Proceedings of the 56th Hawaii International Conference on System Sciences | 2023

A Method for Assessing Knowledge Flow Efficiency, Cost and Performance

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Abstract

Knowledge is key to competitive advantage, and organization leaders and managers are called to implement, maintain and enhance key knowledge management systems and processes. However, knowledge is inherently invisible, intangible, indefinite and resistant to quantification. Hence assessing investments in such systems and processes remains fundamentally challenging. The research described in this article builds upon a growing stream of knowledge visualization, measurement and dynamics work to develop a method for assessing knowledge flow efficiency, cost and performance in the organization. Results from application to archetypical organization systems and processes are highly promising, and they elucidate a novel decision support capability.

1. Introduction

Knowledge is key to competitive advantage (Cole, 1998; Grant, 1996; Spender, 1996): Knowledge enables effective action; effective action drives superior performance; and superior performance supports competitive advantage (Nissen, 2014). Indeed, some scholars argue that knowledge represents the only sustainable source of competitive advantage (Drucker, 1995).

In pursuit of competitive advantage, organization leaders and managers are called to implement, maintain and enhance key knowledge management (KM) systems and processes (Jennex, 2007). However, knowledge is inherently invisible, intangible, indefinite and resistant to quantification (Ahn & Chang, 2004). Hence assessing investments in such systems and processes remains fundamentally challenging.

The research described in this article builds upon a growing stream of knowledge visualization, measurement and dynamics work to develop a method for assessing knowledge flow efficiency, cost and performance in the organization. Results from application to archetypical organization systems and processes are highly promising. For instance, measured differences between alternate knowledge flow processes reveal both qualitative and quantitative commonalities and contrasts in terms of efficiency, cost and performance. Such results also elucidate a novel decision support capability, as organization leaders and managers are able to make more informed KM investment decisions.

2. Background

Researchers across a wide variety of fields (e.g., Economics, Education, Information Theory, Information Systems, Knowledge Management; see Nissen, 2017) have been working to visualize and measure both static and dynamic knowledge for well over a half century (e.g., see Hayek, 1937; Machlup, 1962). Such work continues with current research to quantify knowledge friction (Shigley, 2021), model dynamic KM (Spanellis et al., 2021), personalize dynamic knowledge strategy (Walsh & Lannon, 2020) and address other contemporary knowledge visualization, measurement and dynamics questions in line with our present effort.

Building upon this growing stream of research, we learn further from useful work to assess the return on knowledge (Housel, 2005), gauge knowledge management success (Jennex & Olfman, 2006; Jennex et al., 2008) and measure dynamic knowledge (Preiss, 1999) in the organization. In particular, we leverage analogic reasoning from physical systems (Corallo et al., 2016) to conceptualize a method for visualizing and measuring dynamic knowledge as it flows through the organization.

Analogic reasoning is noted as a powerful and important approach to strategic thinking, especially when used to spark new ideas, in which case creativity and impact may be more important than strict validity (Gavetti & Rivken, 2005). Plus, analogy provides a methodology for developing metaphoric insights to yield scientific models and theories (Tsoukas, 1993). We strive to spark new ideas in terms of knowledge

URI: https://hdl.handle.net/10125/103228
978-0-9981331-6-4

visualization and measurement, and we work to develop scientific theory through analogic reasoning.

This background section begins with a summary of the growing knowledge measurement work emerging through such analogic reasoning. It continues then by outlining an approach to dynamic knowledge visualization and measurement in the organization.

2.1. Growing knowledge measurement work

The growing knowledge measurement techniques are rooted in analogic reasoning about physical systems, the dynamics of which can be represented mathematically through the basic Newtonian equations summarized in Table 1 (Nissen, 2017). Such equations can be found in any introductory Physics textbook, yet they enable quantitative measurement, analysis, prediction and simulation of dynamic physical systems.

Here they interrelate (1) *force* (mass x acceleration; expressed in Newtons), (2) *work* (force x distance; expressed in Joules) and (3) *power* (work / time; expressed in Watts).

