Featured Articles

Measuring Happiness Using Wearable Technology

—Technology for Boosting Productivity in Knowledge Work and Service Businesses—

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OVERVIEW: Instead of the industrial production, which drove economic growth in the 20th century, the driver for growth in the 21st century is productivity in knowledge work and service businesses. For this reason, the authors developed a technique for measuring happiness using wearable technology. The research found a hidden signal representing a person's happiness within the basic pattern of physical activity known as the "1/T rule." This result uncovered a close relationship between the "trinity" of physical activity = happiness = productivity. Combined with a technique for using artificial intelligence to generate KPIs automatically, the technology can foster the ability of groups to engage in "co-creation" while also encouraging autonomy and commitment in individuals. This new technology is recognized as having the potential to open up new pathways in corporate accounting, production, and human resource systems.

INTRODUCTION

It has long been said that enhancing the productivity of knowledge work and service businesses will be key to future economic growth. However, it is not clear how to do this, and no successful examples are evident. Attempts have been made to apply techniques that have proven successful in manufacturing, such as industrial engineering and the Toyota Production System, to knowledge and service businesses. However, the fundamental differences between the manufacturing workplace, where operational processes and deliverables are clearly defined, and the service workplace mean that the simplistic application of such techniques has failed to produce results. Similarly, while practices such as management accounting (including budgeting and cost management) and human resource systems (including management by objectives and evaluations) might also be expected to improve productivity, these too have failed to deliver significant benefits.

Does this mean it is impossible to make fundamental enhancements in the productivity of knowledge work and service businesses? No—and in fact, wearable technology has the potential to make this possible. The use of wearable technology opens up possibilities for the quantification and control of human and social activities that have previously been understood only in qualitative terms. The technology will transform corporate accounting, production, and human resource systems at a fundamental level.

QUANTIFYING HAPPINESS

What the authors chose to look at was people's wellbeing or happiness. At first glance, these may appear to be questions more suited to philosophy or religion. Recently however, various countries, including not only Japan but also the UK, France, Austria, and Bhutan, have considered adopting happiness as an alternative national indicator to gross domestic product (GDP). The Ministry of Education, Culture, Sports, Science and Technology even has a research project in progress aimed at achieving a "Happiness Society."

It has been reported that a person's happiness significantly influences performance. Compared to people who are unhappy, it has been found that people who are happy have 37% higher work productivity and 300% higher creativity(1). They also enjoy higher annual income, faster promotion, and are more likely to have a successful marriage, have friends, and to live longer and healthier lives(2). It has also been reported that companies with a large number of happy people have higher earnings per share.

