PERVASIVENESS OF MATERIALITY OF FACTORS IN OPERATIONS AND THEIR CHANGES IN DECISION SITUATIONS

(Research in Progress - IQ Concepts)

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Abstract: This is a study of the phenomenon of pervasiveness of materiality of factors (including data and information) and their qualities in operations and the pervasiveness of their changes in decision situations. Research and practical endeavors in improving information quality identified a plethora of qualities to be accounted for, but usually they ignore their interdependencies, which taint the outcomes of research and practical endeavors. The emergence of nanotechnology further expands our view on operations and the role of information, its quality, and informing for operations. Further studies have to account not only for their relativity but also for their discrete nature. The paper is presented for challenge, critique, and discussion to enhance our common understanding.

Keywords: Operation factors; quality; quality dimensions; pervasiveness of materiality of factors in operations; meaning and materiality of changes; pervasiveness of changes of factors in decision situations

INTRODUCTION AND BACKGROUND

In 2006, Slone [19, p. 249] stated, *"Despite evidence that lack of attention to IQ problems leads to substantial losses … the literature is devoid of a conceptual model of IQ strategy or of systematic exploration of the nature of the relationship between IQ and organizational outcomes."* For two decades, with the exception of [1, 2, 3, 5, 12, and 18], research about and practical efforts to improve the quality of information has been devoid of attention to the potential interdependencies among the identified factors, their qualities, and the organizational outcomes. To succeed, quantitative empirical studies should be based on exploratory qualitative inquiries into the nature of the phenomena under investigation.

Empirical studies attempted to measure how users/consumers view the relative importance of qualities [21 and 12]. In 2004, an overview of major logical interdependencies among data and information qualities was presented in [6]. In 2006, a more detailed study in [8] identified that the actionable credibility or believability alone (one of six universal primary quality requirements that make a data value usable) is a function of at least 20 other indirect quality requirements.

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[1] I gratefully acknowledge the anonymous reviewers who, by their comments, made abundantly clear how controversial the presented phenomenon on its surface might appear to many, although it should not be so.

This study views quality from the perspective of operations: how the qualities of factors impact the results of operations, as presented in [6, 7, and 9]. It focuses on the *theoretical* approaches, which promise research results of a more lasting validity. TQM and TDQM are not discussed, for as useful they are in practical efforts to improve the quality of data in specific organizations, they intrinsically seem to preclude broader generalizations.

In operations management, information-quality problems are a subset of a broader class of quality problems with any kind of factors. This study takes advantage of this fact. It is a step toward developing a comprehensive model of interdependencies among qualities that may be applied by artificial-intelligence-based analyzers for diagnosing and simulating quality problems encountered by operations management.

Reviewers of the paper perceived the presented problem within a broad spectrum of contrasting views. They range from "*excellent relevance*" and "*excellent originality*" to "*nomologically uninteresting proposition … neither controversial nor falsifiable*," and "*this is a common understanding among researchers and it represents an inevitable limitation that all positivist studies must contend with*." This spectrum could not be broader. It demonstrates how controversial the problem actually might appear for many, although it should not be so. It seems to lie in the common pattern of human cognition: Initially, anything discovered is controversial until recognized; once recognized, it becomes neither controversial nor falsifiable, at least not without significant resistance. It may, however, remain controversial for a long time. Hence, the main purpose of this paper is a call for discussion, critique, and challenge until a common understanding develops that will not be ignored by researchers in empirical studies and by practitioners in endeavors to improve quality.

The main contributions of this paper seem to be the identification and elucidation of what seems to be a relatively complete spectrum of two cases of pervasiveness:

- **pervasiveness of materiality** of any kind of operation factor (viewed also as a data or information value) and its qualities exerted on its remaining qualities and on its other necessary companion (complementary) factors, including their qualities in operations, and
- **pervasiveness of changes** of variables (representing factors viewed also as data or information values and their qualities) on other components of decision situations.

For focused reading, key terms in paragraphs are in **bold**, emphasis is in *italics*, highest emphasis is <u>underlined</u>, and terms followed by their definitions are in ***bold italics***. For brevity, quality attributes or quality dimensions are simply labeled ***qualities***. Following the reviewers' advice, examples of factors of substance and factors in form, such as information, elucidate most definitions and formal statements.

PERVASIVENESS AND ITS MODEL

GENERAL DEFINITIONS

Operation quality denotes here **quality of factors** as viewed from the perspective of **operations management**. Quality consists of **essential** and **distinguishable** characteristics. ***Operations*** may be conducted by autonomously acting humans, their organizations, systems controlled by artificial intelligence, or any combination thereof.