Table 1 Physical system equations

Construct	Description	Equation
Force (F)	Effort required to accelerate mass	(1) F = m x a
Work (W)	Force applied through distance	(2) W = F x d
Power (P)	Work done per unit time	(3) P = W / t

They note also (beyond the table) how *work* and *energy* are exchangeable and expressed in the same units (Joules): energy is required to perform work, and work performance involves the expenditure of energy. They note further how friction affects most physical systems by opposing motion and acceleration. An ordinary shopping cart, for instance, requires greater effort (i.e., more force) to push down a store aisle with a rough floor than a smooth one: the greater friction associated with the rough floor opposes motion and acceleration of the cart, hence it requires more force to push.

Table 2 outlines an analogic system for measuring dynamic knowledge, noting as a key point that none of these analogic constructs or relationships is intended to be precise or perfect. Rather, they are intended to elucidate the dynamics of knowledge and to help a simple, novel and insightful system for knowledge measurement to emerge.

Table 2 Knowledge system equations

Construct	Equation
K-Force (KF)	(4) KF = C x KFr x **o**
K-Friction (KFr)	(5) KFr = I + (sl x E ^ nl)
K-Work (KW)	(6) KW = KF x R (= KE)
K-Power (KP)	(7) KP = KW / FT

Briefly, Equation (4) indicates that *knowledge force* (K-Force or KF) is analogous to physical force and represents the effort required to accelerate knowledge in an organization. It is expressed as a function of the knowledge *chunks* (C; see Simon, 1996) being accelerated; the *friction* (KFr) associated with such knowledge; and vector **o**, which is included to represent a number of other, unspecified factors (e.g., *experience, communication skill, motivation, stress, emotion, organization climate, IT support*) that are likely to play a role—positive or negative (Hornung & Smolnik, 2022)—but which have yet to be integrated explicitly or analogically. Units of K-Force are referred to as "Nonakas" (N), acknowledging the seminal knowledge flow research done by Nonaka (1994).

In this conceptualization, one chunk of knowledge can enable the performance of one atomic action in the organization, such as making a distinction, and represents a knowledge analogy for *mass* in a physical system.

Equation (5) indicates that *knowledge friction* (K-Friction or KFr) is analogous to physical friction and represents opposition to knowledge acceleration and flow. It is expressed as a function of the intercept (I), slope (sl), *explicitness* (E) and nonlinearity parameter (nl).

The intercept represents how much more K-Force is required to accelerate purely tacit knowledge than its purely explicit counterpart; and slope depicts the rate at which K-Friction varies with *explicitness*, whether linearly (nl = 1) or not. *Explicitness* derives from Nonaka's (1994) epistemological dimension and represents the degree (on a [0,1] scale) to which knowledge has been articulated in explicit form.

The slope term is presumed generally to be negative, stemming from the "sticky" nature of tacit knowledge (Szulanski, 2000): a book about how to fly an airplane, for instance—which can be read relatively quickly and effortlessly—would represent highly explicit knowledge, and hence not encounter much knowledge friction; whereas a person's experience flying a physical airplane—which requires generally considerable time and effort to master—would represent highly tacit knowledge, and hence encounter substantially greater knowledge friction. Many knowledge flows are likely to reflect a mix of explicit and tacit ($0 < E < 1$).

Equation (6) indicates that *knowledge work* (K-Work or KW) is analogous to physical work and represents organization output accomplished through knowledge. It is expressed as the product of K-Force and *Reach*. *Reach* (R) derives from Nonaka's (1994) ontological dimension and represents the number of people able to utilize the knowledge from above (analogous to physical distance).

Analogous to the exchange between and common units of *work* and *energy* in physical systems, Equation (6) also indicates a correspondence between *knowledge work* and *knowledge energy* (K-Energy or KE): K-Energy is required to perform K-Work, and K-Work performance involves the expenditure of K-Energy. Units of K-Work and K-Energy are referred to as "Polanyis" (P), for the keen insight into tacit knowledge provided by Polanyi (1967).

Finally, Equation (7) indicates that *knowledge power* (K-Power or KP) is analogous to physical power and represents the knowledge work accomplished per unit time. It is expressed as the ratio of K-Work and *flow time* (FT), the latter of which represents the length of time required for knowledge to flow from one person (e.g., expert), group (e.g., sales team), place (e.g., West Coast office), event (e.g., night shift) or form (e.g., tacit) to another in the organization. Like time in the physical world, flow time can be measured using a stop watch, clock, calendar, timecard or like instrument. Units of K-Power are referred to as "Bacons" (B), acknowledging Sir Francis Bacon, to whom many scholars attribute the aphorism, "knowledge is power."

