factor*** $f \in F$ (e.g., *tool, data value*) *or parameters of its use* (e.g., *availability*) – ***Q(f)*** is defined by a vector of states—properties (e.g., *true, false*)—of the **necessary** (e.g., *credibility*) $nq(f) \in NQ(f)$ and **other** (e.g., *acquisition cost*) gradable quality aspects $oq(f) \in OQ(f)$. Of course, $Q(f) = NQ(f) \cup OQ(f)$: $\boldsymbol{Q(f) = \langle s(q_1(f)), \ldots s(q_j(f)), \ldots s(q_n(f))\rangle}$ for each $q(f) \in Q(f)$ of cardinality $n = |Q(f)|$. A quality aspect q(f) of factor f can take on one out of two or more distinguishable states—properties $s_j(q(f)) \in S(q(f))$—of their quality aspects $q(f) \in Q(f)$ of factor $f \in F$, where $j \in \{1, 2 \ldots n\}$ and cardinality $n = |S(q(f))| > 1$. A *set S of states—properties s(q(f))—of a quality aspect q(f)* can be Boolean {true, false}, can be defined by enumeration, or can be an ordered set of numbers. The last implies ranking of properties (e.g., *materiality, size, caliber of firearms, etc*.).

Definition QD4: ***Quality requirements*** (derived from needs and expectations of stakeholders) *QR(f)* (e.g., a specific degree of *precision, accuracy, currency*, etc.) for a specific factor f or a parameter of its use are defined by a **vector of required properties**—$rs(q(f)) \in RS(q(f))$: $\boldsymbol{QR(f) = \langle rs(q_1(f)), \ldots rs(q_n(f))\rangle}$ **for each** $\boldsymbol{q(f) \in Q(f)}$ **and** $\boldsymbol{n = |Q(f)|}$**.** To this end, factors must meet adequate use requirements, whether intrinsic to the factor or to the situation in which they are used, but all are *contextual*. Assessment of the quality requirements of information products that serve organizational subunits must be subordinated to the corresponding local measures of performance. This fact precludes any general solution.

Assumption QA2: ***M(f)—Materiality attributed to a specific factor*** *f* is a function *M* of significant **materiality** M (see Definition GD5) **of its significant properties** $s(q(f)) \in S(Q(f)$ for each significant quality aspect intrinsic to the factor or parameters of its use $q(f) \in Q(f)$ of the factor f: $\boldsymbol{M(f) = \mathcal{M}[M(S(Q(f))]}$ for significant properties **s** of significant quality aspects $q(f) \in Q(f)$ of factor f according to Assumption QA1. Properties of factors or parameters of their use acquire materiality M(rs(q(f))) (see Definition GD4) from the situation (purpose, circumstances, and adopted criterion of effectiveness) to which they apply. The same applies to the situation-specific materiality M(f) of a factor's use, which also is a function of the materiality of the properties of the factor or parameters of its use, because a factor acquires its materiality from its properties—states of its quality aspects.

Assumption QA3: ***Materiality M(S(q(f))) of most properties*** $s \in S$ ***of most quality aspects*** intrinsic to the factor or parameters of its use $q \in Q$ *of factor* $f \in F$ is subject to the **law of diminishing returns** [3]; hence, each quality aspect should be used at its optimum s_{opt} or acceptable s_{acc} state because they rarely monotonically improve efficiency of operations.

Significant operational quality of a factor is defined by significant properties of its significant quality aspects, which qualify the factor to play a significant role in operations. The significant operational quality of a factor can be represented as a vector of significant properties of all quality aspects in its quality space that is intrinsic to the factor and/or parameters of its use.

Definition QD5: ***Significant operational quality*** $Q_S(f)$ of a factor $f \in F$ is defined by enumerating its **significant properties** $sp(q(f)) \in SP(Q_S(f))$ of its significant quality aspects that are intrinsic to the factor or parameters of its use $q(f) \in Q_S(f)$, which qualify the factor to play a significant role in operations—a vector: $\boldsymbol{Q_S(f) = <sp(q_1(f)), sp(q_2(f)), \ldots sp(q_i(f)), sp(q_n(f))>}$ for each $q(f) \in Q_S(f)$ of cardinality $n = |Q_S(f)|$.

Definition QD6: The ***state*** (not measure) ***of quality of operations*** is defined by a set of vectors of significant properties of all significant quality aspects of significant factors regarding the purpose and the threshold value of significance; it is an ordered sextet of the (1) purpose **P**, (2) measure of the operation results $\mathbf{M_{RO}}$, (3) threshold of significance (the smallest increment of the measure of results) $\mathbf{s_{min}(\Delta M_{RO})}$, (4) set of significant factors **F**, (5) sets of significant quality aspects of significant factors $\mathbf{Q_S(F)}$, and (6) set of vectors of significant properties of significant quality aspects of significant factors.

The goal is to obtain optimal or acceptable results of routine operations that are assessed by the selected criterion. Quality requirements can be met at their optimum, acceptable (but suboptimal), or unacceptable level but not be left undefined, if significant; otherwise, one acts with incomplete information. One can effectively measure quality of operations indirectly by its impact on results, not by properties of operation factors as practiced in empirical studies or industrial applications of Total Quality Management (TQM). Thus, in operations, significant properties of significant quality aspects of significant factors are at their optimal or acceptable level when the results are optimal or acceptable.

Definition QD7: With optimal or acceptable results of operations, the set of vectors of significant properties of significant factors defines by enumeration the ***optimal or acceptable state of quality of operations,*** as defined above in QD6**.**

In operations, properties of factors acquire relevance, meaning, and materiality (importance) from the purpose and circumstances of operations in light of the adopted criteria of effectiveness or efficiency. This occurs only when a factor becomes a subject of interest, the bone of contention of competing decision makers, who perceive it as relevant, meaningful, and significantly material for their endeavours. According to their perception, they project their power, which manifests itself as a "force field" by authority or by sheer force. It is always of limited significant range, radius, or sphere; it entails the physical, political, and economic forces in society, business, administration, or military operations.

Materiality of an entity is established when it becomes the center of intersecting forces in an equilibrium of supply and demand that is exerted by competing participants (e.g., Britain and Argentina contesting ownership of the *Falkland Islands*). It results in a kind of price tag, not necessarily in monetary terms, of the contested entity until *equilibrium* becomes established at a different level. Properties of factors are of no utility value on their own merit if not subject to such forces; however, properties must be distinguishable.

The situation specificity of operational information quality (see QD6 and QD7) renders the statistical methods of TQM inadequate for both research and practical applications. Such methods cannot produce results of universal scientific validity due to dependence on the context of a particular application. We need a radical paradigm shift from the all-pervasive statistical methods to computer simulation of how operational information quality affects the results of routine operations.