A ***factor*** is anything that contributes significantly to **results of operations**. In operations, factors may be **factors of substance** or **factors of symbolic nature**:

- ***Factors of substance****,* including the four known Ms (material, method, machinery, and manpower), products, services, energy, or weapons in warfare

- In contrast to the previous, ***factors in form*** (represented symbolically) may be data or information values. Example: *The location and timeline of a target and/or elements of knowledge, such as rules of engagement and rules of procedure in reasoning and proceeding*.

Factors may be (a) already **available**, such as any available substance, data, relationships among them, and rules of procedure in reasoning and proceeding; and (b) **not yet available**, to be still acquired, unknown or uncertain, such as any additional substance, information, and rule of procedure in reasoning and proceeding. Their representations constitute the decision-maker's knowledge.

Q(f) denotes the **quality of a specific factor f** (*a device, tool,* or *data value*) defined by a **vector of states** $\mathbf{s(q_j(f))}$ (*operational* or *non-operational* for a device, *usable or not* for a data value) of necessary distinguishing qualities **nq(f) ϵ NQ(f)** (*sharpness* of a tool, *credibility* of a data value), and other qualities **oq(f) ϵ OQ(f)** (*acquisition cost*). Of course**, Q(f)** = **NQ(f) + OQ(f)**. Formally,

$$Q(f) = [s(q_1(f)), s(q_2(f)), \dots s(q_n(f))] \text{ for all } q(f) \in Q(f) \text{ of cardinality } n = ||Q(f)||$$

Distinguishing quality - $Q_D(F)$ of a class **F** of factors **f ϵ F** (*cutting tools* for factors of substance or *aerial pictures* for factors in form) is a finite set of **necessary** qualities $\mathbf{nq_i(F)}$ (*length* of the cutting edge for a cutting tool and *number of dots per inch* for the resolution of a picture) of cardinality **k = ||NQ(f)||:**

$$Q_D(F) = \{nq_1(F), nq_2(F), \dots nq_k(F)\}$$

Any quality **q(f)** of a factor **f** can take on one out of two or more distinguishable states $\mathbf{s_i(q(f)) \in S(q(f))}$ for states **s ϵ S** of qualities **q(f) ϵ Q(f)** of factor **f ϵ F** and **i ϵ {1, 2 … n}**, hence, cardinality n = ||**S(q(f))**|| is always at least 2. Thus, a ***set*** **S(q(f))** ***of states s(q(f)) of quality q(f)*** can be Boolean {true, false}, defined by enumeration, or an ordered set of numbers. The last implies measurability and ranking of the states of quality (*calibre of firearms*).

Quality requirements QR(f) for a specific factor **f** are defined by a vector of required states **rs(q(f)) ϵ RS(q(f))** of selected qualities (*type, size, colour, cost,* etc.). Formally,

$$QR(f) = [rs(q_1(f)), rs(q_2(f)), \dots rs(q_m(f))] \text{ for all } q(f) \in Q(f) \text{ of cardinality } m = ||RS(q(f))||$$

In operations, qualities of factors physically intrinsic (naturally belonging) to the factors acquire relevance, importance, materiality, utility value, and usefulness only from the purpose and circumstances in the light of the adopted criteria of effectiveness and efficiency. This occurs only when factors are subject to a force field exerted by the will of competing decision makers, who perceive them as relevant to their endeavours, including the political and economic forces of the market in business, administrative, or military operations. They are of no utility value on their own merit when not subject to such forces. Operations are subject to the collaborative, competitive, or adversary will of decision makers. In operations, the ***meaning of operation factors and their qualities***, also data, information, and rules of procedure in reasoning and proceeding, is defined pragmatically as the **difference between the outcomes of their use,** as viewed by Pierce, the father of the theory of verifiability of meaning [7].

Management plans, organizes, motivates, directs, supervises, monitors, and controls operations. This study distinguishes

- ***Routine management*** (*supervisor*) charged with maintaining the current status of operations
- ***Tactical management*** (*head of a sales district*) charged with adjusting operations according to the perceived changes of reality, but without changing the existing evaluation criteria, the executive decision maker, and the purpose
- ***Strategic management*** (*business owner, board of directors*)**,** which determines
  - The **main purpose of operations P**, which serves as the ***main point of reference,***
  - The criteria of effectiveness, and
  - The chief executive decision maker

Managers are the driving force, who are observing, participating, and interested subjects, as viewed by John Dewey in his theory of inquiry [14, p. 293]. They operate within a ***frame of reference*** (circumstances the operations are subject to), which consists of