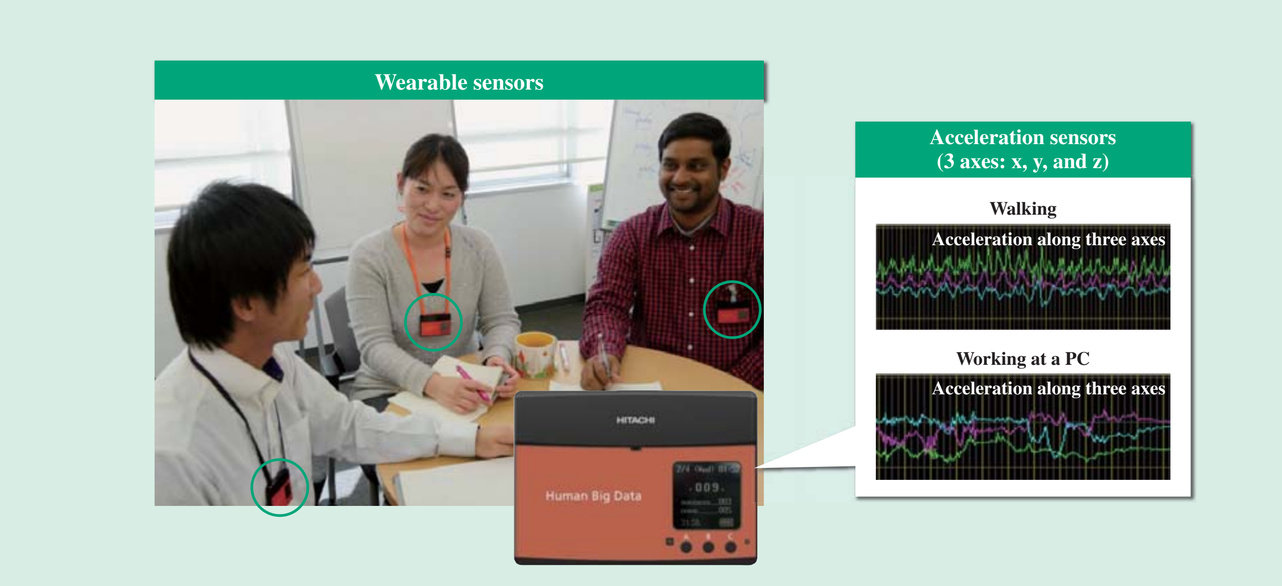

Fig. 1—Identification of Correlation between Group Happiness and Patterns of Physical Activity Measured by Wearable Sensors. Group happiness can be measured in realtime simply by wearing a sensor. Physical activity is measured using three-dimensional acceleration data.

The important point is not that successful or healthy people are happy, but that happy people have a higher likelihood of being successful and healthy. It has also been found that the contribution of success and health to happiness is only 10%(2).

Meanwhile, mental health problems in the workplace have a major impact on employee productivity. The number of people suffering from depression or other mental illness has more than doubled over the last 15 years, with sick leave and the effect on the people around them having a significant effect on productivity.

The problem with this, however, is that it is not possible to quantify happiness. While questionnaires have been used for measuring happiness, the wide range of between-individual variance in questionnaire responses means that these are subjective and suffer from a lack of plausibility and repeatability.

So, is there any way to define, measure, and quantify happiness as if it were a measurable quantity from one of the hard sciences?

Hidden Relationship between Physical Activity and Happiness

Over the span of nine years, Hitachi has collected and studied more than a million days' worth of data on people's activities using wearable technology(3), (4), (5). Using data from wearable sensors with millisecond resolution, the authors have identified characteristic patterns of physical activity that have a strong correlation with happiness. The sensors take the form of a card attached to the chest that can record measurements of the amount and direction of movement in three dimensions and with high resolution (50 times a second, or once every 20 ms)(6), (7), (8) (see Fig. 1).

From this vast amount of data, the authors uncovered a fundamental rule that relates to physical activity. This is the "1/T rule"(9). It categorizes physical activity during each unit of time as either inactive or active, and looks at the "active" times when the person is moving and how long they last (called "sustained activity"). Activities categorized as "active" include not only walking, but also small movements such as nodding or typing. The duration (T) of sustained activity has a wide variance depending on the circumstances. What is found when looking at the distribution of T values within a group is that it follows not the "bell curve" normal distribution, but rather a long-tail distribution. Typically, 30% of sustained activity instances account for 70% of all physical activity, with activity being skewed toward certain times or people. The name of the "1/T rule" derives from the fact that, quantitatively, the probability of changing to inactivity is inversely proportional to T, and accordingly, the fluctuation in physical activity is called "1/T fluctuation"(10), (11), (12) (see Fig. 2). This can be thought of as the human version of Newton's first