HOW MANAGEMENT THEORIES AFFECT INFORMATION

Philosophies and theories of management provide mental and/or formal models of operations. Models determine the factors of operations that are deemed necessary and significant in attaining the purpose. Among them are factors in form such as data, information, relationships, and rules of reasoning and proceeding. Like other factors, they must meet situation-specific requirements, which may differ substantially. Gupta and Boyd [16] suggest that the theory of constraints (TOC) can serve as a general theory in operations management. In the theory of constraints (TOC), Goldratt [14, p. 19] identifies three simple but fundamental questions regarding how much money a company generates, captures, and spends:

1. ***Throughput***: the rate at which fresh money is generated through sales minus the amounts paid to vendors and other providers for the items that went into the product sold [14, pp. 19-22].
2. ***Inventory***: all the money used to purchase the things the system intended to be sold, including machines and buildings [14, p. 23].
3. ***Operating expense***: all the money spent in turning inventory into throughput [14, p. 29].

Presenting data and information needs, Goldratt [14, pp. 72-78] demonstrates a stark difference between the "cost world" and the "throughput world." In the cost world, factors are of equal importance if they are of equal cost. He writes, "*Focus on everything and you have actually focused on anything*" [14, p. 58]. Indeed, it is difficult to focus in the cost world. Any cost-savings measures are proportionate and always limited by zero. One or more changes do not change much in the cost world. TQM even encourages non-financial measures that are not directly related to the ultimate purpose of operations [14, p. 55].

In contrast, the throughput world is open ended and limitless. By its very definition, it is always focused on that which we do not have enough of, that is, on the weakest link—on the **constraint** that limits the performance of the operations. The theory of constraints articulates a clear paradigm procedure within an infinite loop of ongoing improvements. A change of one constraint changes everything and possibly with a multiplying effect. When management focuses on a new constraint, it moves the focus on quality requirements from one set of data and information to another set, but the situation is always well defined. For instance, increasing processing time and the related cost of one task without offsetting it by a similar decrease of a different task of the same product makes no sense. It contradicts the fundamental principle of the cost world and will be instinctively resisted. In the throughput world, a total increase of processing time on non-constraint resources to offload the constraint resource may be highly beneficial when measured by the overall throughput (fresh money) of the company. TOC provides cohesive and dynamically changing guidelines for ongoing improvements and also criteria for assessing the locally relevant quality of information. It easily derives a hierarchical set of criteria that directly contributes to the overall purpose of operations. "*If the latter means making more money, every measure must have a $ sign*" [14, p. 55]. By the same token, any local measure must be of the same unit as the main purpose.

The same pertains to the locally relevant quality of information items. For instance, only the processing time on the constraint resource needs to be accurate. The accuracy of the remaining processing times do not matter anyway, while in the "cost world," striving for better accuracy was a way of life. The throughput world defines clear boundaries within which quality improvements matter. Going beyond them has no impact on the end result [14, p. 84].

The decision process by TOC is very different. It changes the results, the nature of the required data, and their corresponding quality (e.g., *accuracy*). Let us take another example: Why do we need the "product cost"? We need it to decide which one should be pushed and which one we should refrain from pushing on the market. All cost systems would prefer products with a higher profit margin, while the bottom line measured by throughput (fresh money) suggests just the opposite (i.e., lower unit price and profit but higher volume). Therefore, Goldratt summarizes it this way: "*The concept of product cost together with decision process from the cost world should be eliminated*" [14, p. 14]. If applied, it changes the decision model, the required data (factors), and their quality requirements.

This only briefly demonstrates how the decision making, the required data, and aspects of their quality directly and immediately depend on shifts in philosophy and theories of operations management.

HOW INFORMATION AFFECTS ROUTINE OPERATIONS

Effectiveness, ethics, and/or efficiency of operations are functions of significant aspects of factors' use. The focus is on factors in form (data, information, and elements of knowledge) and their use requirements. Wang and Strong's [(1996)] survey identified a plethora of 179 dimensions of data quality. At first, the multidimensional-quality space appears chaotic. Can information quality aspects and the corresponding use requirements be classified and ordered? For factors to play their role, they must meet many use requirements, which affect results of operations in many ways. Only some aspects are intrinsic to the factors, while all are situation specific, hence *contextual*. Requirements analysis calls for many answers:

1. Which of them affect operations directly or only indirectly?

2. Which are necessary or only desirable?
3. Which of the necessary are primary and which are secondary?
4. Which of the primary are universally necessary or only situation-specific necessary?
5. Which of them affect operations qualitatively or mainly quantitatively?
6. In what order should they be examined?
7. What is the extent of their impact, and how should it be measured?

The extent of changes may vary considerably. For instance,

1. the model of the situation, the way the decisions made are implemented, and the results of operations according to the adopted measure may change them all (the largest extent);
2. the model remains unchanged; however, the changes affect the results of operations and the way decisions are implemented; or
3. the model and the way decisions are implemented remain unchanged; only the results of operations change quantitatively (the smallest extent).

Directly means that changes in use requirements directly affect the decision situation, the way decisions are implemented, and/or the results of operations. ***Indirectly*** means that such changes contribute to the state of quality of their respective higher-order factors (ultimately the direct ones). ***Necessary*** use requirements are mandatory. If any of them cannot be met, it precludes further examination of the affected factor. The necessary use requirements may be primary or secondary. ***Primary use requirements*** are those necessary use requirements that are determined by the nature of the situation, thus objectively independent of the decision maker. ***Secondary use requirements*** depend on the chief executive decision maker; they usually pertain to ethics and efficiency.

Necessary requirements are of the highest importance and of the same ultimate consequences; if not met, the affected factor is not usable for operations. Some are always necessary, hence ***universally necessary***, while the remaining ones are ***other situation-specific necessary***. Only the universally necessary use requirements can be explicitly identified. Jointly meeting the necessary use requirements make a factor ***usable.*** Each factor should be tested first for its ***usability*** at some previously defined levels of expectation. Changes of necessary and sufficient use requirements always qualitatively and quantitatively change the decision situation. Asserting completeness of factors before one establishes their individual task-specific usability makes no sense but is frequently practiced in many studies of data quality.

Changes of quality aspects (subject to use requirements) subsequently require a partial redefinition of the decision situation (e.g., *adding or deleting column(s) or row(s)* from a decision-situation matrix) are ***qualitative changes***. Changes to states of gradable quality aspects affect ***mainly quantitatively*** the results of operations, the decision situation, and/or the way decisions are implemented. Mainly means here that gradable use requirements that quantitatively affect operations do not exceed their respective acceptable limits (e.g., *limits for driving under influence*) or reach other critical states (e.g., *melting, evaporating,* or unexpected *freezing* in deep-water-well capping) that also may trigger qualitative changes.