- **SN –** a set of variables **sn ϵ SN** that represent significant **states of nature** and are beyond control of decision-makers—independent variables such as *weather conditions*,
- **D** – a set of dependant variables **d ϵ D** of **significant** materiality that are under decision-makers' control, including all states **s(q(d)) ϵ S(**q**(d))** of significant qualities **q(d) ϵ Q(d)** of significant dependent factors **d**, such as *to use or not to use a toll road for trucking or weather information service about road conditions,*
- An adopted **criterion of effectiveness** of operations, such as *net income after taxes*, and
- **Assumption:** Decision making employs mainly **rational** and **rule following** choices, as defined by March [15]; nevertheless, one should also account for irrational choices (at least to prevent them from happening), for they may qualitatively change the entire situation.

One assumes ***measurability*** of the main **purpose P** and the **results** of operations denoted **RO**. The measure of the results denoted $\mathbf{M_{RO}}$ is a function of the main purpose **P,** the sets **SN** and **D**, formally,

$$\mathbf{M_{RO} = M_{RO}(P, D, SN)} \text{ for all } s(q(f)) \in S(q(f)),\ q(f) \in Q(f), \text{ and } f \in F.$$

Any factor **f** or state of its quality **sq(f)** is ***significant*** when the absolute difference in the results of operations $\mathbf{M_{RO}}$, when conducted with and without them, are greater than the **threshold of significance** $\mathbf{Min(\Delta M_{RO})}$ determined by the policy of the decision maker, formally,

$$|\mathbf{M_{RO}[F} \text{ or } \mathbf{Sq(f)] - M_{RO}[F - f} \text{ or } \mathbf{Sq(f) - sq(f)]}| \geq \mathbf{Min(\Delta M_{RO})}$$

In decision making, significant factors and their necessary qualities are represented by respective decision variables in decision models. Generally, decision situations can be modeled into a decision-situation specification matrix, as shown by Table 1. The components of a decision situation are the possible states of the situation $\mathbf{sn_j}$ (independent variables), potential choices or decision options $\mathbf{d_i}$ (dependent variables), the foreseen outcomes $\mathbf{o_{ij}}$, the utility function that assigns a utility value u$(\mathbf{o_{ij}})$ to each outcome $\mathbf{o_{ij}}$, evaluation criteria of the outcomes, the decision makers, and, finally, the main purpose of operations **P**. They are listed in approximately the ascending sequence of the expected extent of pervasiveness of their changes.

j [1..m]/ /i [1..n]	p_1 sn_1	p_2 Sn_2	… …	probabilities$_j$ states$_j$	… …	p_{m-1} sn_{m-1}	p_m sn_m
d_1	$u(o_{1,1})$	$u(o_{1,2})$	…	…	…	$U(o_{1,1-1})$	$u(o_{1,m})$
d_2	$u(o_{2,1})$	$u(o_{2,2})$	…	…	…	$u(o_{2,m-1})$	$u(o_{2,m})$
…	…	…				…	…
decisions$_i$	…	Utility values of outcomes o_{ij}: $u(o_{ij})$, where u – a utility function					…
…	…						…
d_{n-1}	$u(o_{n-1,1})$	$u(o_{n-1,2})$	…	…	…	$u(o_{n-1,m-1})$	$u(o_{n-1,m})$
d_n	$u(o_{n,1})$	$u(o_{n,2})$	…	…	…	$u(o_{n,n-1})$	$u(o_{n,m})$

Table 1 Decision-situation specification matrix

Outcomes $\mathbf{o_{ij}}$, however, are rarely simple variables. They represent the current, foreseen, or attained state of reality in its various different but significant aspects. They may represent nothing more than a simple change in cost or dramatically different pictures of a scene before and after an accident, of a village before and after a tornado hit, or of a battlefield before and after the battle. The outcome $\mathbf{o_{ij}}$ can be represented as a one-dimensional array or vector of states of all significant aspects of reality, which are projected when decision **i** has been implemented in the state of nature **j**.

The initial version of a situation model is built based on the available data and available elements of knowledge. At first, it is a static picture. The monitored changing reality (the system and its environment), however, requires systematic adjusting of at least some of the major components of the model. The type, number, and degree of the changes is induced not only by the changing environment but also by the management, which adjusts the way it views the situation and reacts to it. In its elementary form matter manifests itself as granular and discrete hence changes have to be of same nature.