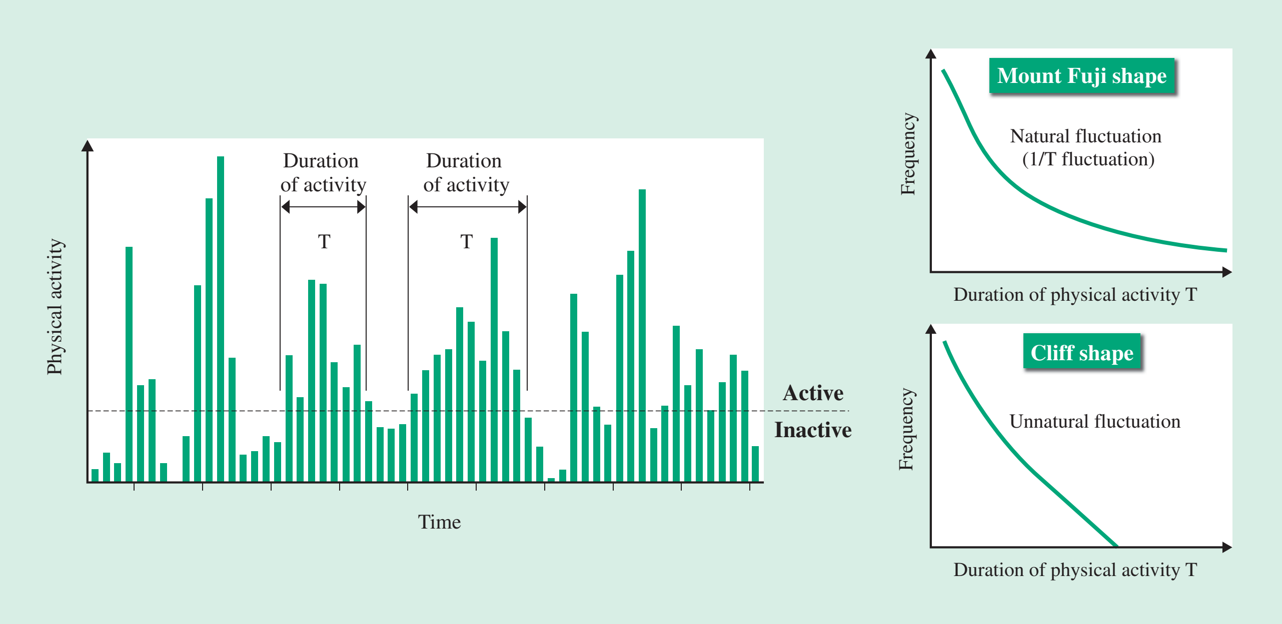

Fig. 2—Discovery of Distinctive Patterns of Physical Activity Associated with People's Happiness.
When physical activity is classified as either inactive or active and a frequency distribution obtained by counting the durations of activities classed as "active," groups with a high level of happiness are found to have a low degree of deviation from the 1/T rule (Mount-Fuji-shaped graph) and groups with a low level of happiness have a large deviation from the 1/T rule (cliff-shaped graph).

law, which states that a body will remain in uniform linear motion unless acted on by an external force.

When looking at the fluctuation data for individual groups, what is found is not a perfect match with the 1/T rule. Rather, some groups follow the rule comparatively closely while others diverge considerably. This 1/T fluctuation (the extent to which the data fits the 1/T rule) is adopted as a numerical indicator. When 1/T fluctuation is large, the frequency distribution of the activity duration T looks like Mount Fuji with a long tail. In contrast, the T frequency distribution becomes more cliff-like and the tail disappears when 1/T fluctuation is low. This corresponds to the second law of motion in the presence of a force.

The authors discovered that this 1/T fluctuation is strongly correlated with happiness[13]. Sensors were attached to 468 employees from 10 departments across seven companies to collect approximately 5,000 person-days or roughly five billion points of acceleration data. The relationship between these results and happiness scores from questionnaires was then analyzed. The questionnaires used were from the Center for Epidemiologic Studies Depression Scale (CES-D)[14]. The CES-D questionnaire asks respondents to give a ranking between 0 and 3 to questions such as "how often you've felt that you were happy during the past week?" It contains a balanced mix of questions relating to things that contribute to or detract from happiness, with the score being obtained by totaling the responses to 20 questions of this nature on things like concentration, enjoyment, desires, good sleep, conversation, appetite, depression, anxiety, loneliness, and sadness (such that 3 × 20 = 60 points corresponds to being most happy and zero points corresponds to being least happy). While the CES-D questionnaire was developed for self-assessment of depressive tendency, it was adopted for testing on the assumption that explaining the decline in happiness due to the depressive tendency would be a necessary prerequisite for constructing a measure for happiness.

The results found a high correlation between the above 1/T fluctuation indicator and the departmental mean values of the happiness scores from the 468 subjects (see Fig. 3). Because the likelihood of this result obtained by chance is less than one in one million, this alternative (chance) can be ruled out. In other words, it is possible to obtain regular ongoing quantitative measurements of happiness within an organization by attaching wearable sensors to people's chests.