2.2. Dynamic knowledge visualization

To outline a system for visualizing dynamic knowledge as it flows through the organization, we build upon well-established Knowledge Flow Theory (KFT; Dierickx & Cool, 1989; Grant, 1996; Nissen, 2006b; Nonaka, 1994; Preiss, 1999; Spender, 1996) to conceptualize the multidimensional flow space delineated in Figure 1.

The vertical axis represents *explicitness*, which is one of the knowledge measurement constructs from above and derives from Nonaka (1994). The horizontal axis represents *reach*, which is another of the knowledge measurement constructs from above and derives from Nonaka also. The third axis represents *life cycle*, which is helpful for visualization and used to extend Nonaka's model (Nissen, 2002). *Life cycle* pertains to what is being done with knowledge (e.g., *create, share, apply*).

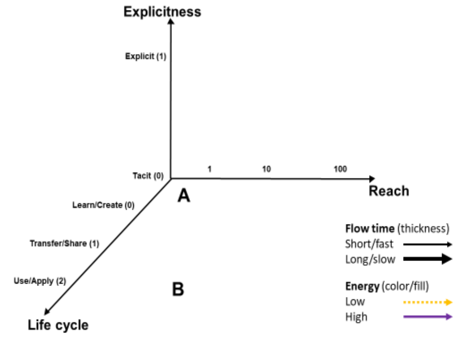

Figure 1 Knowledge visualization space

Flow time is not delineated via separate axis, but it is another of the knowledge measurement constructs from above and used to extend Nonaka's model further. Within the context of this multidimensional visualization scheme, *flow time* represents the time required for knowledge to flow between any two coordinate points in the space (e.g., Points A and B in the figure).

When knowledge flows quickly through an organization (i.e., when flow time is short), for instance, the corresponding flow is delineated with a relatively thin vector arrow, whereas a comparatively thick one is used when knowledge flows slowly. The K-Friction equation from above suggests that "sticky" tacit knowledge will flow more slowly in general than its explicit counterpart. Hence tacit flows would be represented generally by relatively thick arrows, whereas comparatively thin ones would reflect explicit flows better.

Finally, different vector arrows are also utilized to delineate *knowledge energy,* which is noted above with correspondence to the measurement construct *knowledge work*. In this conceptualization, K-Energy corresponds to the performance level of actions enabled by knowledge as it flows through the organization. Higher energy knowledge flows (e.g., that enable higher performance levels of knowledge work) are delineated with solid (purple) vector arrows, for instance, whereas dotted (orange) arrows are used for lower energy knowledge flows.

Expectations from KFT are that tacit knowledge, which can enable higher performance levels (Nissen, 2006a), will flow with greater energy in general than its explicit counterpart. Hence tacit flows would be represented generally by solid (purple) arrows, whereas dotted (orange) ones would reflect explicit flows better. In theory, *flow time* and *knowledge* *energy* represent orthogonal dimensions, but in practice, they may covary.

As noted above, *explicitness* is represented as a continuous dimension, with tacit and explicit endpoints on a ratio scale [0, 1]. *Reach* is measured along an integer scale (e.g., 1, 10, 100). *Life cycle* is measured along a somewhat arbitrary ordinal scale (e.g., 0, 1, 2). *Flow time* is measured on a continuous ratio scale. *K-Energy* (and *K-Work)* is the product of K-Force and Reach.

This multidimensional framework enables the visualization of dynamic knowledge in the organization and is very general. Theoretically, any dynamic flow of knowledge can be characterized in terms of these dimensions and delineated in this space; and in theory, knowledge can flow via an infinite number of different paths between any two points. In practice, however, the number of feasible paths is likely to be finite and few (Nissen, 2020).

Consider, for example, Points A and B in Figure 1. Assume that an individual worker in the organization discovers some new and useful knowledge (Point A), and management is interested in having all ten people in a group learn and apply such knowledge (Point B), preferably at the same performance level. Assume further that the new knowledge is tacit and represents 100 chunks. This implies that the individual worker could perform 100 novel atomic actions (or one novel compound action comprised of 100 atomic elements, or some conforming combination of atomic and compound actions).

