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Hitozukuri and Monozukuri: Centuries' Old Eastern Philosophy to Seek Harmony with Nature

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This plenary lecture addresses concepts of Hitozukuri and Monozukuri, centuries' old philosophy deeply rooted in Japanese culture to respectively addresses educating human to be a responsible individual who can lead the world to a better place and making things with excellence, skills, spirit, zest, pride, and more. Hitozukuri and Monozukuri are the philosophy to seek balance and harmony with nature, where integration and synthesis play a key role than specialization and analytical skills. This lecture is intended to address a possibility to create win-win philosophy by harmonizing the eastern thinking and the western thinking in education and research in the global world where we live now.

KEYWORDS: Hitozukuri, Monozukuri, globalization, education, interdependence

Introduction

The University of Kentucky's Institute of Research for Technology Development (IR4TD) operates through interdependent and sustainable partnership with industry. This unique institute is a good example of University of Kentucky's (UK) effort to seek a new and better way of doing research, education, and service.

It is sometimes claimed that industry and academia are two very different cultures, with the former concerned with how to deliver reasonably-priced high quality products to customers in a timely fashion [1], while the latter academic institutions, focus on education, research, and service. Yet this difference does not mean there is no common ground. Toyota's Chairman, Fujio Cho stressed the importance of "hitozukuri and monozukuri" in his anniversary lecture at Toyota Motor Vietnam [2]. A common mission does exist between companies that value "hitozukuri and monozukuri" and academic institutions that focus on education and research. This lecture discusses IR4TD's win-win strategy in R&D based on principles of hitozukuri and monozukuri, and our recent progress in surface coating and inspection technology.

Hitozukuri and monozukuri (both are Japanese words) may require some explanation for non-Japanese audiences. Monozukuri consists of "mono" which means "products," and "zukuri" which means "process of making or creation." But the word means more than simply making something; it has overtones of excellence, skill, spirit, zest, and pride in the ability to make things, good things, very well. Monozukuri is not mindless repetition; it requires creative minds and is often related to craftsmanship which can be earned through lengthy apprenticeship practice rather than the structured curricula taught at traditional schools. Monozukuri represents the maker's philosophy of how to make things — the philosophy deeply rooted to Japanese tradition in Zen [3], Confucius's teaching [4], two important pillars to support the century old Japanese culture. Monozukuri is therefore a philosophy rather than technique or method.

If "mono" is replaced with "hito" which means human, monozukuri becomes hitozukuri, education the closest English word. But hitozukuri contains a much broader meaning and stresses a life-long process of learning. Hitozukuri emphasizes several different steps of human development, whose original form was emphasized by Confucius in his famous six different human development stages. It goes: "when I (Confucius) was fifteen year's old, I decided to study; at thirty I became independent; at forty I focused; at fifty I realized my mission in my life; at sixty I became able to listen to people without bias and prejudice; finally at seventy I attained the stage that my thinking and action are harmonized with nature [4]. Hitozukuri is a continuous life-long process of human development.

Looking at education and research on the other side of world, America, the National Science Foundation which provides funding for American universities and government laboratories to study broader aspects of science and engineering, assesses the effectiveness of academic institutions based on productive faculty, quality students, and a strong support system. Productive faculty and quality students require a special academic environment that supports the current education and research and stimulates their future learning and research. Creating a supportive and stimulating

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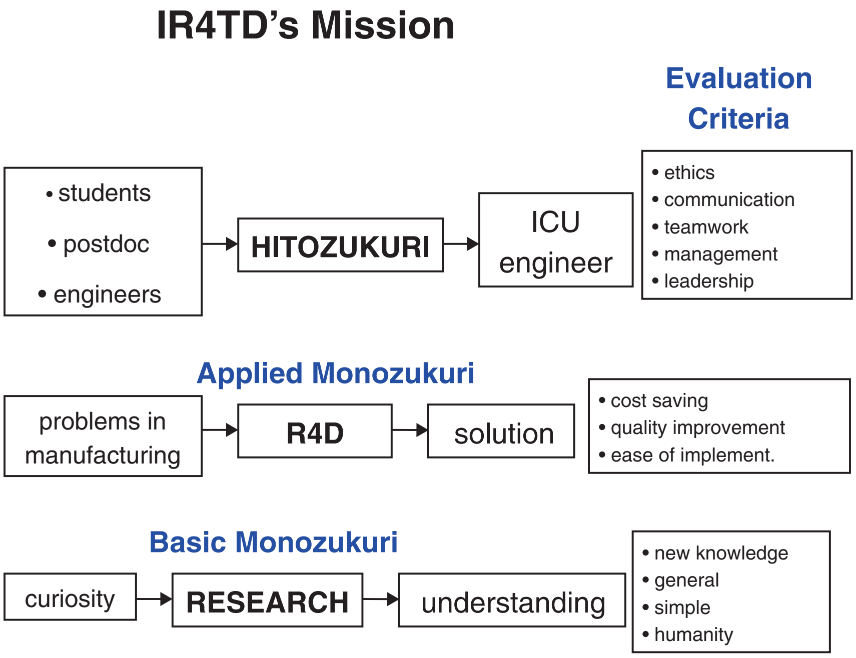