Note that happiness and level of activity are completely different things. The level of activity in a sales job that entails a lot of walking around is typically much higher than in sedentary office work. Despite this, sales work is not invariably happier

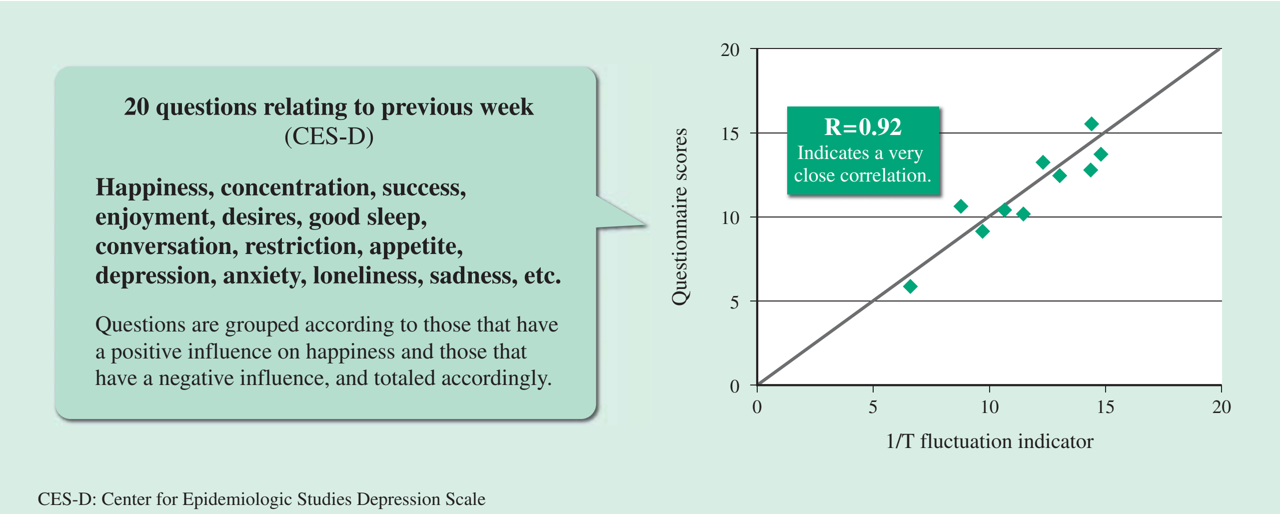

Fig. 3—Relationship between People's Physical Activity and Questionnaire Results.
The results of a questionnaire were compared with approximately 5,000 person-days or roughly five billion points of measurement data collected from 468 employees from 10 departments across seven companies.

than office work. Although people's level of physical activity varies depending on their job and position, this measure of happiness captures hidden features of physical activity that do not depend on such superficial factors as job and position.

One characteristic of 1/T fluctuation is that physical activity in a group has many components. Accordingly, groups that have a high level of happiness also have a high level of diversity in their body movements. Conversely, groups that have a low level of happiness also have a low level of diversity in their body movements. In other words, this technique is using the lens of physical activity to quantify whether or not there is diversity in group activities.

Happiness Influences Call Center Productivity

There are some people who think this way: As a subjective concept, happiness could be just an indication of self-satisfaction; if people are placed in a comfortable environment, they may lose the motivation to achieve; it should be true that it is when people feel threatened or anxious that they exert their power to the fullest. Nevertheless, the data indicates otherwise.

The authors conducted an experiment at a call center[15]. Specifically, this experiment involved having 215 subjects working at two different sites wear sensors over a 29-day period (providing a total of 6,235 person-days of acceleration measurements comprising roughly six billion data points), and then investigating the relationship between the 1/T fluctuation of physical activity and work productivity (as measured by the rate of successful sales). The call center engaged in cold calling potential customers to try to sell them a particular service.