From the perspective of communications, each change is a new piece of information $\Delta\mathbf{I}$**,** which Shannon and Weaver's formula [20] associates with some amount of information. At the lowest end of the spectrum of changes, they have to be of discrete nature and so have to be information and its quality. Incoming symbolic representation of reality, which overlaps with what has been already known, does not change the model and its entropy and conveys zero amount of information. Data – the given, known, available – cannot change the situation. Only symbolic representations that convey a non-zero amount of information can do it (see Table 2).

Changes Δ of independent variables $\mathbf{sn}_j$ and $\mathbf{p}_j$ are viewed as the difference between their respective previous (”) and current states (**’**)**,** caused by incoming information $\Delta\mathbf{I}$**,** can be defined respectively as $\Delta\mathbf{sn}(\Delta\mathbf{I}) = \mathbf{sn}''_j - \mathbf{sn}'_j$ and $\Delta\mathbf{p}(\Delta\mathbf{I}) = \mathbf{p}''_j - \mathbf{p}'_j$ **.** Such changes invariably cause changes in the affected outcomes $\mathbf{o}_{ij}$, their utility, and results of operations. Subsequently, decision makers may also change their tactic by changing the decision options from $\mathbf{d}_{i'}$ to $\mathbf{d}_{i''}$**.** Summarily, these changes will change the total outcome $\Delta\mathbf{o}(\Delta\mathbf{I})$ equal to the difference between the two vectors – of the previous outcomes $\mathbf{o}''_{I'',j''}$ and the current outcomes $\mathbf{o}'_{i',j'}$, formally,

$$\Delta\mathbf{o}(\Delta\mathbf{I}) = \mathbf{o}''_{I'',j''} - \mathbf{o}'_{i',j'}$$

This is the ***operation meaning*** of the **received information** Δ**I**, as viewed pragmatically by Peirce [17], while

$$\mathbf{M}(\Delta\mathbf{I}) = \mathbf{M}_{\mathbf{RO}}(\mathbf{o}''_{I'',j''}) - \mathbf{M}_{\mathbf{RO}}(\mathbf{o}'_{i',j'})$$

is ***materiality*** of Δ**I**. Of course, the utility function **u** assigns different utility values to the respective differences with regard to each aspect of reality[2].

Pervasiveness of materiality of factors is measured by the extent of their impact on their companion factors; their qualities; and, by the same token, on the respective variables that represent them in decision making. They are viewed in the context of **operations** and **decision making.** Some changes of said materiality affect quantitatively and qualitatively the respective specification matrix of the decision situation and may require its qualitative redefinition with respect to some or all of its components, its operation meaning, utility value, and materiality.

Pervasiveness of changes of components of decision situations on the remaining components is measured by the extent of their impact on one or more of them.

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[2] To some reviewers the model has much in common with classical information economics such as the one discussed in Hilton's paper [13]. One may agree only with the first part of the statement. The normative and descriptive theories of <u>information processing</u> (emphasis added) discussed by him reduce each information system to a set of signals and a signal generator. Those theories assume that there is a function that maps pairs of states and actions (decision options) into usually monetary outcomes. They do not consider, however, information qualities, their states, or any interdependencies among them.

PERVASIVENESS OF MATERIALITY OF FACTORS

OPERATION FACTORS AND THEIR MATERIALITY (DEFINITIONS)

The purpose of this section is it to demonstrate how the concept of materiality manifests itself in operations. Of course, an operation factor must be interpreted or recognized and assessed as relevant and of significant materiality before its pervasiveness can be assessed. In operations, any factor considered for use must be usable. To this end, it must meet at least six universal quality requirements: (1) interpretable or recognizable; (2) operation relevant; (3) significantly material; (4) operation timely available; (5) actionably credible, reliable, or believable; and (6) operation effective complete. There may emerge additional situation-specific requirements, which determine the materiality of the factor [9].

Interpretable or recognizable

For the purpose of this study, it is assumed that, for a factor under consideration, the decision maker has it successfully (a) **interpreted** for factors in form (data or information values), such as *air temperature,* or (b) **recognized** for factors of substance, such as *type of measuring device*. It is a universal prerequisite for its further examination.

Data and information values are stored as factual statements, vectors, graphs, images, and patterns. At least pairs, usually vectors of values, must be considered. A single value without a context cannot be interpreted. In robots, such vectors may trigger a designed sequence of state transitions. In operations, neither factors of substance nor factors symbolically representing reality can be used on their own. They can be used at least in pairs or, rather, clusters of complementary factors. Factors devoid of their environment, context, or complementary companion(s) cannot be usable and, consequently, cannot be useful later. For instance, *a number that represents temperature, if not accompanied by the type of measurement units it represents, can cause a deadly misinterpretation of patient's condition when it pertains to body temperature*.