Figure 2 delineates two, contrasting, archetypical knowledge flow processes. In the process labeled "Explicit Path," assume that the individual worker (Point A) expends time and energy to articulate his or her knowledge in explicit form (e.g., written instructions, graphic depictions, mathematic formulae and calculations, solved examples). This is represented by Point M in the figure. Then this individual could encode such explicit knowledge digitally within a computer network (e.g., via email attachment, website resource, document repository), which could be shared very quickly with all ten coworkers, wherever in the world they happen to be located. This is represented by Point N in the figure. After sharing as such, each of the coworkers could apply the knowledge directly to his or her work activities (Point B).

This organization process and corresponding knowledge flow are illustrated by light (orange) dotted vector arrows in the figure to represent the relatively low energy nature of this explicit knowledge. The first segment (i.e., A-M) is delineated with a relatively thick vector to indicate that the process of articulating tacit knowledge into explicit form can be time consuming, particularly when compared to the other segments corresponding to explicit knowledge sharing (i.e., M-N) and application (i.e., N-B). By using a stopwatch, calendar, employee timecard or like instrument, researchers or managers could measure the time required for this knowledge to flow from A to B, and hence obtain a measured value for flow time.

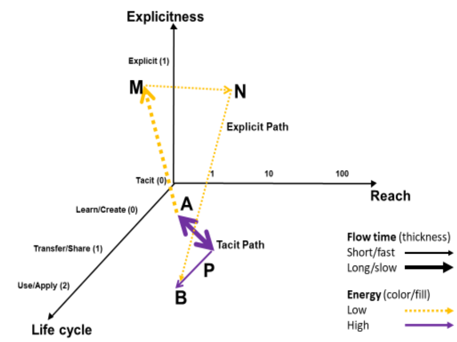

Figure 2 Knowledge flow archetypes

In the process labeled "Tacit Path," assume that the individual worker interacts interpersonally with the group members, working closely with these people, soliciting and answering their questions, observing and correcting the coworkers as they practice, and both mentoring and coaching them until everyone in the group has learned the knowledge. This is represented by Point P in the figure. With such learning accomplished effectively, all ten coworkers would be able to apply the knowledge directly to their work activities (Point B).

This Tacit Path differs greatly from its explicit counterpart above, and the corresponding tacit knowledge flow is illustrated by dark (purple) solid vector arrows in the figure to represent the comparatively high energy nature of this tacit knowledge. The first segment (i.e., A-P) is delineated with a relatively thick arrow to indicate that the process of sharing tacit knowledge can be especially time consuming, particularly when compared to the other segment corresponding to tacit knowledge application (i.e., P-B). This first segment is delineated with a double headed arrow also to indicate that knowledge sharing goes both ways: the individual worker (Point A) is learning (e.g., group norms) from the other members as they interact interpersonally, and the coworkers are learning (esp. the new knowledge) from this individual.

As above, researchers or managers could use the same stopwatch, calendar, employee timecard or like instrument to measure the time required for knowledge to flow from A to B, and hence obtain a measured value for flow time along this alternate, tacit path. Since these two, contrasting, archetypical knowledge processes are very different, one would expect for the corresponding flow times and energy levels to differ accordingly.

2.3. Dynamic knowledge measurement

Using the dynamic knowledge equations discussed above, Table 3 summarizes three key measured values for the knowledge flow processes. For the 100 chunks moving through the Explicit Path, K-Energy (KE) totals 7050 Polanyis. (KE and FT values are summarized as thousands in the table.) Worker timecards would be used to measure flow time (FT) of over four hours (16,400 seconds) for the flow (Nissen, 2019), which combines to reveal the K-Power (KP) measurement of 0.43 Bacons.

Table 3 Knowledge flow process comparison

Path	KE	FT	KP	Comment
Explicit	7.05	16.4	0.43	Less energy Less time More power
Tacit	20.00	55.1	0.36	More energy More time Less power

For the same 100 chunks moving through the Tacit Path, K-Energy totals 20,000 Polanyis with flow time over 15 hours (55,100 seconds), which combines to reveal the K-Power measurement of 0.36 Bacons.