The rate of daily orders differed by a factor of three depending on such things as the site or day. The main factor in this variation in results was found to be the 1/T fluctuation of physical activity (in other words, happiness) (see Fig. 4). Because many of the call center staff worked part time, the mix of people at work was different every day. The overall happiness of the staff as measured by the sensors varied between sites and from day to day. Furthermore, staff (days, sites) with above-average 1/T fluctuation had an order rate 34% higher than those with below-average 1/T fluctuation.

This demonstrates that the 1/T fluctuation of physical activity (happiness) that is associated with staff performing at a high level and achieving good results is not simply a matter of providing a relaxing, stress-free environment. In fact, these results confirm that the level of happiness in relaxing environments is not high. According to Mihaly Csikszentmihalyi, this is because such conditions are close to a state of boredom[16]. Achieving happiness and enjoyment requires challenging but achievable tasks that push the limits of the person attempting them. On the other hand, a level of challenge that is too high invokes anxiety and diminishes performance. It also reduces productivity. Happiness corresponds to the roof covering the valleys of boredom and anxiety and is a state of high productivity. The measurement of 1/T fluctuation is a valuable tool for staying on top of this roof.

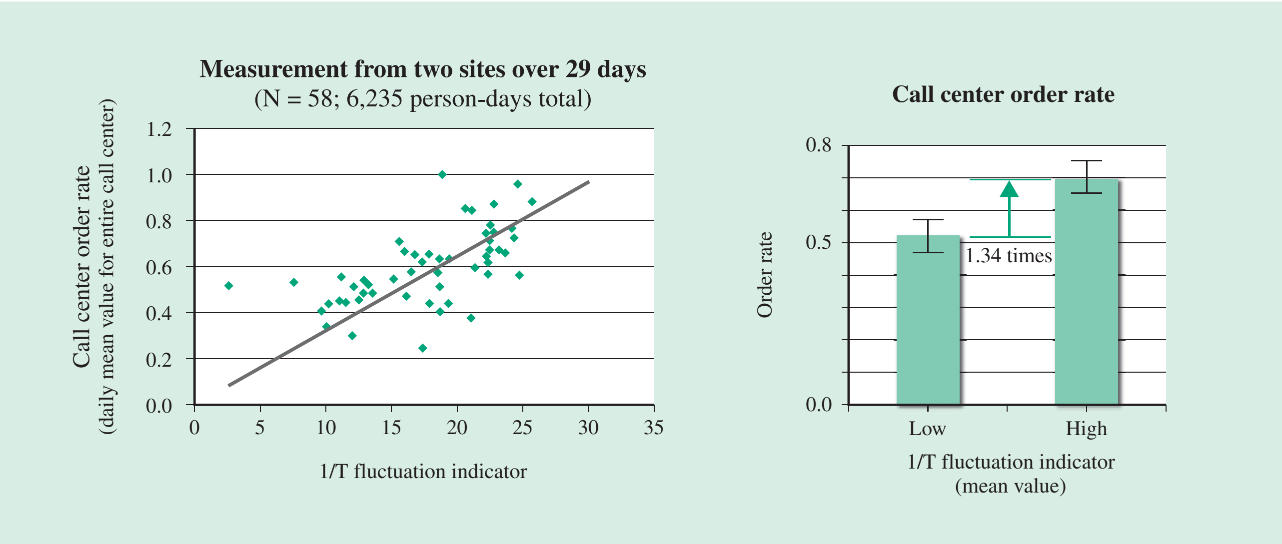

Fig. 4—Demonstration of Direct Link between 1/T Fluctuation of Physical Activity (Happiness) and Work Productivity at Call Center.
An experiment found a 34% higher order rate on days with above-average 1/T fluctuation compared to below-average days.

In the case of this call center, the thing that determined staff happiness turned out to be something quite unexpected: it was their level of physical activity during breaks. The staff room is a place to sit down and relax. The physical activity recorded by the sensors consisted largely of people chatting with other staff. On days when there was a high level of conversation among staff as a whole during breaks, the call center's overall level of happiness was high, as was the order rate.