Fig. 1. Schematic diagram of IR4TD's mission in hitozukuri and monozukuri.

environment for all the members of IR4TD research team to function best is important but challenging, since all individuals think and act differently. Therefore, IR4TD encourages each individual to go through a particular training to find each individual's strengths and utilize his or her strengths to achieve the status of ICU (innovative, creative and unique engineer). ICU engineer is a product of past, present and future — the current stage of the researcher's innovative mind comes from his or her unique past history which will help his or her creativity now and in future activities. Figure 1 describes a schematic of hitozukuri, applied and basic research (here applied research is called applied monozukuri and basic research is called basic monozukuri).

There are two different types of University research: curiosity-driven basic research (basic monozukuri) and purpose-driven applied research (applied monozukuri). R4D is a good example of applied research. IR4TD believes that it is important to keep both applied and basic research, because if university researchers only conduct R4D research by staying inside the boundary determined by a well focused R4D plan, ignoring curiosity-driven basic research, we will lose our ability to see the entire forest, a vision so important to help us look at the same problem from different points of view [5, 6].

Painting Technology Consortium

Toyota's Kentucky plant was opened in 1986. This was also the same year that I joined UK. This fortunate coincidence gave me a new opportunity to study the automobile manufacturing process [7]. Toyota's managers and engineers and UK faculty members soon started discussing collaboration in research. Toyota's Japanese executives were instrumental in starting this joint partnership. In 1993, UK's College of Engineering received the project to study the automobile coating process. For the next four years, our focus was mostly learning the automobile coating system and processes by visiting Toyota plants, paint booth manufacturers, and paint companies both in the US and Japan. During this learning period, Toyota provided continuous and steady funding without asking for short term results related to immediate practical applications.

We started to conduct a series of scientific studies on automobile coating technology. We found that some automobile coating processes were largely experience-based, and required scientific analysis for effective improvements. We often asked questions: What are the scientific principles to support this process, that equipment, and that system? After collecting data at various plant sites and in discussions with engineers and operators, we then conducted laboratory experiments and CFD (Computational Fluid Dynamics) model calculations.

Abraham Salazar who joined our group in 1996 as a doctoral student (now research faculty at UK) had a strong background in CFD. He analyzed the airflow pattern containing paint particles and the capturing mechanism of typical conventional wet scrubbers used by automobile manufacturers to capture over-sprayed paint. His CFD analysis, based on fluid dynamics, helped us to scientifically estimate waste in energy use and relative efficiency in particle capturing of existing wet scrubbers.

Our next task was focused on how to improve the performance of wet scrubbers. This task required new ideas through thinking outside-the-box and a paradigm shift. We learned from nature that sand dune structure in a desert can be the most efficient way to capture paint particles with minimum energy consumption. This approach led our team to