Which process is "best" depends upon the circumstances: Where knowledge is required to flow quickly, and the organization can tolerate the lower energy level (i.e., performance level) corresponding to the Explicit Path, the first archetype would be preferable, because it has the least flow time. Alternatively, where the performance level (i.e., energy level) must be high, and the organization can wait for tacit knowledge to flow, the Tacit Path would be preferable, because it has the most energy.

Further, the comparative measurements show that knowledge flows with the greatest K-Power through the Explicit Path, as the very low flow time more than compensates for the low energy level. When comparing K-Power across different knowledge flow processes, one gains insight into the degree to which additional K-Work accomplished is commensurate with additional flow time that may be involved. In the present case, a decisionmaker may opt for the higher K-Power knowledge flow process if indifferent otherwise to the Explicit or Tacit Path.

3. Model Extension

In this section the system of knowledge equations is extended to develop an assessment method for measuring knowledge flow efficiency, cost and performance in the organization. Such development progresses in two steps: 1) *knowledge flow efficiency* is conceptualized first, followed by 2) articulation of *knowledge flow cost* and *performance* constructs.

3.1. Knowledge flow efficiency

Recall from above the correspondence between K-Work and K-Energy (i.e., KW = KE). This correspondence assumes that the amount of work accomplished through a particular knowledge flow equals the energy associated with such flow. Reconsidering the physical system supporting our analogic reasoning, this would imply perfect efficiency, meaning that all energy expended by a system is converted to useful work.

Efficiency of physical systems (e.g., heat engines) is expressed often as the ratio of work accomplished to energy expended (e.g., $E_P = W / E$, where E_P represents efficiency of the physical system, W represents work accomplished, and E represents energy expended). For a physical system with perfect efficiency (i.e., $E_P = 1$), work and energy would be equal.

Nearly every physical system suffers from energy losses (e.g., from thermal radiation), however, meaning that the amount of work accomplished by a physical system is generally less than the amount of energy expended by it. Hence the perfectly efficient physical system is unlikely in practice (i.e., $E_P \leq 1$).

Analogously the implicit equivalence between K-Work and K-Energy is unlikely in practice also, and nearly every knowledge system probably suffers from energy losses too (e.g., from **o** vector factors). As expressed in Equation (8a), the system of dynamic knowledge equations is extended here to specify *knowledge flow efficiency* (E_K) as the ratio of knowledge work accomplished (KW) relative to knowledge energy expended (KE).

Equation (8a) $E_K = KW / KE$

Rearranging the terms a bit, K-Work is expressed as a function of K-Energy in Equation (8b).

Equation (8b) $KW = KE \times E_K$

Now substituting Equation (6) from above for K-Energy (i.e., KF x R = KE), we derive Equation (8c) for K-Work.

Equation (8c) $KW = KF \times R \times E_K$

Clearly where E_K equals one, K-Work and K-Energy are equivalent as in Equation (6) above, but for all (likely) efficiency values below that (i.e., $E_K \leq 1$), some energy loss (E_L) is expected. Such loss is expressed in Equation (8d).

Equation (8d) $E_L = KE - KW$

To summarize, here the system of dynamic knowledge equations is extended to incorporate knowledge flow efficiency (E_K) through continued analogy with dynamic physical systems, nearly all of which suffer energy losses. This enables the differentiation between K-Work and K-Energy (8b), to refine the specification of K-Work in terms of K-Force and Reach (8c), and to specify energy loss in terms of knowledge work and energy (8d). These refinements to the system of dynamic knowledge equations should increase fidelity and enhance its capability for analysis and comparison across organization knowledge flows (Nissen, 2020).

3.2. Knowledge flow cost and performance

The knowledge flow visualization and measurement systems from above have a distinct engineering look and feel to them, as they derive from a system of equations describing the dynamics of physical systems. This is useful for describing the dynamics of organization knowledge flows, but it remains unclear how to inform organization leaders and managers interested in KM system investments. The measurement system from above is extended here to address knowledge flow cost and performance.

Two insights drive the development of the performance measures. The first derives from the adage, “time is money.” The measurement system from above includes the construct *flow time*, which represents the length of time required for organization knowledge to flow from one point to another.