Operation relevance

Operations **O** can be decomposed into a network of elementary tasks $\mathbf{t} \in \mathbf{T}$ as it is practiced by project management with PERT [16]. Each task **t** requires a cluster of resources **cr(t)**. Their union constitutes a set of indispensable resources $\mathbf{R_O(T)}$, formally,

$$\mathbf{R_O(T) = cr(t_1) + cr(t_2) \ldots + cr(t_n) = \bigcup cr(t)} \text{ for all } t \in T\text{, and cardinality } n = ||T||$$

An interpretable or recognizable vector **rv** must be tested for its operations relevance. ***Vector rv*** represents a **relevant factor rf**, if there exists any such match (For instance, *is body temperature a factor in any of the elementary tasks to be performed?* If not, it is operation irrelevant), formally,

$$\mathbf{V\ [rv \equiv rf]} \text{ for all } rf \in R_O(T).$$

By definition, any resource $r \in R_O(T)$ is a potentially relevant factor rf, hence r = rf.

Of significant materiality or impact on operations

In operations, mere relevance is insufficient. One is interested in factors of *significant* materiality or impact on the situation under consideration. Materiality ***M(f)*** is assessed by the extent of operational consequences the factor **f** causes in the decision situation itself, and/or the actions necessary to implement the decisions made, and/or in the results of operations. (For instance, *the difference in the net income after taxes of a trucking company while using a toll road or a specialized weather information service for truckers*.) Formally,

$\boldsymbol{M(f) = M_{RO}(F) - M_{RO}(F - f)}$

The degree of significance of the impact measured by the materiality of the factor is a matter of policy and is determined by decision makers. It is a situation-specific threshold of the operations model's sensitivity **Min** (ΔM_{RO}). Potentially relevant factors **rf** must be significant factors **f**; thus, their set **F** is only a subset of $\mathbf{R_O(T)}$, formally $\mathbf{F \subset R_O(T)}$, which requires that each absolute value of materiality **M(f)** must meet this necessary condition. (For instance, *only factors that make a difference in results of operations greater than 1% will be considered in comparing competitive projects*.) Formally,

$$\Lambda\ [|\mathbf{M(f)}| \geq \mathbf{Min}(\Delta \mathbf{M_{RO}})] \text{ takes place for all } f \in F \subset R_O(T)$$

If absolute materiality of a factor is insignificant from the perspective of decision makers, the remaining qualities of the factor are insignificant too. On the one hand, factors acquire their materiality from their necessary qualities while these qualities acquire materiality from the situation in which they are used. On the other hand, the materiality of a factor determines the **upper limit of materiality** of the remaining qualities of this factor.

Once the materiality of all factors is known, one may rank each factor **f** relative to other factors by computing their respective ratios over the sum of absolute values of materiality of all factors. The ratio indicates the relative importance of each factor:

$$\boldsymbol{Rank\ (f) = M(f) / \sum |M(f)|} \text{ for all } f \in F$$

This implies that the sum of the absolute values of the relative ranks of factors equals 1, formally, $\sum|\mathbf{Rank\ (f)}| = \mathbf{1}$ for all $f \in F$, and **Rank (f)** stays within the range $0 \leq |\mathbf{Rank\ (f)}| \leq 1$. Once operation factors have been ranked, one may sort them. Example: Now, one may easily check whether indeed in the operations under consideration, according to the frequently observed statistical regularity, *the first 20% of the most important factors generate approximately 80% of the results.*

EXTENT OF PERVASIVENESS OF MATERIALITY

In operations:

- The materiality of a factor is a function of its quality, thus its materiality can increase or decrease with changes of its quality. For instance, the *length of a lever determines the payload of specific materiality one can lift with a given force,* for a factor of substance, or *the probability of winning determines the expected payoff of a Lotto ticket for a given amount of money available this period,* for factor in form. At the same time,
- The materiality of a factor limits the materiality of its remaining qualities; however, then *the rigidity of the lever, whatever it is, cannot be of higher materiality than the lever itself,* for a factor of substance, or *the availability of Lotto tickets cannot be of higher importance or materiality than the expected payoff minus the price of the ticket,* for a factor in form. In other words, the materiality or importance of its other qualities cannot exceed the materiality of the factor itself.

The above are obvious relationships, but many researchers, when conducting empirical studies, ask users questions about how they rank different dimensions of qualities of data frequently by undefined importance. Answers to such questions are clearly task specific and cannot be reasonably answered without knowing the context. Then one may obtain results that simply defy logic, as later demonstrated.