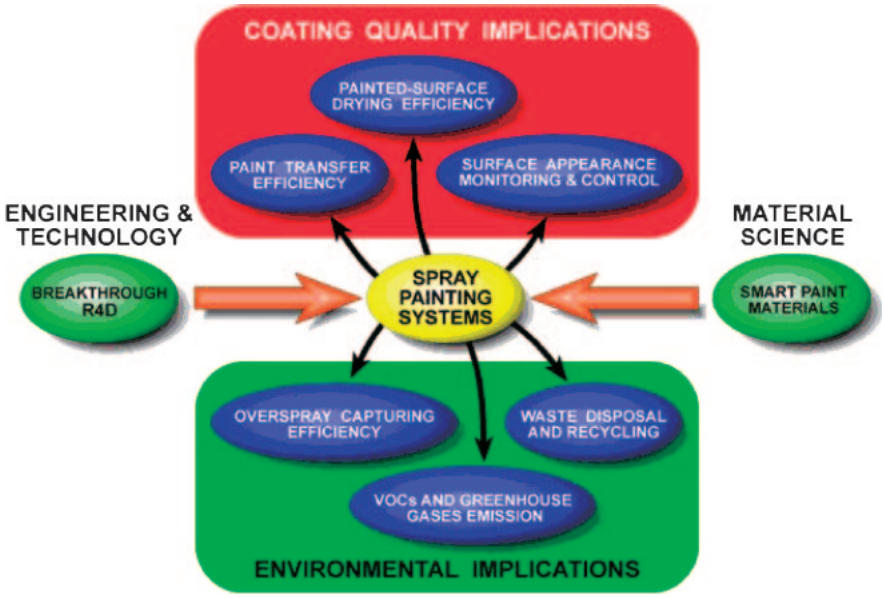


Fig. 2. Six different coating research areas of UK's PTC.

invent Vortecone in collaboration with Toyota and Trinity engineers. Vortecone wet scrubber is 30–50% energy efficient and has a higher capturing capability than other similar products available on the market [8]. Our team's success lies in the combination of the following factors: Basic research to understand the capturing mechanisms, thinking outside-the-box, paradigm shift, and Toyota' continuous and steady funding support. Without any of the above elements, I doubt this invention would have been possible. In this case, the box was technology, that is, the outcome if human thought combined with engineering principles. We shifted our focus to nature, another source for models of how to make things efficiently.

This initial success attracted other companies to pay attention to the University of Kentucky's automobile coating research, leading to the establishment of UK's Painting Technology Consortium (PTC) in 1999. In the following year, we initiated the annual Painting Technology Workshop [9] with the following aims: (1) to provide a place where industry engineers, government agency regulatory personnel, and academic researchers meet and discuss coating research and technology development; (2) to share common problems in coating technology and seek win-win solutions; and (3) to provide educational and training opportunity. Figure 2 shows six different areas of UK's PTC coating research.

In the meantime, UK's PTC received ever-increasing requests from industry for immediate and long-term solutions to process problems and challenges beyond automobile coating technology. This led to the creation of Institute of Research for Technology Development (IR4TD), a stepped-up version of the Painting Technology Consortium (PTC), with broader aims to cover almost all types of engineering problems related to manufacturing industries. The following summarizes IR4TD's mission and operational principles.

IR4TD

The Institute of Research for Technology Development (IR4TD) was proposed in 2006 and approved in 2007. To stress the way research and development are integrated in our work, we call our approach R4D — research for development. We chose the number 4 instead of the word to suggest our difference from engineering as usual. The new institute's purpose is to directly and effectively respond to requests from industries. R4D is a demand-pull rather than a supply-push approach; we respond to the needs of clients who approach us rather than approach companies with our research interests. This partnership development approach is based on the win-win buffer theory proposed by F. Cho [10], who promotes the importance of creating common interests among different parties and different individuals when they work together. The common interest will emerge when each individual or each party is willing to seek an interdependent relationship where push-principle is replaced with pull-principle. Cho's buffer theory is based on Confucius's teaching where compassion "Jo" is the foundation for human relationship building [4]. Figure 3 shows a schematic of Cho's buffer theory.

IR4TD's mission is aligned with the University of Kentucky's strategic plan. It states: "The University will accelerate industry-funded research and partnerships, technology transfer, and business development to advance Kentucky's economy… we must seize opportunities to develop further our intellectual property, corporate relationships, and business ventures, and we must enhance our efforts to fulfill the vision and promise of UK's Research Campus."