The important point here is not that the order rate was high only for those staff whose level of physical activity (conversation) was high, but that the overall level of group happiness was higher and a better overall order rate was achieved on days when the group as a whole had a high level of physical activity. In other words, physical activity, happiness, and the level of orders all turned out to be collective phenomena. This means that, even in work that would be expected to depend on individual performance, staff were performing influenced by unconscious interaction with those around them.

Furthermore, the data also clearly indicates a way of invigorating conversation during breaks: have the supervisor speak to staff during work time. Appropriate communication with the supervisor during work times led to more conversation during breaks, which enhanced staff happiness and boosted the order rate. A sustained improvement in call center order rate of more than 20% was achieved when, prompted by this result, the call center utilized a cloud application that facilitated supervisors speaking to staff.

SHORTENING THE BUSINESS CYCLE

There is no reason to assume that the strong relationship between physical activity, happiness, and work productivity only applies at call centers. It has been reported that the contribution of happiness to performance is even greater in creative work[1]. Although lack of space prevents the inclusion of details in this article, the authors have demonstrated that the 1/T fluctuation of development team members two months after the start of a product development project is a leading indicator of sales five years later.

In the case of knowledge work, there is often a long time-lag before financial results emerge. In the case of product design, for example, it is not unusual for a year to pass before it is clear whether or not the product has been a success. In the case of business sales, orders are often determined by a year-long budgeting cycle. These time-lags are even longer in the case of research and development.

Because the people involved and other external circumstances change over time, it tends to be unclear which actions were instrumental to success. This is why existing management accounting and human resource systems fail in practice. Financial results on their own are inadequate as feedback for knowledge workers.

On the other hand, the use of 1/T fluctuation as a three-way indicator of physical activity, happiness, and work productivity enables the plan, do, check, and act (PDCA) cycle to be implemented in a very short timeframe. This can be incorporated into corporate systems.

Corporate Systems that Incorporate Happiness

Business is made up of many people and organizations. Nevertheless, there is a tendency to go no further than local optimization within the scope of individual responsibilities. On the other hand, attempting to consolidate the administration of all information and authority does not work either. This is because there is a lack of utilization of experience and other forms of workplace information that cannot be transformed into data. This is the biggest challenge facing the 21st century workplace.

However, by measuring happiness it is possible to build systems that overcome this challenge. Specifically, this involves treating business as a "system of systems" made up of a large number of people who play the role of sub-systems. The terminology includes "outcomes" (meaning overall results), "key performance indicators (KPIs)" as the measure of individual performance, and "evaluation functions" as the formulas used to calculate KPIs. It is possible to work toward system-wide optimization in a changing environment by incorporating factors that affect overall performance into the KPIs set for individuals, while also having people decide and act autonomously in accordance with their own KPIs.

There should be the best way to incorporate the factors that contribute to system-wide optimization into the KPIs of individuals. The baseball concept of sacrifice hits (such as bunts) provides a model for this. Although a player who makes a sacrifice hit gets out without reaching first base, that player still contributes to the team. If this sacrifice hit is included in the player's batting evaluation, then it can improve overall team performance. In baseball, sacrifice hits are excluded from the batting average calculation and are assessed on their own. Here, getting on base is called a "direct variable" and a sacrifice hit is called a "symbiotic variable."

In practice, the chain of influence from one person to another in an actual business is complex and identifying symbiotic variables is more difficult than it is in baseball. Hitachi's "H" artificial intelligence (an abbreviation of "Hitachi Online Learning Machine for Elastic Society") can automatically generate individual KPIs that include symbiotic variables and the evaluation functions used to calculate them from big data, and can also provide the rationale for them. In particular, by using the 1/T fluctuation indicator for all people involved as a leading indicator of business performance, it is possible to simplify the problem to a large degree by shortening the cycle time for action and results. The inputs to H are the outcome definitions and various operational data such as the activity data for each person. Based on this, H automatically generates a large number of hypotheses about the factors that influence outcomes (with a number of candidate variables ranging between one hundred and one million), narrows these down to a small number of important factors, and then generates the evaluation function[9].