Researchers still seem unaware that there exist at least six universally necessary or mandatory qualities that make a factor first *usable* (recognizable or interpretable, operation relevant, significantly material, operation timely available, actionably credible or reliable, and operation effective complete[3]) and then *useful* under additional conditions, as defined in [9, p. 241]. Consequently, the above requirements are necessarily of equal weight because they have the same consequences—a complete loss of usability and usefulness. They cannot be ranked differently from the factor's materiality when one agrees that it best measures their importance.

One may, however, relatively easily assess how frequently each of the necessary quality requirements is not met, causing loss of usability and usefulness of factors and their respective qualities. While adding up their corresponding materiality as potentially lost, one can compute their relative weight as fractions of the total potential losses. If potential losses are calculated this way, they might many times exceed the real losses because a single loss of materiality of any elementary task can be incurred due to multiple quality deficiencies. The actual total loss will be closer to the total losses due to the incompleteness of value-adding elementary tasks and the replacement cost for other necessary but operation incomplete elementary tasks. No known research has attempted such an evaluation of relative importance of different aspects of quality.

Due to the requirement of completeness, factors cannot be used on their own. Among the significant factors **F**, one should distinguish two disjoint subsets of them: factors **adding value** or payoff **avf ϵ AVF**, and factors **indirectly adding value**. When necessary for effective use of the previous ones, however, the other factors may be called **necessary, complementary, companion, or even prerequisite factors f ncf** ϵ **NCF** of adding-value factors. Thus, the complementary factors still significantly impact the ultimate outcome because nothing can be attained without them[4]. Here again, another principle is evident: In operations, each value-adding factor avf ϵ AVF confers or endows its materiality on its corresponding necessary companion factors **ncf ϵ NCF**. Example: *If the possession of a precision weapon that determines effectiveness of a high-value warfare operation, it also requires the knowledge of the position and timing of the target. Thus, the latter acquire the materiality of the precision weapon*. Formally,

Λ [materiality(ncf(avf)) = materiality(avf)] for all ncf ϵ NCF, avf ϵ AVF

The **necessary or complementary companion factors NCF** are the remaining factors of the set **F**, hence, **NCF = F – AVF.**

One may summarize **pervasiveness of materiality** of operation factors as follows: Materiality of a factor is a function of its significant qualities within a specific task. On the other hand, a factor's materiality

- determines the materiality of the remaining necessary qualities of the factor,
- determines the upper limit of the materiality of the remaining qualities of the factor, and
- any factor adding value endows its materiality on all of its complementary operation factors.

In research, it is common to disregard the above principles. In [21], for instance, respondents ranked believability higher than relevance or added value, which in operations makes no sense. When the importance of a quality is measured by its materiality, its materiality cannot be separated from the materiality of the factor endowed by such quality. Results of research ignoring the above principles are questionable.

[3] It may happen that materiality of a factor might depend on other factors, such as the degree of the factor's availability: whether restricted only to a specific decision maker, fully unrestricted, or something between the two. Restricted availability of a factor gives advantage to some decision makers over others. Unrestricted availability may reduce that advantage, hence its materiality to insignificance. These, however, are examples of *situation-specific necessary* requirements.

[4] For instance, emergency calls for roadside assistance with a well-defined **added value** must be accompanied by information values about the location and some indispensable equipment or tools (**necessary companions**) to provide the service. Without them, such calls cannot be effectively handled.

PERVASIVENESS OF CHANGES OF FACTORS IN DECISION SITUATIONS

The initial version of a decision-situation model is based on the available knowledge. When viewed from the perspective of communications, changes are represented by incoming information always associated with a non-zero amount of information, as defined by Shannon and Weaver [20]. The emerging nanotechnology calls for an extension of the operation view of information, its quality, and informing in general to account for their discrete nature. In the dynamic setting of operations management, one may distinguish

- **Routine information** of known factors, which change the situation mostly quantitatively (i.e., usually minor adjustments such as *increase in demand*), unless the quantitative changes reach a critical point causing qualitative changes (i.e., a major discrete change—*evaporation, melting, freezing*); or
- **Non-routine potentially important information** about new significant, not-yet-recognized factors, such as *a new competitor*, who always qualitatively and quantitatively changes the affected decision situation, hence the results of operations.