Among the universally necessary requirements, only operational materiality adequately measures the scope of a factor's impact on operations. Without it, a comparative impact analysis is impossible. It is the fundamental, central, and most pervasive use aspect. Materiality, if of sufficient value, determines the significance of each factor by providing a sufficient reason for its examination; it orders, ranks, and prioritizes factors, their aspects of quality, and properties. Materiality of each factor also lends importance to its necessary companion factors in operations. Thus, information items, including their respective quality aspects and use requirements, can be partially (asymmetric, transitive) ordered by materiality.

Use requirements should be examined in an economical sequence. The necessary requirements may be ordered by their strength as prerequisites. The ***strength of a prerequisite use requirement*** is measured by enumerating the number of necessary use requirements that must be tested if that requirement is met (or not tested if it is not met). Difficulty of testing may again rank those of equal strength as prerequisites. Ordering of the necessary requirements can be determined by their pair-wise comparison with regard to a stated criterion. Indirect use requirements may be ordered by the level of their indirectness, measured as one plus the number of intermediaries between the examined indirect use requirements and the ultimately affected direct one. Thus, indirect factors may be of the first, second, and subsequent orders. Hence, members of each subclass of use requirements can be ordered by their materiality and some other applicable criterion. Subsequently, all categories of use requirements satisfy the axiom of choice [1] of the theory of sets making use requirements *well-ordered sets,* at least in most cases.

In operations, usable factors must be actionably usable. To this end, they must be **operationally effectively complete** for the task to be performed (e.g., *time* and *location* of a meeting of a target). Only when complete can they actually be applied or engaged in operations to become ***actively useful***. Any of them can be ***sufficiently useful*** at any of the four levels of expectation defined before (Assumption GA7).

Factors, to be operationally usable, actionable, and useful, must meet many necessary (primary and secondary) use requirements, which are the focus of the following section.

USE REQUIREMENTS OF FACTORS

Factors in form (data, information, or other elements of knowledge) must be usable for operations by meeting all the necessary **primary** and **secondary** use requirements. Where possible, definitions also contain formal articulations to facilitate their computer-simulated testing.

NECESSARY PRIMARY USE REQUIREMENTS AND EFFECTIVE USABILITY

Primary use requirements of information quality are (1) operationally recognizable, (2) operationally relevant, (3) of operational meaning, (4) operationally significantly material, (5) operationally available on site, (6) operationally available on time, (7) actionably credible, and (8) they must meet all other applicable situation-specific necessary use requirements. The first seven are universally necessary. Their necessity is easier to comprehend when one compares the examination of factors conducted for the first time in contrast to routine examination of factors that play relatively known roles. All of them are **contextual**.

In the literature, quality aspects are commonly attributed to factors that mostly pertain to their use in a specific situation. The commonly used label, “information quality,” actually is a communication shortcut. For instance, operational materiality of a factor in form is the consequence of a state transition that is triggered in a model (mental or formal) by the communicated representation of the factor. It may only marginally depend on the value of its content—its linguistic meaning, if at all. In most cases, it is determined by its operational meaning (e.g., *password*) by design or by an agreement. In well-defined routine operations with informed and knowledgeable participants, linguistic semantics may not play a significant role in communications. This is in stark contrast to the world of politics where not actions but demagogy reign, where skilled and reckless politicians take advantage of uninformed, uneducated, or, worse, government-educated participants with subdued freedom of expression and docile or bought-off, biased media. While reading the following definitions one must keep these remarks in mind.

Operationally recognized**:** First, an observed, transported, or communicated pattern **cp** should be recognized by the entity informed. A communicated pattern **cp** is recognized if it matches at least one (existential quantification ∃) existing pattern **ep ∈ EP** (e.g. *variable, state of a computer, device, or state of mind*—in human terms familiar to them) within the using entity. Formally, **IF** $\exists$ ep $\in$ EP: cp = ep, **THEN** cp = e_r ***– a recognized entity***, **ELSE** cp is ***operationally useless***, excluding research. This is the *first* primary, universally necessary prerequisite use requirement for further examination of potential factors.

Operationally relevant: A recognized entity $\mathbf{e_r}$ should be operationally relevant; otherwise, discontinue its examination. To be ***relevant***, the pattern $\mathbf{e_r}$ must match at least one actual factor $f \in F_O(T)$ of operations or a variable in the decision model. Formally, **IF** $\exists\, f \in F_O(T)$: $e_r = f$, **THEN** $\mathbf{e_r} = \boldsymbol{f_r}$ ***- a relevant* factor, ELSE** $\mathbf{e_r}$ is ***operationally irrelevant***. This is the *second* primary, universally necessary prerequisite use requirement for further examination of factors. The set $F_O(T)$ is the union $\bigcup$ of clusters c of necessary factors f for elementary tasks $t \in T$ (closed set) in the network into which operations O can be decomposed as practiced with PERT [24] according to assumption GA4 of any significant factor $f \in F$ (Assumption QA1), formally $\forall\, t \in T$, n = cardinality of $|T|$ **:** $\boldsymbol{F_O(T) = cf(t_1) \cup cf(t_2) \ldots \cup cf(t_n) = \bigcup cf(t)}$.

Of operational meaning: A relevant factor $\mathbf{f_r}$ must make a difference in the operational situation and must yield a non-zero difference or a non-empty set Θ of differences between the set of current outcomes $O_c(f_r)$ with the relevant factor $\mathbf{f_r}$ and the set of outcomes O_p (without $\mathbf{f_r}$), as viewed by Peirce [27]—the father of verifiability theory of the meaning; otherwise, discontinue its examination. Formally, **IF** $O_c(f_r) - O_p = \Theta$, **THEN** $f_r = \boldsymbol{f_m}$ - a ***factor of operational meaning*, ELSE** f_r is an ***operationally meaningless* factor**. This is the *third* primary, universally necessary prerequisite use requirement for further examination of factors.

Operationally significantly material: The impact of a factor of **operational meaning** $\mathbf{f_m}$ must be of significant materiality $\mathbf{f_{sm}}$ with a significant difference in results of operations when one acts with and without the factor; otherwise, discontinue its examination. Formally, **IF** $M(f_m) \geq S_{min}(\Delta M_{RO})$, **THEN** $f_m = \mathbf{f_{sm}}$ – a ***significantly material factor*, ELSE** f_m is an ***operationally insignificant*** factor. This is the *fourth* primary, universally necessary prerequisite use requirement for further examination of factors. Materiality ranks each factor $\mathbf{f_{sm}}$ relatively to the sum of absolute (||) materiality $M(\mathbf{f_{sm}})$ of all significant factors F: $Rank(f_{sm}) = M(\mathbf{f_{sm}}) / \sum|M(\mathbf{f_{sm}})|$ over all $f_{sm} \in F$. Among significant factors F, one must distinguish two disjoint subsets of them: factors adding value and their necessary companion factors (e.g., *location* and *time*). The focus on materiality of impact on results of operations is the core principle of the suggested framework and model of operational information quality. It is a unique, universally necessary primary use requirement that is not only universally necessary but also

- ***fundamental***—the only one that provides sufficient reason to consider a factor for operations.
- ***central*** in all considerations about effectiveness and efficiency of operations; it partially (asymmetric, transitive) ranks all significant entities (factors, quality aspects, and/or their properties), allowing an objective indirect aggregate measure of situation-specific operational quality of factors.
- the ***most pervasive***—it determines the materiality of the remaining necessary properties of a factor, its necessary companion factors, and, to a lesser degree, the materiality of its indirect factors. (Each ($\forall$) factor that adds value $avf \in AVF$ confers its materiality upon its necessary companion factors $ncf \in NCF$, formally, $\forall\, ncf \in NCF, avf \in AVF : M(ncf(avf)) = M(avf)$.