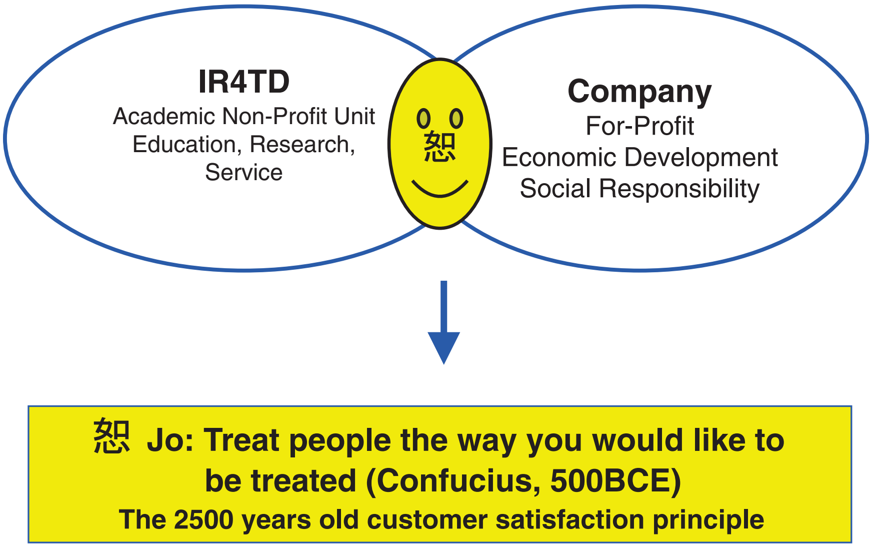


Fig. 3. The win-win buffer theory.

Our R4D approach has worked to help us build industry relationships that continue to grow and to offer us more challenging and complex problems. The approach also provides an excellent education for our graduate students in tackling pressing industry problems, working as a team, accepting responsibility, coping with real budgets and real deadlines, communicating effectively with clients, and understanding their point of view. A client may see a problem with the current process; we can see in fact that they have come to the limits of a current technology so that a new generation technology or even a radical new approach to the whole question is needed. The "R" of our work is not simply paired with the "D" but tied directly to needed innovations.

Overall, this approach leads to:

- high probability of immediate in-plant benefit to the company;
- high likelihood that new technology needs will be accurately identified — thus, new generation technologies that fit efficiently into the company's manufacturing systems, and the potential for discovering "quantum leap" (revolutionary) solutions that can be transferred to other industries; and
- a higher percentage of successful proposals (>60%).

Two Kinds of Innovation in R&D: Incremental and Major

(1) In-plant Improvements

A corporate client identifies manufacturing issues that have significant impact on its costs structure. IR4TD research team proposes concepts for in-plant improvements that could be integrated into the company's manufacturing systems; it could be encoded in hardware or software products meeting improved efficiency and production targets while remaining within the cost basis of the plant. Prototyping is essential for the overall solution to fit into existing manufacturing systems. Projects may be completed within 3–12 months, depending on the urgency of the manufacturing issue.

This part of our research is what the recent Department of Commerce report *Manufacturing in America* calls "incremental innovation." Where the first kind of innovation is major and dramatic, this second type of innovation is "the steady improvement in products and manufacturing processes within major technology lifecycles. Such improvement involves much less dramatic improvements, but collectively these innovations have a significant effect." Figure 4 illustrates typical progress in technology development in customer satisfaction (CSF)-competition/demand diagram, where evolutionary progress is made by the continuous improvement through Kaizen and revolutionary progress is made by major breakthroughs in research. It is important to see that both incremental and major innovations are necessary to form the entire innovation process. As can be seen in Fig. 4, stage-one Kaizen (incremental innovation) is leading to the breakthrough (unsteady) point providing the condition for the major innovation to occur; therefore, the major innovation is not a stand alone activity. After the technology jump created by breakthrough technology, stage-three Kaizen will start to provide small incremental improvements to the new technology, leading eventually to another breakthrough point. This is a typical Kaizen cycle in R&D. Interestingly, the Fig. 4 diagram is similar to a well-known S-curve of ignition theory in combustion. In the ignition theory, the vertical line is temperature and the horizontal line is Damkoler number (non-dimensional time: flow time divided by chemical reaction time) [11]. The breakthrough point is the ignition point; after that point, suddenly flaming occurs, pushing the pre-ignition temperature (350 °C) to the post-ignition temperature (1500 °C). Note: here again, thinking by analogy as a way to shift a point of view.