In the example above, employee timecards are used to measure flow time. The Payroll Office or like function can provide monthly salaries or hourly wage rates for employees in most organizations, which we can apply to flow times for all employees involved in each knowledge flow. Equation (9a) summarizes knowledge flow cost (KFC_i) for an individual employee (i) in terms of flow time (FT_i) and wage rate (WR_i).

Equation (9a) $KFC_i = FT_i \times WR_i$

If more than one person is involved with a particular knowledge flow, then knowledge flow cost for all involved employees (KFC_A) is simply the sum (employee i = 1 - n) as reflected in Equation (9b).

Equation (9b) $KFC_A = \sum KFC_i = \sum FT_i \times WR_i$

The second insight derives from how knowledge energy is characterized above as corresponding to the performance level of actions enabled by knowledge: higher energy knowledge enables higher organization performance. The measurement system from above includes the construct *knowledge energy*, which represents the product of K-Force and Reach in Equation (6).

Operationalizing the knowledge flow performance construct is not as straightforward as its cost counterpart above, as various organizations are likely to assess performance in different ways. For several instances, *product, service* or *information quality, quantity, reliability, speed, bandwidth* and like performance measures are common across the myriad organizations in practice today. Nonetheless, any specific organization is likely to have its preferred measures, which can be associated with the underlying knowledge flows driving organization performance (Nissen, 2014). As with flow time above, this can simply be a measured value in the organization.

Alternatively, it may be possible to interrelate performance with knowledge energy as suggested by KFT. For instance, say that performance, measured in terms of output quantity, scales linearly at S_i units per Polanyi of knowledge work and is sensitive to knowledge flow efficiency. This would enable the specification of output quantity (O_i) in Equation (9c) for any particular product or service (i).

Equation (9c) $O_i = S_i \times KW_i = S_i \times KE_i \times E_{ki}$

Although primitive, these equations for knowledge flow cost (9a) and performance (9c) can be combined with efficiency (8a) and used to assess KM investment decisions.

4. Practical Application

Knowledge flow efficiency, cost and performance are illustrated here through practical application to the archetypical processes delineated and measured above. Cost, revenue and profit margin are calculated first for each knowledge flow process with the assumption of imperfect efficiency. Then KM investments to improve efficiency are examined.

4.1. Knowledge flow cost and performance

As above, assume for example that the same 100 chunks of new knowledge are created by the employee at Point A in Figure 4 and that the Explicit and Tacit Paths are just as described via Figure 2. Assume further that all employees involved with these knowledge flows are paid at the same hourly rate of \$100; that performance, measured in terms of output quantity, scales linearly at 1 unit per Polanyi of knowledge work; that each unit sells for \$1; and that knowledge flows at 50% efficiency. Table 4 summarizes knowledge flow cost, revenue and profit margin for the two processes.

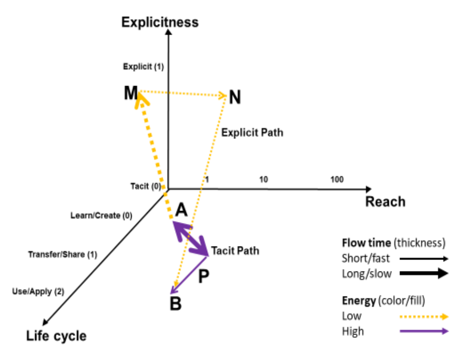

Figure 3 Knowledge flow processes

Results (\$k for cost and revenue, % for profit margin) are as expected for this straightforward example: cost for each knowledge flow process is simply \$100 x FT (measured in hours); output quantity (not shown in the table) is 1 x K-Work, which reflects 50% efficiency or half the knowledge energy levels; revenue is \$1 x O (output quantity); profit (not shown) is revenue minus cost; and margin is profit divided by revenue.

Table 4 Cost, revenue & margin comparison

Path	Cost	Rev	Margin	Comment
Explicit	\$0.46	\$3.53	87.1%	Lower cost Lower rev Best margin
Tacit	\$1.53	\$10.00	84.7%	More cost More rev Less margin

Clearly the Explicit knowledge flow process reflects lower cost (\$0.46k) and revenue (\$3.53k) but has the best profit margin (87.1%). The Tacit flow shows higher cost (\$1.53k) and revenue (\$10.00k) with less margin (84.7%). Organization management now has a baseline for evaluating KM investment alternatives.