Operationally on-site available: A significant factor should be available on-site of the tasks at hand (e.g., *location of the evacuation task before a tsunami hits*); otherwise, discontinue its examination. This is the *fifth* primary, universally necessary prerequisite use requirement for further examination of a factor.

Operationally available on time: A significant factor should be available on time before it becomes useless; otherwise, discontinue its examination. This is the *sixth* primary, universally necessary prerequisite use requirement for further examination of a factor. It should be tested after the site has been determined because the local astronomical time is a function of the site.

***Actionably credible or reliable*:** An available factor must be sufficiently credible to act; otherwise, discontinue its further examination. Observations, measurements, and communications are vulnerable to their inherent quality problems [9]. Actionable credibility of a factor in form $\mathbf{f_{ac}}$ is a complex function of at least 20 indirect factors [6] that must be tested for quality assurance. In cases of the highest importance, such an examination may require extensive use of intelligence and counter-intelligence resources. A general overview of the framework and model of operational information quality cannot cover all of the necessary details. Situation-specific actionable credibility is the *seventh* primary, universally necessary prerequisite use requirement for further examination of factors.

Other primary use requirements**:** An actionably credible factor $\mathbf{f_{ac}}$ may be subject to **other situation-specific necessary primary use requirements**, denoted $\mathbf{f_{ossr}}$**,** which, if any of them is not met, it precludes further use of the factor. Such requirements may pertain to restricted or exclusive availability to decision makers. This is important in competitive situations when operations are subject to licenses, permits, security regulations, prohibitions by local laws, etc. They are none, one, or more necessary primary use requirements for factors in form; they close the list of necessary primary use requirements that make a single information item effectively usable.

Effective usability**:** Finally, we arrived at a compound **sufficient** condition for a tested factor f_x to be declared situation-specific effectively usable - **euf**. The qualifier ***effective*** denotes a restricted usability that does not include ethical and economical considerations. Formally, **IF** $f_x \equiv$ operationally_recognized(f_x) ^ operationally_relevant(f_x) ^ of_operational_meaning(f_x) ^ operationally_significantly_material(f_x) ^ operationally_on-time_available(f_x) ^ operationally_on-site_available(f_x) ^ actionably_credible(f_x) ^ meets_other_situation-specific_necessary_primary_use_requirements(f_x), **THEN** f_x = ***euf*** – an ***effectively usable factor,*** **ELSE** f_x is ***operationally useless*** . One must be aware that *uncertainty about factors' effective usability degrades decision situations*. If usability of a factor

- is certain, the situation is *deterministic,* at least regarding the specific factor.
- is only probable (the most likely case), the situation is *stochastic.*
- is nil, zero (e.g., *not on-site timely available*), the outcome is the result of a desperate *game*.

Usability on its own does not guarantee effectiveness; it also depends on whether it is skilfully used. This, however, equally pertains to all factors, whether in form or in substance.

NECESSARY SECONDARY USE REQUIREMENTS AND HIGHER LEVELS OF USABILITY

Those who manage operations, the society within which they are conducted, and other stakeholders may expect more than merely effectiveness. They may also pursue ethics and efficiency. ***Ethically*** may mean that they meet; for instance, the *Widely Endorsed Standards of Corporate Conduct* [27], the ITT Code of Conduct [18], the *military code of conduct*, etc. ***Economically efficient*** may mean that an item of information has been acquired at joint cost JC(f) that is significantly less than its materiality **M(f),** hence $\mathbf{M(f) - JC(f) \geq S_{min}(\Delta M_{RO})}$**.** When both expectations are met, an effectively usable factor **euf** is also ethically (***ethuf***) and efficiently (***efuf)*** usable. Any factor may be **directly** or only **indirectly** usable.

In routine operations, the use requirements for data that are stored in common databases should be **max–min**. The quality of each datum should be at the minimal levels of its use requirements for the most demanding task. When they significantly exceed their max–min level, the efforts made to attain them are wasted. If **d** represents a datum, **ur** use requirements, $\mathbf{q \in Q}$ quality aspects, and $\mathbf{t \in T}$ tasks, its max–min use requirements are ***max–min(ur(q(d,t)))*** = max(min(ur(q(d,t))) for q(d,t)) $\in$ Q(d,t)), t $\in$ T.

With ***indirect informing***, users of data may differ from those who acquire and prepare them. The latter may be of different mindsets, have different cultural backgrounds, speak different languages, etc.; hence, they may face difficulties in recognizing, interpreting, understanding, and using the data. Thus, new problems of recognizeability emerge. We must distinguish between (a) recognizable, and (b) economically recognizable, which may be an additional situation-specific necessary primary use requirement although not a universal one. Effectively, ethically, and/or efficiently usable factors must also be actionably usable.

OPERATIONALLY COMPLETE AND ACTIONABLE USABILITY

In operations, usable factors in form must be actionable so that one may act upon them. To this end, they must be operationally complete with regard to the tasks at hand. Operational completeness [9] is more complex than completeness of mapping reality into states of information systems [36] or completeness of rows and columns in database tables [26], as it usually is interpreted in information-quality studies. The never-attainable cognitive completeness at the strategic level of management is not discussed here.

Operational completeness measures the degree to which the usable data/information items are available. It may be expressed in percentage points (0–100%) as the ratio of the sum of the results that can be attributed to the corresponding items available and the sum of all the results attainable with full completeness. The more of the task-specific factors that are effectively usable, the more tasks may be effectively performed. There are degrees of completeness that may cause the decision maker (also a decision-making mechanism) to change the mode of operations: trigger, continue, modify, or discontinue them.