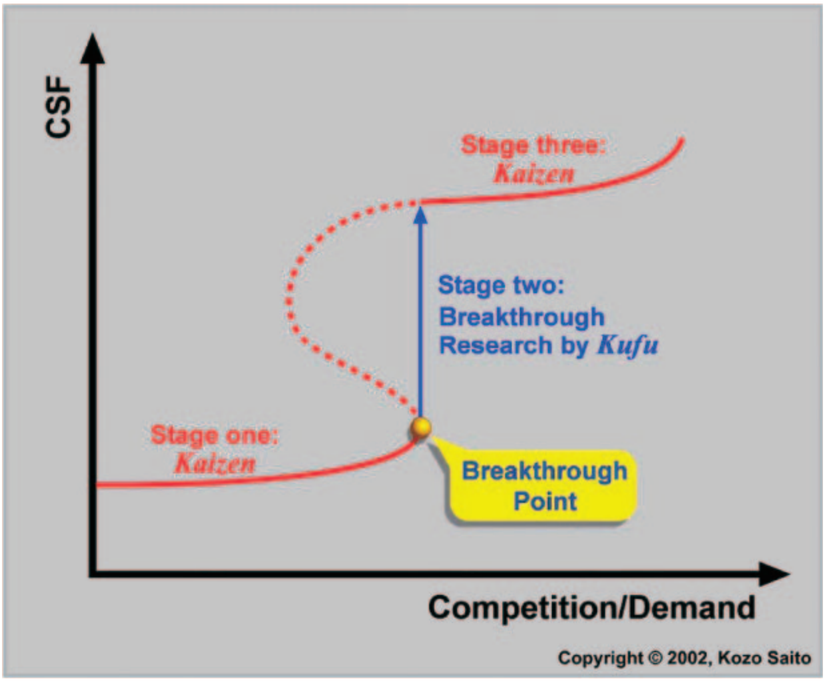


Fig. 4. Research for development function theory (CSF stands for customer satisfaction factor).

(2) New Generation Technology Development: Is the current Spray Painting Technology Possible to Achieve 100% Transfer Efficiency by Kaizen?

An important question related to current spray cup technology: Is it possible to achieve 100% transfer efficiency by improving the current spray cup design? This question needs to be answered before any effort toward 100% transfer efficiency takes place. The IR4TD team discussed how to obtain this answer, and identified the need for basic study that can reveal the mechanism of the current rotary spray cup: how does it work and what is the limitation of the current design. Careful inspection of the current spray cup design and review of a high speed video of atomized paint mist behavior revealed that the paint film thickness on the cup surface can be on the order of 10 microns; on the ejection velocity of paint from the cup's edge it is a few m/s. The atomization process includes interaction between liquid, gas and a geometrically complex solid surface.

This highly transient phenomenon requires an instrument capable of measuring three-D velocity vector components with a micro-meter level spatial resolution and sub-micron second time resolution in approximately 10 cm × 10 cm area. This is simply not achievable within the current timeline and budget. Computational fluid dynamic (CFD) modeling has a better chance to achieve this goal, if we can simplify the atomization process capturing only by the essential mechanisms ignoring the secondary effects to the degree that we can manage our CFD calculations with UK's supercomputers.

This study has been one of the most challenging and difficult tasks since the initiation of our group. Abraham Salazar (CFD expert and lead of this project) coordinated this project with three other members. This project required at least the following knowledge: (1) phase transition between liquid and gas, (2) surface instability of liquid film, (3) liquid-surface wetability, (4) molecular level Rheology on non-Newtonian fluid, (5) liquid atomization, (6) ligament formation and breakdown, (7) computer code making and modification, and (8) advanced CFD methods.

As a result, we eventually identified the limitation of the current spray cup design, due to the inherent instability of thin liquid film on the rotating cup surface. Due to this instability of liquid (paint) film, the current spray cup design is not able to eject the same diameter size droplets all the time. Figure 5 shows our CFD simulation of ejected water droplet trajectory which shows periodic motion associated with the surface wave, and shows experimentally measured and CFD calculated surface wave structure. Our CFD calculation images (left) are similar to the high speed photography images obtained by Nissan's laboratory [12].

After this basic research was done, the next step was the generation of ideas to create new types of paint applicators. Here again, outside-the-box thinking and paradigm shift will help in this idea generation process. This research is still on-going; we created several new ideas, tested concepts, prototyping is half-way completed and planning for eventual commercialization has began.