Factors that represent reality are subject to changes that reflect the changing reality. Thus, a system that monitors the (constantly changing) real world must be established to keep the symbolic representations current. In routine operations, collection of a symbolic representation from the monitored reality takes place for known and rather well-established factors that impact the operations. Such representation describes a relatively stable picture of routine operations whose quasi-equilibrium will eventually be disturbed. From the viewpoint of managing routine operations, the collected values are either

- ***routine data values*** only, because no changes have taken place—preserving the status quo, or
- ***routine information values***, because changes took place, with all the subsequent consequences.

<table>
<tr><td colspan="3"><u>K N O W L E D G E</u>
- a symbolic representation of reality in operations (objects, events, their identifiers and attributes, relations among them, and rules of procedure in reasoning and proceeding</td></tr>
<tr><td rowspan="2"><u>D A T A</u>
about the given, known, available, assumed true operation factors; they never can change the existing decision situation—the status quo</td><td colspan="2"><u>I N F O R M A T I O N</u>
about the unknown or uncertain operation factors, not yet available, still to be acquired, and always associated with non-zero amounts of information, as defined by Shannon and Weaver (1949)</td></tr>
<tr><td><u>Routine Information</u>
reflects changes about known operation factors, usually causing only quantitative changes of results; they are the subject of routine operational and tactical management</td><td><u>Potential Information</u>
about still unknown factors, which, if significant, always result in qualitative changes of the existing decision situation; they are the subject of strategic management</td></tr>
</table>

Table 2 A general taxonomy of situation-specific elements of knowledge about operations

Non-routine information obtained from monitoring reality about potentially significant factors that may impact operations should be considered separately. They are mainly the realm of strategic management and decision making. Non-routine information that constitutes new elements of knowledge after being acquired or recognized as valid, if only relevant and of significant materiality, always *qualitatively and quantitatively change the entire decision* situation because they represent factors not yet accounted for. (They require a subsequent redefinition of the decision-situation model. This certainly represents a qualitative change of the situation. It is extremely unlikely that such changes occur without quantitative changes of the results). All of the above represent the decision-maker's knowledge about the situation and are summarized in Table 2.

Table 1, on the other hand, facilitates comprehension about how incoming information values that represent the occurring changes may dramatically impact various components of decision situations. For a known factor or its quality, at least a significant quantitative change of a single variable that affects other components of a decision situation must occur. Generally, one may distinguish the following degrees of pervasiveness of the changes of factors in decision situations (see summary in Table 3):

1. **Quantitative change** of a **single variable** (*for instance, air temperatur*e) may only affect a single column or row
2. **Quantitative changes** of **some variables** (*for instance, the available water supply*) may affect more columns or rows
3. **Qualitative change** of **variables** when
    a. the quantitative change reaches a critical state of the variable (*temperature reaches the melting point of a substance*), or
    b. new opportunities emerge/vanish, then the new dependent (*a San Francisco Bay crossing*) or independent factors or their qualities (*new California State environmental regulations*) must be considered or can be ignored
4. **Changes** in the adopted **evaluation criterion** (*adoption of a different cost-accounting method*)
5. **Change** of the **executive decision maker** by strategic management[5] (*CEO is forced to step down*)
6. **Change** of the **purpose** of operations (*transition from non-profit to for-profit operations*)

The latter two items (5 and 6) are the subjects of strategic management. The degrees of pervasiveness are listed in their ascending order.

THE DEGREES OF PERVASIVENESS OF CHANGES OF FACTORS

Table 3 summarizes the degrees of pervasiveness of the changes of factors in decision situations. The prerequisite for studying pervasiveness of changes of variables in decision-situation models is their **operation relevance,** as defined before. The degree of pervasiveness of anything operation irrelevant or of insignificant materiality is zero. Once a change of a relevant factor exceeds the level of minimal significant materiality, its pervasiveness is worth tracking. Any further increase of materiality of such factor quantitatively increases the level of its impact but not its pervasiveness. An increase/decrease of pervasiveness of the factor occurs when fewer or more factors become dependent/independent on it. Example: *Extending irrigation makes more crops vulnerable to changes of the available water supply but simultaneously decreases their dependence on the changes of weather conditions.* A quantitative change, for instance of temperature, as long it stays within its critical range, usually only quantitatively affects the results of operations. When however, it reaches any critical point (e.g., *freezing, boiling, or melting point of substance*), it may trigger qualitative changes of extreme consequences.

