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Dynamic multiple criteria decision making in changeable spaces: from habitual domains to innovation dynamics

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Abstract Human behaviors involve dynamic, evolving, interactive and adaptive processes. Important decision makings usually are dynamic, involving multiple criteria in changeable spaces. This article introduces the behavior mechanism that integrates the findings of neural science, psychology, system science, optimization theory and multiple criteria decision making. It shows how our brain and mind operate and describes our behaviors and decision making as dynamic processes of multiple criteria decision making in changeable spaces. Unless extraordinary events occur or special effort exerted, the dynamic processes will be stabilized in certain domains, known as *Habitual Domains*. Habitual Domains, which play a vital role in upgrading the quality of our decision making and lives, will be explored. In addition, as important consequential derivatives, concepts of *Competence Set Analysis* and *Innovation Dynamics* will also be discussed. Note that these concepts involve transitions between dynamic and static states.

Keywords Multiple Criteria Decision Making (MCDM) · Dynamic MCDM · Dynamics of human behavior · Habitual domains · Competence set analysis · Innovation dynamics

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1 Introduction

As a living system, each human being has a set of goals or equilibrium points to seek and maintain. Multiple criteria decision problems are part of the problems that the living system must solve. Take "dining" as an example. There are many things we, consciously or subconsciously, consider when we want to dine. Location, price, service, etc. might be the factors that affect our decision of choosing the place to eat. Nutrition, flavor, the preference to food and external events such as good friends arriving or economic crisis could influence our choices, too. Eating, indeed, is a dynamic multiple criteria decision making (dynamic MCDM) in changeable spaces in our life.

Indeed, human history is full of literatures recording dynamic MCDM events. The studies of multiple criteria decision making (MCDM) started in the 19th century by economists and applied mathematicians including Pareto, Edgeworth, Von Neumann, Morgenstern and many more. In the last two decades, the researches about MCDM have covered a wide range of concepts, methodologies and application areas which lead to an abundant literature of MCDM (Dong et al. 2005; Dyer et al. 1992; Ehrgott 2006; Jaramillo et al. 2005; Junker 2004; Kou et al. 2005; Shi 2001; Wallenius et al. 2008; Yu 1985 and quoted therein).

In fact, each of the non-trivial decision problems involves a number of elements such as decision alternatives, decision criteria, decision outcomes, decision preference, and decision information inputs. It also involves with the following four environmental facets: decisions as a part of the behavior mechanism, stages of the decision process, players involved, and unknowns in decision making. These decision elements and decision environment facets, in a broad sense, are decision parameters. The parameters can interact each other and vary with time, situation, and the change of the psychological states of decision makers involved. Great solutions are usually located after these parameters are properly studied, searched and restructured.

According to Habitual Domains theory, the ways of our thinking, judging, and reacting to decision problems can be stabilized in a certain domain over a period of time. Although being with dynamic nature, MCDM, as a part of human's behavior, can reach some steady state and show its habitual patterns as time goes by. As a consequence, in mathematical programming or ordinary MCDM problems, we can unwittingly assume that the decision elements are fixed. Thus we try to select an alternative from a *fixed* set of alternatives so that *fixed* set of criteria is best satisfied. This kind of assumption is valid only in static decision making. If the decision makers are not aware of the dynamic nature of the decision problems, they may unwittingly fall into decision blinds and traps (Yu and ChiangLin 2006) and make serious mistake.

Superior strategists find the best strategies by changing the relevant parameters, while ordinary strategists find the optimal solutions within some fixed parameters (Yu 1990, 2002). The above observation prompts us to study dynamic decision making from the viewpoint of Habitual Domains (HD). Understanding the behavioral dynamics and HDs of ourselves and others can enable us to study, search, and identify the best change of the relevant parameters as to become a superior strategist.

In order to facilitate our presentation, we shall use some examples to illustrate dynamic MCDM in changeable spaces of parameters in Sect. 2. In Sect. 3 we shall present a dynamic behavioral mechanism which is essentially a dynamic MCDM in changeable spaces. The concepts of HD will also be sketched. As important applications of HD, concepts of Competence Sets Analysis and Innovation Dynamics will be introduced in Sects. 4 and 5 respectively. In Sect. 6 we use a case study to illustrate dynamic MCDM from the viewpoint of HD theory and Innovation Dynamics. Conclusion and further researches are provided in Sect. 7.