Effective completeness pertains to direct tasks or at least those prerequisite tasks that may trigger the execution of a direct task, which generate effects equal to its situation-specific materiality. For a task to be a ***direct task dt***, its task-specific cluster CUF(t) of usable factors euf must contain at least one (∃) factor that adds value avf(t) ∈ AVF(t) to the results of operations. Formally: **IF** ∃ euf ∈ CUF(t) ^ euf ∈ AVF(t), **THEN** t **=** ***dt - a direct task***, **ELSE** t is an ***indirect task***. A direct task dt is ***effectively operationally complete eoc(dt)*** if all effectively usable factors euf_i ∈ CUF(dt) are available to be engaged in action for i = {1, 2, … n}, where cardinality n = |CUF(dt)|. Formally: **IF** n = |CUF(dt)| ^ CUF(dt) = {euf_1, euf_2, … euf_i, … euf_n}, **THEN** dt = ***eoc(dt) - an effectively operationally complete*** direct task, ELSE dt is an ***operationally incomplete*** task.

Only task-specifically complete usable factors can be ***actionably usable*** to become engaged in operations and thus become useful. Operational completeness may be ***effective completeness*** with operations conducted with an *all-out effort,* such as military special operations or acts of terror, according to their purpose, when ethics and efficiency (e.g., *cost* or *lost lives of those who act*) are of secondary or deliberately of no concern. Only ethically and/or efficiently usable factors can be respectively tested for task-specific ***ethical*** and/or ***efficient operational completeness*** (e.g., *just war* [19]).

SUFFICIENT REASON TO CHANGE THE MODE OF OPERATIONS

We have reached the point where we ask the last question: What provides the chief executive decision maker with a sufficient reason to change the mode of operations? A simple philosophical answer to this question is the will [31] of the chief executive decision maker. Will is always a sufficient reason even when entangled in emotions, but it may be controlled by intellect. Such decisions may be the outcome of planning, preparations, and calculations. All of them are based on the representation (data, information) of the situation provided by others of influence. As always, an assessment is emotionally loaded with wishful expectations and projections. According to the purpose, the mode of operations may be changed if it is perceived to be effectively, ethically, and/or efficiently complete to **trigger**, **continue**, **change**, or **discontinue operations**. It is a matter of doctrine and policy. This is the way humans act in personal matters, the way they launch new and fold old businesses, and the way they wage small and world-wide wars and/or declare unconditional surrender.

OPERATIONAL USEFULNESS (ACTIVE, INACTIVE, IN WAITING)

An effectively usable factor may be ***actively useful - auff*** only when task-specifically complete and actually engaged in conducting operations (e.g., *intelligence used in drone attacks*); otherwise, it is a usable but ***inactively useful factor - iauff*** (e.g., *intelligence kept for future use*) or only a ***usable factor in wait-***

ing **-** eufw (e.g., *a bond of a bonded contractor*). Formally: **IF** ∀ (euf ∈ eoc(dt) ^ euf ∈ tpt(dt))) ^ eoc(t) ∈ CUF(T) ^ t ∈ T ^ operations are conducted, **THEN** euf **=** ***auff – actively useful factor*** **ELSE** euf = ***iauff - inactively useful factor*** or euf = ***eufw*** **-** a ***usable factor in waiting***. It equally pertains to ethically and/or efficiently usable factors. Usefulness is not a distinguishing attribute of anything, data or information, as practically all MIS textbooks claim. Usefulness is contextual, never intrinsic to factors, only to the situation and is desirable from the perspective of the purpose of operations.

Sequence of Examining Necessary Use Requirements

Operationally effective, ethical, and/or efficient completeness of usable factors closes the list of the *nine* (eight universally) necessary primary properties of factors. They all are *prerequisites* for effective, ethical, and/or efficient operations. Changes of these properties result in qualitative and quantitative changes of decision situations. The presented diagnostic sequence of examining the necessary (primary and secondary) use requirements of operation factors seem to be logical and the most economical.

Such a sequence can be determined by pair-wise comparison of the necessary use requirements. One begins with necessary requirements of factors of the highest impact on further examination, which, if not met, precludes its further operational considerations and provides a sufficient reason to terminate its examination. The factor still may remain a valid object of research; however, it is operationally useless. In our case, the very first requirement is "*operationally recognizable*." However, if recognized, the next use requirement of the broadest impact is "*operationally relevant*"; that is, it is pertinent to the planned operations. Again, if not operationally relevant, it is a sufficient reason to terminate further examination and so on until one reaches the level of at least effective, ethical, and/or efficient completeness of clusters of factors engaged in operations. This provides a sufficient reason for a factor in form to be considered actually *directly effectively, ethically, and/or efficiently useable* before operational completeness is attained, which may suggest changing the mode of operations. To realize how differently the examination of the use requirements of factors can be conducted, it may help to compare the examination of completely unknown factors with examination of routine information for routine operations.

Simplified Assessment of Use Requirements

In *routine* operations, the impact of factors is viewed and perceived differently by decision makers and/or users when their role is qualitatively known. Those deemed useful are stored in common databases and warehouses to be shared among many users; one may say that they have been internalized. Thus, in routine operations,

1. factors can be easily recognized, and they are of established operational relevance and meaning.
2. materiality is experienced differently for different applications or tasks.
3. availability of factors that are stored for common use is assured for all users but limited by rules of authorized access. Exactly the opposite occurs with the strategic factors that are frequently extracted with great difficulty from the outside world and not lightly shared with others.
4. credibility or reliability of factors is less the concern of individual internal users but should be subject to established rigorous procedures of quality assurance on behalf of all users—verification, validation, monitoring, and auditing.
5. completeness of usable data, in most cases, boils down to a careful design of a corresponding *subschema* for application processing and predefined inquiries. This starkly contrasts with problems faced by strategic management—"*connecting the dots from disparate sources*."

The next fundamental question arises: whether the diverse plethora of use requirements can be formally categorized and ordered. Despite the apparent chaos, tight interdependencies exist among use requirements. These interdependencies lead to articulation of a rigorous disjoint universal taxonomy and ordering of the universe of information use requirements.

Use Requirements Classed and Ordered [8]

Critique of Empirical Survey-Based Studies

The before-mentioned study by Wang and Strong [(1996)] about how data consumers perceive data quality identified 179 aspects of data quality. These were reduced to 118 for subsequent statistical factor analysis, later to 20, and boiled down to the parsimonious deemed manageable 15 that were perceived by respondents as being the most important. The product of this study, the "Conceptual Framework of Data Quality," divides them into four categories, labeled intrinsic, contextual, representational, and accessibility. The elements are defined by enumeration. This pioneering exploratory study is a summary of perceptions of mostly MBA alumni representing data consumers. Alas, such perceptions rarely provide a reliable insight into the mechanism of how quality impacts business operations. A cursory reflection reveals that

1. the questions asked and the responses provided pertained to unknown contexts of use.
2. the identified categories overlap. In operations, not many quality aspects are intrinsic to data, while all corresponding requirements <u>are always situation specific</u>. There are no requirements, whether intrinsic to data or to the situation, that are not contextual with regard to the purpose, circumstances, and adopted assessment criteria of results, while the study limits contextuality to only some of them.
3. believability and reputation of data are never intrinsic to data values; they depend on circumstances. A data value may be 100% accurate, true, and precise but may still be rejected as not trustworthy (see conditions of effective informing resonance [10, pp. 46-47]). In the said survey, believability ranked first, but traceability to sources has been rejected. Believability can easily become gullibility unless data are easily replicable from other sources, which rarely is the case.
4. operational materiality of factors is the fundamental, central, and most pervasive quality requirement; it is the only one that provides a sufficient reason for considering a datum but is absent. Its closest proxy is "value-added," even ranked second, while cost effectiveness has been dismissed for marginal statistical reasons.
5. quality aspects that pertain to representation and accessibility of data also depend on circumstances and context; they can never be attributed to the data values by themselves.