Opportunity for Start Ups and Commercialization

IR4TD activities will create new technologies, some of which will be commercialized by starting small high technology businesses. Others will be licensing technology to IR4TD industrial collaborators, spin-offs from IR4TD

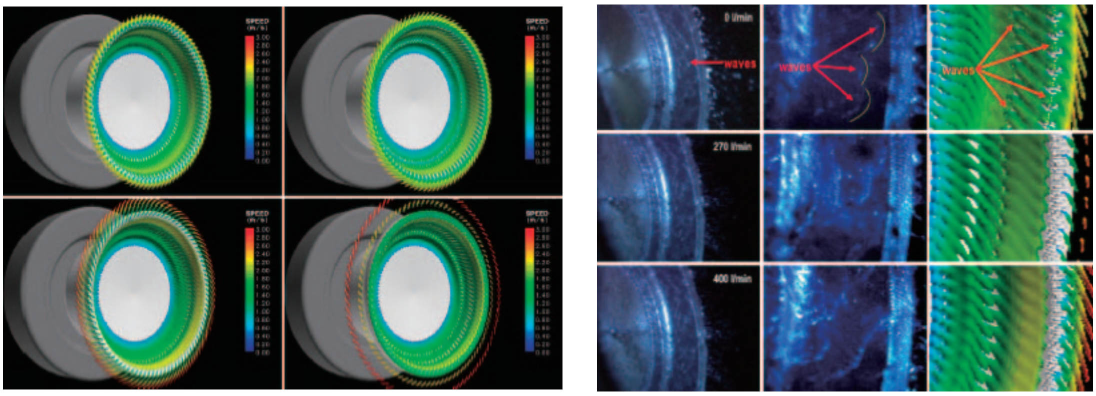


Fig. 5. CFD simulation of trajectory of water ligaments and droplets ejected from a rotating spray cup (left), and the measured and calculated liquid surface structure (right).

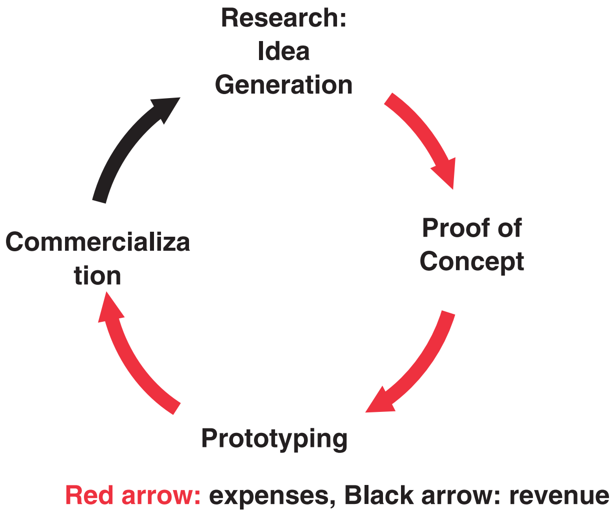


Fig. 6. Research-commercialization cycle.

Table 1. List of potential commercialization projects.

Project 1	Vortecone over-spray capturing device for coal ash capturing
Project 2	Infrared thermography inspection of the condition of bridge coating
Project 3	Infrared thermography inspection of bacteria and infectious disease
Project 4	Digital paint applicator
Project 5	Quick curing paint
Project 6	Bio-diesel from waste vegetable oils and bio mass from agricultural waste

sponsors, and technology transfer to companies that are not sponsors of IR4TD projects. The preferred route will depend on the technology, the potential markets, and selecting commercialization methods that have a high probability of success. To commercialize research results created by IR4TD, recently Synova R&D LLC was formed. Synova will closely work with IR4TD researchers to assess application of their research results. This new collaboration cycle is shown in Fig. 6 whose aim is to create a self-supporting Institute, where research begins with ideas followed by proof of concept and prototyping. Commercialization is the fourth and the final step which transforms research results into commercial products to create a revenue stream. Table 1 lists six different projects recently identified for commercialization.

Lean Manufacturing and Engineering Problem Solving

The current IR4TD structure includes hitozukuri and monozukuri which includes Lean Manufacturing. Lean Manufacturing is a philosophy or a way of thinking to improve efficiency and effectiveness of any system by continuously applying a small incremental step of improvement, known as Kaizen. Ken Kreafle, associate director of IR4TD who is responsible for our Lean program will address Lean Product Development in one of the workshops in