4.2. KM investment efficiency

Assume now that management is interested in increasing knowledge efficiency, which is reflected at 50% in the example above; and is willing to invest \$1,000 (e.g., in technology, training, recruiting) to do so, provided the return on investment (ROI) exceeds its 25% hurdle rate based upon increased profit. Management asks how much efficiency gain would be required to justify this investment for each knowledge flow process.

Given the system of knowledge equations above, as extended to integrate knowledge flow efficiency—along with rudimentary accounting knowledge—the answers can be found analytically. Without detailing all of the algebraic steps, we list the key equations.

Equation (10a) $ROI = ([(PR_1 – PR_0)] – I) / I$

Equation (10b) $PR_i = R_i – C_i$

Equation (10c) $R_i = \$1 \text{ x } O_i = \$1 \text{ x } 1 \text{ x } KW_i$

Equation (10d) $KW_i = KE_i \text{ x } E_{ki}$

Equation (10a) expresses ROI in terms of increased profit (i.e., $PR_1 – PR_0$) stemming from the investment, net of the investment amount (I), as a rate of return. Equation (10b) expresses profit as revenue minus cost, which is calculated before ($PR_0 = R_0 – C_0$) and after ($PR_1 = R_1 – C_1$) the investment ($C_1 = C_0$). Equation (10c) expresses revenue in terms of output ($R_i = \$1 \text{ x } O_i$), which scales from knowledge work ($O_i = 1 \text{ x } KW_i$) and is calculated likewise before ($R_0 = \$1 \text{ x } KW_0$) and after ($R_1 = \$1 \text{ x } KW_1$) the investment. Equation (10d) expresses knowledge work in turn as the product of knowledge energy and efficiency ($KW_i = KE_i \text{ x } E_{ki}$), which would be calculated before ($KW_0 = KE_0 \text{ x } E_{k0}$) and after ($KW_1 = KE_1 \text{ x } E_{k1}$) the investment ($KE_1 = KE_0$).

Solving for the knowledge flow efficiency level (E_{k1}) required to meet some investment hurdle rate (HR) for each knowledge flow process of interest, we specify Equation (10e).

Equation (10e) $E_{k1} = [([(1 + HR) \text{ x } I] / KE_0) + E_{k0}]$

Using the 25% hurdle rate from above, the key investment results (i.e., efficiency after investment

[E_{k1}], beginning profit [PR_0], profit after investment [PR_1]) are summarized in Table 5.

Table 5 Key investment results

Path	E_{k1}	PR_0	PR_1	Comment
Explicit	67.7%	\$3.07	\$4.32	Largest E_{k1}
Tacit	56.3%	\$8.47	\$9.72	Smallest E_{k1}

Clearly the Explicit Path requires the largest efficiency gain (E_{k1} = 67.7%) to attain the 25% investment hurdle rate. Because the same \$1,000 investment applies to both knowledge flow processes, the comparatively low initial revenue (\$3.53k) for the Explicit Path makes it more difficult to generate the return necessary to meet the hurdle rate. Alternatively, the Tacit Path has greater initial revenue (\$10.00k), hence the percentage return required to meet the investment objectives is lower. Thus, size matters in terms of knowledge efficiency gains.

5. Conclusion

Knowledge is key to competitive advantage, and organization leaders and managers are called to implement, maintain and enhance key KM systems and processes. However, knowledge is inherently invisible, intangible, indefinite and resistant to quantification. Hence assessing investments in such systems and processes remains fundamentally challenging.

Background research summarizing a system of knowledge flow equations and visualization techniques enable application to two, contrasting, archetypical knowledge flow processes—Explicit Path and Tacit Path—each of which is delineated in multidimensional space and measured in terms of knowledge energy, flow time and power. Such delineation reveals qualitatively different knowledge flow patterns, and measurement quantifies considerably less energy and flow time for the Explicit Path, although the explicit knowledge flows with more power than its tacit counterpart.

This system of knowledge equations is then extended to develop an assessment method for measuring knowledge flow efficiency, cost and performance in the organization. Such specification of knowledge flow efficiency enables differentiation between knowledge work and knowledge energy, and it parallels analogic energy losses of physical systems.