The above confirms that statistical factor analysis is inherently a weak tool in discovering qualitative dependencies, which always are stronger than respective quantitative dependencies. There is a need for a more objective approach to quality. The presented universal disjoint impact-focused taxonomy of well-ordered, or at least nearly well-ordered, use requirements (required properties) related to the use of factors in form rests upon a qualitative analysis of their impact on operations.

Taxonomy and Ordering of Use Requirements

When viewed from the teleological perspective of operations through the lens of decision making, *the entire universe of quality requirements related to the use of factors in form is subject to a universal disjoint taxonomy and ordering*. Which requirements affect operations directly or only indirectly? A decision-situation matrix identifies the direct factors but not the use requirements related to them. Some of the direct factors, however, may be complex functions of indirect factors affecting them.

First, all factors must meet the necessary use requirements. They are always prerequisites for further examination of the affected factor with respect to its remaining necessary use requirements. The necessary use requirements of factors can be further subdivided into primary and secondary ones. Again, the primary ones can be subdivided into universal and other situation-specific necessary primary use requirements. The primary ones should be tested first, beginning with the universal ones. Ultimately, such testing subdivides factors into usable or not, such as

1. operationally recognized or not;
2. the recognized into operationally relevant or irrelevant;

3. the relevant into those of operational meaning or not;
4. the ones of operational meaning into those of operational significant materiality or insignificant;
5. the ones of significant operational materiality into on-site available or not;
6. the on-site available into operationally on-time available or not;
7. the ones that are on-time available into actionably credible or not;
8. the ones that are actionably credible into those that also meet other situation-specific necessary primary use requirements or not.

From the perspective of the conducted operations, factors in form that meet all of the primary necessary requirements related to their use are *effectively usable*; otherwise, they are *operationally useless*, and so on. More formally, ***the universal hierarchical impact-focused taxonomy of requirements that are related to the use of factors in form*** (data, information, elements of knowledge) ***for operation*** subdivides as follows:

1. The entire universe of their quality requirements QR into **direct** and **indirect** ones and **orders** them partially (asymmetric, transitive) by **materiality** of the situation-specific use of each factor.

   a. Changes from the previous state s_p to the current state s_c of a ***direct quality requirement of its use*** s(dqr), where dqr ϵ DQR ⊂ QR ⊂ Q—the quality space—**immediately affect** the decision situation itself, the actions to implement the decisions, and/or the results of operations. It implies that it changes the value of the adopted measure of results of operations ΔM_{RO}, formally: $\mathbf{(s_p(dqr) \neq s_c(dqr)) \Rightarrow (\Delta M_{RO} \neq 0)}$.

   b. Similar changes of states of an ***indirect quality requirement of their use*** s(iqr)), where iqr ϵ IQR ⊂ QR ⊂ Q—the quality space, as the name suggests—only **indirectly affect** the situation because they determine or contribute to properties of indirect aspects of qualities of a higher order (closer to the direct ones) and at the upper end of the chain, to the direct quality requirements. When s_p and s_c denote, respectively, the previous state and the current state of an indirect aspect of quality, and iq_n and iq_{n-1} denote, respectively, indirect aspects of quality of the n^{th}-order and indirect aspect of quality of a higher $(n-1)^{th}$-order (for n = 1 indirect aspect of quality of 0^{th}-order is a direct aspect of quality iqr_0 = dqr), it implies that a change of state of an indirect aspect of quality of the n^{th}-order causes a change of state of the related indirect aspect of quality of the higher order $\mathbf{iqr_n}$, or, at the extreme, of a direct aspect of quality: $\mathbf{(s_p(iqr_n) \neq s_c(iqr_n) \Rightarrow (s_p(iqr_{n-1}) \neq s_c(iqr_{n-1}))}$. Elements of this subclass are partially ordered by their distance (number of intermediaries + 1) in the chain of functional dependencies from their respective direct aspects of quality that they indirectly affect.

2. The direct and indirect quality requirements that are related to the use of factors in form in operations into **necessary** and **desirable** ones. The necessary ones are usually **binary,** and the desirable ones are **gradable**. The gradable ones, however, may be both necessary with regard to the minimum and maximum of their range, while the states in between are gradable with regard to their intensity. Whichever use requirement is necessary, by default, is a prerequisite quality requirement (for testing other requirements) denoted **pqr**. A prerequisite quality requirement, if not met, precludes further examination of the entity. Individual factors in form that meet their necessary quality requirements are ***usable;*** otherwise, they are ***useless***. The usable ones, depending on the level of expectations, may be **effectively**, **ethically**, and/or **efficiently usable**. The efficiently usable can also be partially ordered by the degree of their efficiency.

   a. Changes to the ***binary necessary quality requirements*** s(bqr(f)) of a factor f with regard to their required states s (properties) (bqr(f) ϵ BQR(f) ⊂ QR(f) ⊂ Q—the quality space) result in *qualitative and quantitative* changes of decision situations. They may add or eliminate a factor from consideration, where $\mathbf{F_c}$ and $\mathbf{F_p}$ are, respectively, the current and the previous sets of significant factors F. Formally: $\mathbf{[s_p(bqr(f)) \neq s_c(bqr(f))] \Rightarrow [(F_p \neq F_c) \wedge (\Delta M_{RI} \neq 0)]}$**.** This leads to a partial redefinition of the decision situation with qualitative and quantitative consequences.

b. Changes to ***gradable necessary use requirements*** s(gqr(f)) of a factor f—their required states s (properties) (gqr(f) ϵ GQR(f) ⊂ QR(f) ⊂ Q—the quality space) mainly *quantitatively* change the results of operations (hence, they may not be significant ($\Delta M_{RI} \geq$ Min (ΔM_{RI})) unless the quantitative changes reach a critical state $s_c \in$ C(s(gqr)) (member of critical states C); they may also trigger qualitative changes. Formally: **$[s_p(gqr(f)) \neq s_c(gqr(f))] \Rightarrow [(\Delta M_{RI} \neq 0)$ ^ If $(s_c(gqr) \in C(s(gqr))$ then $(F_p \neq F_c)]$.**

c. Changes to the only ***desirable gradable quality requirements*** s(**dgqr(f))** of a factor f—their required states s (dgqr(f) ϵ DGQR(f) ⊂ QR(f) ⊂ Q—the quality space) only quantitatively change the results of operations (hence, they may not be significant ($\Delta M_{RI} \geq$ Min (ΔM_{RI})). Formally: **$[s_p(dgqr(f)) \neq s_c(dgqr(f))] \Rightarrow [(\Delta M_{RI} \neq 0)$.**