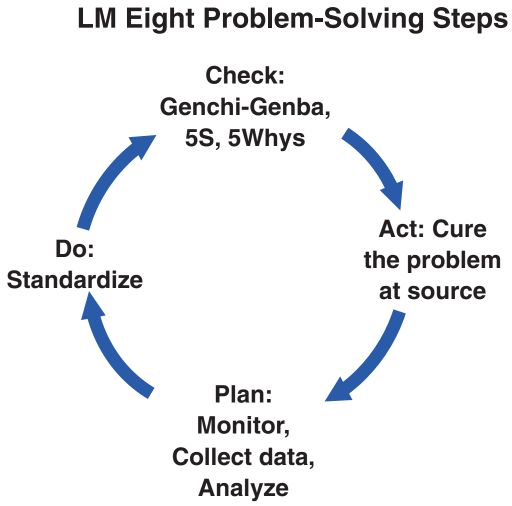
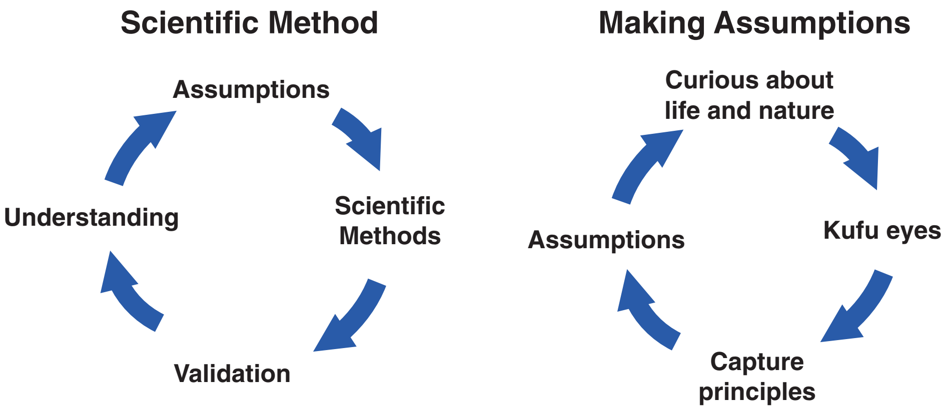


Fig. 7. LM problem solving cycle consisting of eight different steps of problem solving.



(a) (b)

Fig. 8. (a) Scientific method and (b) Making assumptions.

this symposium: sustainable atomization and spray technology [13]. Details of the University of Kentucky's Lean Manufacturing program are also available [14]. For the benefit of readers, therefore, only the problem solving process practiced in Lean Manufacturing is schematically shown in Fig. 7 in comparison with scientific method and making assumption cycles of Fig. 8.

The late Professor Emori who was famous for his engineering spirit and a strong advocate for the engineer as problem solver for industry problems, once said: "engineers need to learn two distinctly different methods: science as a tool to understand things, and engineering as a tool to create things [15, 16]." His belief in engineering problem solving resonates well with the founder of arerothermochemistry, von Karman who once declared, "Scientists see things that exist and ask why. Engineers dream things that do not exist and ask why not." [17]. The engineers' role to create new products, invent things, and find solutions for industry's problems is clear. Professor Emori claimed: "Engineering problem solving is an art but not a science." He believed that ultimately engineering problem solving is deeply related to an engineer's psychological state of mind and on how the engineer sees the world, rather than what kind of technical skills and scientific knowledge the engineer has. This means that learning engineering and science is not enough. There is a third element: professional intuition, probably the most important, yet most difficult to master, but required for the engineering problem solving process. Taichi Ohno, one of the pioneers who developed Toyota Production System, once declared that the essence of TPS is to develop the well trained "eyes" that can see waste which is invisible to the untrained [1, 2].

Kufu and Monozukuri

To effectively conduct research and technology development, we conduct experiments (both full scale and scale model), evolve theory, perform computations, and use professional intuition. My listeners may be familiar with the first three traditional tools [5], but not the fourth one, which may require some explanation.