2 Dynamic decision makings in changeable spaces

Let us use two examples to illustrate how the challenge problems are solved by looking into the possible changes of the relevant parameters.

Example 1 (Alinsky's 1972 strategy) During the days of the Johnson-Goldwater campaign (in 1960s), commitments that were made by city authorities to the Woodlawn ghetto organization of Chicago were not being met. The organization was powerless. As the organization was already committed to support the Democratic administration, the president's campaign did not bring them any help. Alinsky, a great social movement leader, came up with a unique solvable situation. He would mobilize a large number of supporters to legally line up and occupy all the restroom facilities of the busy O'Hare Airport. Imagine the chaotic situation of disruption and frustration that occurred when thousands of passengers who were hydraulically loaded (very high level of charge or stress) rushed for restrooms but could not find the facility to relieve the charge or stress.

How embarrassing when the newspapers and media around the world (France, the United Kingdom, Germany, Japan, Soviet Union, Taiwan, China, etc.) headlined and dramatized the situation. The supporters were extremely enthusiastic about the project, sensing the sweetness of revenge against the City. The threat of this tactic was leaked to the administration, and within forty-eight hours the Woodlawn Organization was meeting with the city authorities, and the problem was of course, solved graciously with each player releasing a charge and claiming a victory.

Example 2 (The 1984 Olympics in Los Angeles) The 1984 Summer Olympics, officially known as the Games of the XXIII Olympiad, were held in Los Angeles, California, United States. Following the news of the massive financial losses of the 1976 Summer Olympics in Montreal, Canada, and that of 1980's Game in Moscow, USSR, few cities wished to host the Olympics. Los Angeles was selected as the host city without voting because it was the only city to bid to host the 1984 Summer Olympics.

Due to the huge financial losses of the Montreal and that of the Moscow, the Los Angeles government refused to offer any financial support to the 1984 Games. It was then the first Olympic Games that were fully financed by the private sector in the history. The organizers of the Los Angeles Olympics, Chief Executive Officer Peter Ueberroth and Chief Operating Officer Harry Usher, decided to operate the Games like a commercial product. They raised fund from corporations and a great diversity of activities (such as the torch relay) and products (for example, "Sam the Eagle", the symbol and mascot of the Game), and cut operating cost by utilizing volunteers. In the end, the 1984 Olympic Games produced a profit of over $220 million.

Peter Ueberroth, who was originally from the area of business, created the chances to let ordinary people (not just the athletes) and corporations to take part in the Olympic Games, and altered people's impression of hosting Olympic Games.

In the above examples, new players, such as the passengers and the media in Example 1 and all the potential customers to the Olympic Games besides the athletes in Example 2, were brought into the decision problems. These examples show us that in reality, the players, criteria, alternatives, perception of rules of games, and outcomes (part of decision parameters) are not fixed. The parameters, including their dimensions, are dynamically changed depending on how deep, how far and how broad we look into the potentiality (or potential domains as to be introduced shortly). The fact that the parameters can themselves be the control or decision variables is a main feature of dynamic MCDM in changeable spaces (of parameters).

Note that in Example 1, the decision making process was at first in an unstable tangle with the Woodlawn ghetto organization actively looking for effective ways to fight against the city authorities. The state was not stable until Alinsky suggested legally and patiently occupied all toilets in the airport.

In Example 2, when the organizers of the Los Angeles Olympics decided to focus on introducing more potential players into the decision problems and making good use of their competence, the old solution and alternatives, such as asking financial support from the government, were dropped, and the decision problems began to move in more effective and stable direction. These transitions of the states of decision making, from transient to stable, are important in nontrivial decision problems. Interested readers may also refer to the experiment study in Chan et al. (1982) where in the house purchasing decision making process, over a period of time, numbers of criteria were converged to only few important ones after several times of house touring and after the buyers received information from diverse channels.