By using the evaluation functions produced by H (which include symbiotic variables), it is possible to achieve system-wide optimization through the effect of these symbiotic variables while still enabling individuals to make their own decisions based on their own KPIs. That is, it is possible for corporate accounting, production, and human resource systems to maximize the happiness and productivity of everyone involved. By having H automatically update these evaluation functions using daily data, it is possible to work continually toward system-wide optimization in a changing environment by having KPIs adapt to the circumstances.

This has the potential to revolutionize a wide range of corporate activities (see Table 1).

Table 1. Applications for Measuring Happiness

The technique has applications in a wide range of businesses where organizational revitalization and productivity improvement, etc. are relevant.

Business	Objectives	Anticipated benefits
Research and development	• Evidence-based project management • Early assessment and action on objectives and organizational structure	• Accelerate innovation. • Improve return on investment.
Organization management (M&A, etc.)	• Management of organizational restructuring • Performance assessment and actions for leaders	• Successful restructuring • Improve employee satisfaction.
HR (promotions, evaluation)	• Organizational revitalization • Assessment and training of managers	• Improve employee satisfaction, reduce staff turnover. • Improve management capabilities.
Engineering and manufacturing	• Evidence-based engineering and manufacturing • Improve product quality (defects, accidents).	• Improve productivity of engineering and manufacturing, prevent delays. • Prevent major recalls, improve quality.
Sales and marketing	• Evidence-based sales management • Expedite training of sales and marketing staff.	• Increase sales revenue. • Improve customer engagement.
Services	• Motivate and improve productivity of staff. • Get new sites established quickly.	• Improve productivity, improve ability to acquire workers. • Get new sites established quickly.

HR: human resources M&A: mergers and acquisitions

Controlling Happiness

The controllable degrees of freedom for maximizing happiness are extensive. Controlling the air conditioners in buildings is one example. Instead of conventional air conditioning that maintains a constant temperature, using happiness measurements and artificial intelligence, it is possible to operate the air conditioning in a way that maximizes the overall happiness of the people in the building.

At the call center, it was possible to enhance overall happiness and productivity by controlling communication between staff. In that case, conversation during breaks was treated as a symbiotic variable for operators, and talking to staff while they are working in the right way was treated as a symbiotic variable for supervisors. By having a business system that included such symbiotic variables, the overall productivity of the call center was significantly improved by operators raising their KPIs, which included symbiotic variables as well as direct variables like their order rate.

Another example to be considered is improving healthy life expectancy while minimizing medical costs at community healthcare systems. In a case like this, the cycle time is too long to permit a data analysis of the relationship between policy changes and changes in the community's healthy life expectancy. However, the cycle can be shortened dramatically by treating 1/T fluctuation as an outcome, enabling the PDCA cycle to be worked through on a daily basis.

CONCLUSIONS

The 18th century philosopher, Jeremy Bentham, put forward the idea of "the greatest happiness of the greatest number," suggesting that the quantification of happiness could provide a benchmark for ethical decisions. Subsequent criticisms of Bentham, however, concluded that, ultimately, happiness is not something that can be measured. This technology has the potential to overturn this state of affairs.

In the past, many organizations have persisted with unilateral rules even in cases where flexible judgment based on the circumstances is called for. This is because establishing and then sticking to detailed unilateral rules and other processes have become the main way of managing groups. This approach has its origins in the scientific management methods proposed by Frederick W. Taylor in the early 20th century. However, as noted by Peter F. Drucker, scientific management lacks flexibility and does not adapt well to change[17]. Management in the 21st century needs to set its sights beyond these limitations and equip itself with the flexibility to handle a variety of different situations.

The 20th century was characterized by people having to adjust to systems and rules. The future, in contrast, will see the level of individual happiness enhanced through artificial intelligence and the quantification of happiness, with systems and rules having to adjust to people. As a breakthrough in assessing the collective unconscious, the measurement of happiness has the potential to revolutionize not only people's lives but also management and consensus-building within companies, communities and nations, and even humanity as a whole, by providing a means of visualizing people's happiness.

The data presented in this article was obtained by the human big data / cloud services of Hitachi High-Technologies Corporation and is managed under a business-to-business service contract that includes ethical terms (including protection of personal information and information security) under the ethical standards of the Hitachi Group.

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