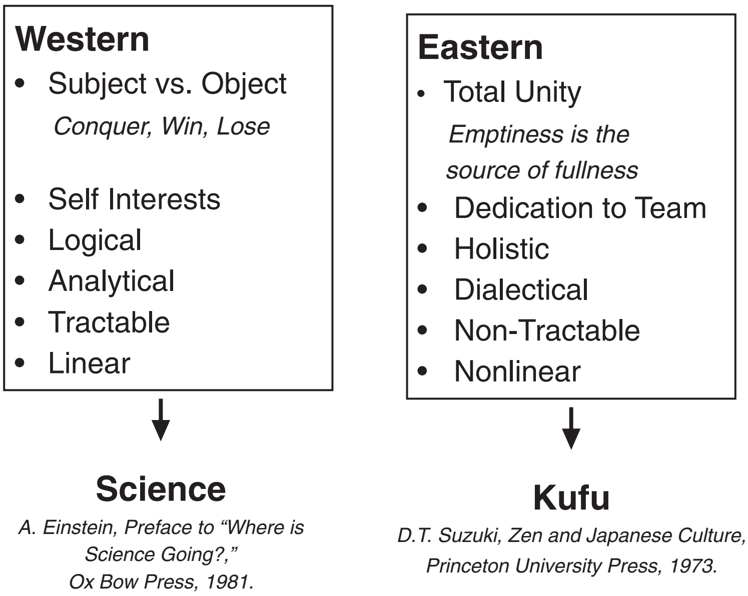


Fig. 9. Comparison between Western mode of logical thinking vs. Eastern mode of holistic approach: Kufu [3].

The fourth tool is not discovered very much in scientific and engineering communities, although it has been used for years by scientists, engineers and skilled craftsmen. I call it Kufu, the term that was used by D.T. Suzuki in his book: Zen and Japanese Culture [3]. The following provides some background information on how kufu plays an important role in the breakthrough and discovery processes of scientific research and technology development.

> "The term kufu is the most significant word used in connection with Zen and also in the fields of mental and spiritual discipline. Generally, it means 'to seek the way out of a dilemma' or 'to struggle to pass through a blind alley.'
>
> A dilemma or a blind alley may sound somewhat intellectual, but the fact is that this is where the intellect can go no further, having come to its limit, but an inner urge still pushes one somehow to go beyond. As the intellect is powerless, we may enlist the aid of the will; but mere will, however pressing, is unable to break through the impasse. The will is closer to fundamentals than the intellect, but it is still on the surface of consciousness. One must go deeper yet, but how? This how is kufu. No teaching, no help from the outside is of any use. The solution must come from the most inner part of oneself. One must keep knocking at the door until all that makes one feel an individual being crumbles away.
>
> That is, when the ego finally surrenders itself, it finds itself. Here is a newborn baby. Kufu is a sort of spiritual birth pang. The whole being is involved. There are physicians and psychologists who offer a synthetic medicinal substance to relieve one of this pang. But we must remember that, while man is partially mechanistic or biochemical, this does not by any means exhaust his being; he still retains something that can never be reached by medicine. This is where his spirituality lies, and it is kufu that finally wakes us to our spirituality."

Kufu plays a significant role in monozukuri, as explained by Professor Emori in his famous book in Scale Modeling [16], "professional intuition leads to kufu, the best tool in engineering problem solving." Taiichi Ohno, one of the fathers of the Toyota Production System, reminds us that "If you look up the word 'engineer' in an English dictionary, you might find 'technologist,' while in Japanese, its meaning uses the character for 'art." [1] A schematic showing characteristics of Eastern culture on which professional intuition is based, is shown in Fig. 9, in comparison to characteristics of Western culture on which scientific methods are based.

A skilled craftsman can design parts or fix problems based mainly on his/her experience and professional intuition and not on scientific reasoning and understanding. His/her experience and know-how can help solve industry problems. Three scientific methods: theory, experiment and computation, can help us to understand why the craftsman's solution worked for a particular problem, but may not work for different types of problems. Here again, the craftsman's role is the same as the engineer's role in creation and problem solving, while a scientist's role is needed here to understand why the solution worked.

Summary

The principles of our coating research are in line with the University of Kentucky's three mission components: education, research and service whose goal is to improve the quality of our life, make our society safer, environment cleaner, and provide opportunity for everyone to become better people. IR4TD plays a part in this larger mission of academic institutions articulated by Boyer: "The aim of education is not only to prepare students for productive career, but also to enable them to live lives of dignity and purpose; not only to generate knowledge, but to channel that knowledge to human ends; not merely to study government, but to help shape a citizenry that can promote the public good. Thus, higher education's vision must be widened if the nation is to be rescued from problems that threaten to diminish permanently the quality of life [18]."

Let me close my lecture by quoting Albert Einstein's message on the role of science in human affairs and education.

> "There are two ways in which science affects human affairs. The first is familiar to everyone: Directly, and to an even greater extent indirectly, science produces aids that have completely transformed human existence. The second way is educational in character — it works on the mind. Although it may appear less obvious to cursory examination, it is no less incisive than the first." [19]

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