3. The necessary use requirements that are related to the use of factors in form in operations into **primary** and **secondary use requirements**. ***Necessary*** requirements are of the highest importance and of the exact same consequences; if not met, they make the factor unacceptable for operations. For economy of testing, the necessary requirements should be examined by their descending ***strength of prerequisites***, which are measured by the number of the remaining necessary requirements that need not be tested if the examined requirement is not met. It orders them ***partially*** (asymmetric, transitive), but when some of them are of equal strength as prerequisites, one may ask which of them is easier to test and order them partially by the increasing **difficulty of their examination**. Both criteria combined nearly always provide for ***well ordering*** of a necessary quality requirement because the axiom of choice [("Axiom of choice," 2008)] in the set theory is satisfied.

a. The ***primary necessary*** ones are those determined by the nature of the situation, thus objectively independent of the decision maker.

b. The ***secondary necessary use requirements*** can be controlled and manipulated, whether legally or not, by the chief executive decision maker; thus, they are **dependent requirements**. They usually pertain to **ethics** and **efficiency** of operations.

4. The primary use requirements into **universally** or **situation-specific necessary.**

a. ***Universally necessary quality requirements*** of a factor **f** are always necessary. Changes to their state s(unqr(f)), where unqr(f) ϵ UNQR(f) ⊂ QR(f) ⊂ Q—the quality space—add or delete the affected factors from consideration: **$[s_p(unqr(f)) \neq s_c(unqr(f))] \Rightarrow (F_p \neq F_c)$.**

b. ***Other situation-specific necessary primary use requirements*** of a factor **$f = f_{ssqr}$** are also necessary but not always. In specific situations, changes to them s(sspqrf), where ssnqr(f) ϵ SSNQR(f)⊂QR(f) ⊂ Q—the quality space—also add or delete the affected factors in form from further consideration: **If $\{f = f_{ssqr}\}$ THEN $[s_p(ssnq(f)) \neq s_c(ssnq(f))] \Rightarrow (F_p \neq F_c)$** (e.g., *restricted availability of factors in a competitive situation*). The usable factors in form to become actionable must be tested for completeness with regard to the tasks at hand to be performed. Only those engaged in the conducted operation are actually directly useful. Whether the factors are **effectively, ethically,** and/or **efficiently usable,** the engaged ones may be ***actively effectively, efficiently, and/or ethcially useful***; otherwise,

c. they are ***inactively effectively, efficiently, and/or ethically useful factors,*** else only effective usable factors ***in waiting***—for needs to arise.

PRIORITIES OF EXAMINING REQUIREMENTS

Once a point of reference and a result-determined taxonomy of use requirements of factors have been defined, one can universally prioritize their examination for research and practical applications.

1. Identify the necessary and desirable information support (information products) for the areas that constrain (a bottleneck with TOC methodology) the attainment of the purpose or a success factor.

2. Examine the necessary primary use requirements, which make factors in form usable and directly affect the decision situation, the implementation of decisions, and the results of operations. Some are always necessary, hence universal. The non-universal other necessary requirements are also situation specific. Both are at least nearly well ordered by combining two criteria: their strength as prerequisites and the difficulty of their examination. Changes to primary use requirements always qualitatively and quantitatively change results. This examination determines whether effective use of information is possible at all.
3. If any of the primary use requirements are of potential high materiality and could not be met, examine them by decreasing materiality with regard to the indirect factors that affect them. Possibly by improving on them, the direct primary one could be met. The necessary use requirements of the indirect factors inherit the materiality of the direct factor. The indirect use requirements can also be well ordered by combining two criteria: difficulty of their examination and the distance from which they affect the direct one (of the first, second, and subsequent orders).
4. If operations should meet higher expectations, examine the secondary necessary use requirements that make operations ethical and/or at least minimally efficient with regard to their implementation and results. They are nearly always well ordered by combining two or three criteria: strength as prerequisites, difficulty of their examination, and materiality of the factor.
5. Finally, examine the gradable use requirements, whether further improvements are feasible. Changes to desirable gradable use requirements cause mainly quantitative changes unless they reach a critical point (e.g., *melting, freezing*) and then cause qualitative changes. They are at least nearly well ordered by combining, again, two criteria: their impact on efficiency and the difficulty of their examination.

The presented framework and model are anchored in realistic assumptions and definitions. As such, before embarking upon extensive empirical validation, the model should first be scrutinized theoretically to find any examples to the contrary or other objections with regard to it. Then the model may need revisions. The model of operational quality of information should be tested by computer simulation with real-life examples.

Measuring Quality as Compliance with Requirements [7]

How do we measure quality? Such a question assumes that at least (a) a metric of quality can be developed, (b) it may be useful, and (c) the more quality the better. The answer to this question brings surprises in light of the amount of effort, time, and resources spent on developing metrics of quality. With a well-defined point and frame of reference, a yardstick, and well-defined distinctions about quality, one may examine how use requirements of factors may impact operations.

1. The first step is to operationalize the commonly used term, “quality.” In rigorous parlance, it is a set of vectors of significant properties (states) in a multidimensional space of quality aspects of all significant factors in operations. The initial set may be the 179 potential quality aspects identified in [37]—at least those deemed significant (Assumption QA1).
2. Within each quality aspect, its states are measured or ranked specific to that aspect (e.g., *time*, *distance*), and the aspects may be <u>interdependent</u>. Whatever their number and their measures are, direct exchange or trade-off rates are unavailable. Hence, they cannot be reduced to a common scalar value, and, as such, they *cannot be measured directly and summarily.*
3. In operations, the impact of factors, whether in substance or in form, is subject to at least eight universal use requirements and some others that are task-specific only. In business and other operations, there are also secondary necessary use requirements imposed by ethics and economy. Trade-offs between necessary requirements is <u>impossible</u>. They must always be met; hence, their ranking is precluded despite attempts in this direction [37]. They may be ranked by their strength as prerequisites, difficulty of their examination, and materiality of the factor considered.