Further, specification of knowledge flow cost and performance marks a transition from dynamic knowledge equations with a distinct engineering look and feel to them: they derive from a system of equations describing the dynamics of physical systems, and they are useful for describing the dynamics of organization knowledge flows.

Alternatively, extension of the measurement system to address knowledge flow cost and performance brings equations into the domain of organization leadership and management: they enable the costs and performance levels corresponding to diverse knowledge flows to be measured and compared, and they support quantitative decisionmaking to inform organization leaders and managers regarding KM system investments.

This method of decision support regarding KM system investments is illustrated in turn through practical application to the two knowledge flow processes from above, as KM investments to improve efficiency are examined in terms of cost, revenue and profit margin: the Explicit knowledge flow process reflects lower cost and revenue but has the best profit margin. This equips organization leadership and management with a baseline for evaluating KM investment alternatives.

Several key equations for calculating ROI in terms of knowledge flow revenue, cost, output, energy, work and efficiency are outlined to reflect rudimentary accounting knowledge. Such equations are then solved to find the knowledge flow efficiency level required to meet some investment hurdle rate for any knowledge flow process of interest.

Results reveal that the Explicit Path requires the largest efficiency gain to attain a 25% investment hurdle rate. This stems largely from the lower revenue produced through that knowledge flow process, along with the realization that size matters in terms of knowledge efficiency gains.

These results are highly promising. For instance, measured differences between the alternate knowledge flow processes reveal both qualitative and quantitative commonalities and contrasts in terms of efficiency, cost and performance. This helps to equip organization leaders and managers with tools to understand critical knowledge flow differences and to select the most appropriate process for given financial circumstances.

Such results also elucidate a novel decision support capability, as organization leaders and managers are able to make more informed KM investment decisions. For instance, managers can compare the revenue, efficiency, cost and profit profiles associated with diverse knowledge flow processes, and they can assess the relative potential of KM investment decisions across alternatives. This helps to equip such managers with tools to support investment decisionmaking through quantitative financial analysis.

Future research can work to understand how this extended knowledge visualization and measurement system can meld with, leverage and expand the considerable Decision Support literature. Knowledge is clearly fundamental to informed decision making, hence KM is likely indispensable to decision support.

Future research can work also to extend KM through knowledge flow visualization and measurement of additional archetypical and theoretical models (e.g., Spiral Model; see Nonaka, 1994), as a great many KM theories and models remain unexplored along these lines. A great many KM theories and models also remain conceptual and descriptive for the most part. Knowledge flow visualization and measurement offer potential to complement them with qualitative, quantitative and prescriptive insights.

Future research can work further to measure the knowledge flows of operational organizations in the field. As such measurements accumulate, the KM Community may be able to establish an increasingly rich set of data for use in comparing different organizations, processes, technologies and knowledge flows on a quantitative basis. Perhaps it can even establish sets of norms, benchmarks and like measures that can be utilized practically and productively by organization leaders and managers.

Additionally, investigating the impact of emotion, in addition to personal habits and behaviors, on (esp. tacit) knowledge flow represents another exciting and uncharted research trajectory. In addition to including emotion as a component of the **o** vector noted above, there is much room for learning about the interaction of emotion with varying degrees of knowledge explicitness.

Finally, following Physics, this line of research has great room for standardization of measures. Physical measures such as *length, mass* and *energy* are defined precisely (e.g., meter, gram and Joule, respectively), and everyone can agree on them. When considering the analogic knowledge flow measures presented in this article (e.g., *reach, chunk* and *K-Energy*), in contrast, we offer corresponding operationalizations (e.g., number of people accessing knowledge, ability to make a distinction, performance level of knowledge work, respectively) that appear to fall very short. This remains a rich direction for continued research.

Knowledge visualization and measurement remains a nascent research endeavor. Although the systems described in this article draw analogically from Physics, the study of dynamic *knowledge* systems is many centuries behind in terms of understanding with respect to their dynamic *physical* counterparts. Even small, admittedly imprecise, analogic, theoretic steps such as ours can contribute much. As the saying goes, it is better to light a candle than curse the darkness. We welcome others to contribute likewise.

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