Qualitative changes of factors always add to or delete entire rows or columns from the decision-situation matrix. This calls for at least a partial qualitative redefinition of the decision situation. It always adds or deletes entire rows or columns of outcomes and their utility values and modifies the utility function **u** with inevitable changes of the results M_{RO}. Change of the adapted evaluation criterion, the executive deci-

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[5] Changes of executive decision makers may not be triggered by strategic management. It might be a consequence of natural causes due to retirement, more attractive job opportunities, health, family problems, or death. Then they usually are not the result of a major strategic shift, and simply a caretaker replacement is found to continue the established conduct of operations.

sion maker, when triggered by strategic management and of the main purpose of operations, are of progressively increasing pervasiveness up to a total redefinition of the entire decision situation.

<table>
<tr><td rowspan="7">Relevant variables</td><td rowspan="6">Significant variables</td><td rowspan="4">Qualitative changes</td><td rowspan="6">Degrees of pervasiveness of changes in decision situations</td><td>6</td><td>Change of the purpose of operations is of the highest degree of pervasiveness; literally nothing remains unchallenged and unchanged.</td></tr>
<tr><td>5</td><td>Change of the executive decision maker triggered by strategic management always changes how major components of a decision situation are viewed and consequently modified, except for the main purpose of operations. It calls for a redefinition of the entire decision-situation matrix, including the list of decision options, independent variables, forecasted outcomes, evaluation preferences, the utility functions, and the results.</td></tr>
<tr><td>4</td><td>Change in the adopted evaluation criterion profoundly and qualitatively changes the way the results of operations $\mathbf{M_{RO}}$ are computed and the results by themselves. They change all m*n utility values $\mathbf{u_{ij}(o_{ij})}$ of outcomes $\mathbf{o_{ij}}$ and the results of operations $\mathbf{M_{RO}}$.</td></tr>
<tr><td>3</td><td>Qualitative change of variables with regard to independent variables sn and dependent variables d add new or delete some existing column or row, which at least calls for a partial redefinition of the decision situation, modification of the formula (which computes the results of operations $\mathbf{M_{RO}}$), and/or change of the results by themselves. They, occur when
• a quantitative change reaches any critical state of a variable, or when
• new opportunities emerge/vanish; then new dependent or independent factors or their qualities must be considered or ignored.</td></tr>
<tr><td rowspan="2">Quantitative changes</td><td>2</td><td>Quantitative change of some variables may affect more than one column or row in the decision-situation matrix. Their respective degrees of pervasiveness may reach any number from m or n to n*m outcomes $\mathbf{o_{ij}}$, their utility values $\mathbf{u_{ij}}$, and the final results of operations M_{RO}, where n*m is the maximum number of outcomes in the decision-situation matrix (see Table 1). In trucking for instance, a change of diesel fuel price requires a recalculation of all utility values of all the respective outcomes, such as using different trucking routes.</td></tr>
<tr><td>1</td><td>Quantitative change of single independent variables $\mathbf{sn_j}$ or single dependent variables $\mathbf{d_i}$ affects only their respective foreseen m or n outcomes $\mathbf{o_{ij}}$; subsequently, their respective utility values $\mathbf{u(o_{ij})}$ and the results of operation $\mathbf{M_{RO}}$.</td></tr>
<tr><td colspan="5">Relevant variables but of insignificant materiality M(v) $\mathbf{< \Delta M_{RO}}$</td></tr>
<tr><td colspan="6">Irrelevant variables</td></tr>
</table>

Table 3 The degrees of pervasiveness of the changes of factors in decision situations

CONCLUSIONS AND LIMITATIONS

This study presents as clearly as possible the pervasiveness of materiality of operation factors and their qualities and the pervasiveness of changes of factors in decision situations. It demonstrates the intricate interweaving of their impact on other factors, their qualities, and the variables that represent them. The main problem lies in the fact that most studies ignore the interdependencies of factors and their interdependencies and their widespread pervasiveness in particular. By nature, this phenomenon is to some extent universal and situation specific in other aspects. It explains at least to some degree, why so many empirical studies end up with mixed and inconclusive results. The emergence of nanotechnology further expands our view on operations and the role of information, its quality, and informing for operations. Further studies have to account not only for their relativity but also for their discrete nature.

The sharpest critique describes this study as a “*nomologically uninteresting proposition … neither controversial nor falsifiable*,” which represents “*a common agreement among researchers*.” Why, then, does none of the known empirical studies about information quality (even about quality in general) consider it? At the same time, one reviewer describes it as “*the first paper of which I am aware that attempts to model potential interdependencies among IQ factors and organizational outcomes*” and the second as of “*excellent*” originality. Hence, the problem cannot be more controversial than this, if not for all, at least for many. Likely, this is the reason this paper was accepted to be presented for challenge, critique, and discussion.

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