4. According to the postulate of teleological perspectivism and relativity of assessments (Assumption GA5), the materiality of all properties is determined by the situation-specific purpose and circumstances of the operations, hence relative only to them. It affects the materiality analogously to a force field that affects a mass of matter in physics. It implies individuality of properties. The results of operations are determined by the situation-specific combination of factors that acquire materiality from the circumstances of operations. Thus, any direct, general (transcending specific situations), and compound measure of quality is impossible; such attempts are arbitrary until one identifies something in common for them. For operational quality, it is their common purpose. Materiality derived from the purpose provides a gradable quality aspect that is attributable to any factor, quality aspect, and property serves as a common scalar measure of their contribution to the common purpose. It is, however, an indirect metric similar to what is known in economy as a common exchange value or rate.
5. What purpose might serve a direct aggregate measure of operational quality when effectiveness, ethics, and efficiency are expected? To reduce the problem ad absurdum, let's assume that trade-offs among direct measures of disparate gradable quality aspects are possible and an aggregate measure of quality can be developed. Results of operations, especially their cost effectiveness, are functions of individual properties—states of specific quality aspects of the impact exerted by specific factors but not groups thereof. Intuitively, many think that improved gradable quality of any factor improves the results of operations. It may or may not. Improving on any single quality aspect at first may tangibly improve results of operation, but later the marginal return may become negative when the additional (marginal) cost becomes prohibitively high—true in any economy. When, with only a few exceptions, improvements on most quality aspects do not *monotonically improve efficiency of operations, the same holds true for their aggregate measure*. For the best results of operations, the significant gradable properties of operational factors must be used at their optimum, acceptable, or satisfactory levels. Unchecked efforts to improve quality in all aspects are counterproductive when economy and, subsequently, efficiency are an issue. No aspect of quality is an end on its own.

When economy or efficiency is expected, one may summarize it as follows: By the law of teleological perspectivism and relativity, all assessments, including assessments of impact of factors on operations, are (a) always situation specific, not universal; (b) measured differently within most quality aspects; (c) necessary, hence always of equal importance; (d) with no exchange trade-offs; (e) always of situation-specific materiality that cannot be generalized; and (f) with only a few exceptions, never monotonically affecting the results of operations due to the law of diminishing returns of improved quality in each aspect. Thus, direct metrics of quality for groups of properties must be arbitrary and useless.

One may, however, test by simulation, not statistical analysis, the impact (on operation results) caused by changes of individual properties, which should be individually fine tuned for maximized results of operations. The impact of any quality aspect of information (e.g., *astronomical time*) on the results of a space mission or a landscaping service is incomparable. Nevertheless, still, many sophisticated efforts to develop such metrics using statistical methods are under way with many other misconceptions about information that are easily revealed when assessed within a well-defined theoretical framework.

One may, however, ask the legitimate question of why, according to common perception, an increase in quality of anything is generally perceived as beneficial. It is not only a delusion; economy is willingly ignored in a multitude of situations by detached government officials at any level, by public administrators, even by business executives when they spend not their money but that of taxpayers or shareholders. Higher quality is attractive in many aspects, such as reliability of operations (e.g., *overkill factor*, *double or even triple assurance of execution*); security assurance, including terror and crime prevention; comfort of participants; durability and esthetics of products and services; prestige; and decorum. They appeal to the majority of humans despite actual economic waste and alienation of those with unmet basic needs. Undeniably, they motivate others; contribute to the arts, entertainment, etc., which abound outside of frugal routine operations.

In 2005, Oliviera et al. presented "*A formal definition of data quality problems*." They limited it to database perspectives, left untouched the management perspective, ignored other limitations of their approach, and took an exclusively internal view of quality problems. They assume that "let *u(t,a)* be the <u>correct</u> and <u>updated</u> value that the attribute *a* of tuple *t* was supposed to have" (emphasis added) [25, p. 17)]. Managers rarely enjoy such luxury. Correct values are better than incorrect, but, still, even the correct ones may be useless. The authors did not test whether the data values were ever used and, when used, whether they were useful at all. Neither "correct" nor "updated" were defined, while one knows well that there are no formal, logical, or computational ways of assuring correctness and currency of data values in general. Oliviera et al. ignored the fact that data meeting all of the identified 29 quality criteria are only uncorrupted values regardless of their operational quality. The presented definitions, however, are useful for cleansing databases from gross corruption and for testing how error prone database systems are in their design and manipulation of the entrusted data values. To the above extent, the study indeed appears to be complete. The proposed criteria facilitate testing the database design and operations by detection of distortions inflicted on sets of input test data of whatever actual operational quality.

With a simplistic view of quality, one may argue as follows: Storing data values in databases implies that they are deemed useful. If corrupted, they are less useful, useless, or even hazardous. Under special circumstances, the corrupted data may become a liability of deadly consequences [5, p. 5]. It may even produce some worthy immediate improvements in organizations, but it does not address the core issue of quality from the operations-management perspective that offers answers of lasting universal validity.

Thus, a general direct aggregate measure of quality is unattainable when efficiency is expected. We need a distinction between the quality of factors in operations and the degree by which they were later corrupted while manipulated. The first one is of management's concern. The second one is of concern for designers and operators of information systems who may not be aware of the operational implications of such corruption.

SUMMARY

Quality of information is the aggregate of the entire experience of users at all the touch points related to use of information for routine operations when it is a significant factor. Here, operations are limited to processes (natural and by design) that are conducted and/or controlled by humans. They are decomposable into closed-ordered sets of transformations (tasks) that can be represented as graph structures. Factors are limited to routine factors that entail data, information, and elements of articulated knowledge.

The framework and model of routine operations entail seven general assumptions and four definitions, while the model of quality of factors in operations entails two assumptions and seven definitions. Within this context, no direct aggregated measure of quality for any group of factors can exist when efficiency is expected. An objective and aggregated metric can only indirectly measure how factors, their quality aspects, and properties affect a well-defined measure of the extent of the purpose of operations that are derived from any theory of operations management. Thus, the suggested framework and model of information quality may be integrally embedded in and subordinated to preferred philosophies of management.

Information affects operations as objectively as other factors do, and so does their quality. Quality affects effectiveness, ethics, and efficiency of operations directly and indirectly, qualitatively and quantitatively. Among the plethora of quality aspects, it is possible to identify at least seven universally necessary or categorical quality requirements for using single information items (always explicitly or implicitly at least pairs of values) and one for their task-specific clusters. While accounting also for other necessary use requirements, one may objectively define sufficient reasons for operational usability, actionable usability, usefulness, and for changing the mode of operations (trigger, continue, modify, or discontinue) while using information. Assessment can be done at four levels of expectations: effective, ethical, efficient, and both ethical and efficient operations. All quality requirements of information use may be objectively classified and ordered (ranked), thus their examination may be prioritized for research and practical applications.

In contrast to TQM metrics of quality as statistically significant deviations from semi-arbitrary base lines, the **model of operational quality** of factors provides users with the necessary and other use requirements, including a situation-specific aggregate but indirect measure of impact that can be examined by simulating real-life cases after a thorough review of the formal correctness of the model**.**

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