Mathematically, dynamic MCDM in changeable spaces can be described as follows:

Assume that changeable decision parameters involve the following decision elements (extension to include other parameters can be done similarly):

(i) the alternative set at time t, denoted by X_t;
(ii) the criteria at time t, denoted by F_t;
(iii) the outcome measured in terms of the criteria at time t, denoted by $\mathcal{F}_t$;
(iv) the preference of decision maker at time t, denoted by D_t; and
(v) the information inputs at time t, denoted by I_t.

Each decision element is a set which can vary with time, situation, and the decision maker's perception to the decision problems. The alternative set at time $t + \Delta t$ can be denoted by

$$X_{t+\Delta t} = G(X_t, F_t, \mathcal{F}_t, D_t, I_t, \mathrm{HD}_t) \tag{1}$$

where HD_t, consisting of actual domains (AD_t), reachable domains (RD_t), potential domains (PD_t) and activation probability (AP_t), is the habitual domain at time t as to be described in Sect. 3. As in (1), $X_{t+\Delta t}$ not only depends on X_t, but also on the other decision elements, $F_t, \mathcal{F}_t, D_t, I_t$ as well as HD_t.

Note that X_t and $X_{t+\Delta t}$ can be set functions, and the difference between X_t and $X_{t+\Delta t}$ would describe the changes due to time and situation. Also note that X_t and $X_{t+\Delta t}$ can have different dimensionality.

Similarly, we can write the dynamic change of other parameters as followes:

$$F_{t+\Delta t} = H(X_t, F_t, \mathcal{F}_t, D_t, I_t, \mathrm{HD}_t) \tag{2}$$

$$\mathcal{F}_{t+\Delta t} = J(X_t, F_t, \mathcal{F}_t, D_t, I_t, \mathrm{HD}_t) \tag{3}$$

$$D_{t+\Delta t} = K(X_t, F_t, \mathcal{F}_t, D_t, I_t, \mathrm{HD}_t) \tag{4}$$

$$I_{t+\Delta t} = L(X_t, F_t, \mathcal{F}_t, D_t, I_t, \mathrm{HD}_t) \tag{5}$$

Note, (1)–(5) describe the fact that the decision elements (or parameters) not only vary with time, but also mutually interact with each other through time. Refer to the illustration of Examples 1–2 on their mutual interaction. For further discussion see Chaps. 7–8 of Yu (1990, 2002).

A dynamic MCDM in changeable spaces can then be defined as a collection of $\{X_t, F_t, \mathcal{F}_t, D_t, I_t, \mathrm{HD}_t\}$. *Time optimality* and *time satisficing* solution (optimal or satisficing as perceived during certain period of time, see Chaps. 7–8 of Yu (1990, 2002)) become important solution concepts. To avoid distraction, we will not stop to elaborate. Section 3 will introduce the dynamics of human behavior and the concept of HD, which offers an insight of dynamic MCDM in changeable spaces.

3 Habitual domains

Habitual domains was first suggested in 1977 (Yu 1977) and further developed (Chan and Yu 1985; Yu 1980, 1981, 1985, 1990, 1991, 1995, 2002 and quotes therein) by Yu and his associates. It states that over a period of time, the set of ideas and concepts which we encode and store in our brain can gradually stabilize in certain domain, know as *Habitual Domains* (HDs); unless there is an occurrence of extraordinary events, our thinking processes will reach some steady state or may even become fixed. This phenomenon can be proved mathematically (Chan and Yu 1985; Yu 1985). In this section, we shall introduce the human behavior mechanism first, and then discuss the concepts of HDs as to better understand Competence Set Analysis.

3.1 Dynamics of human behavior

MCDM is only a part of human behaviors. It is a dynamic process because human behaviors are undoubtedly dynamic, evolving, interactive and adaptive processes. The complex processes of human behaviors have a common denominator resulting from a common behavior mechanism. The mechanism depicts the dynamics of human behavior.

Based on the literature of psychology, neural physiology, dynamic optimization theory, and system science, Yu (1980, 1981, 1985, 1990, 2002) described a dynamic human behavior mechanism as presented in Fig. 1.

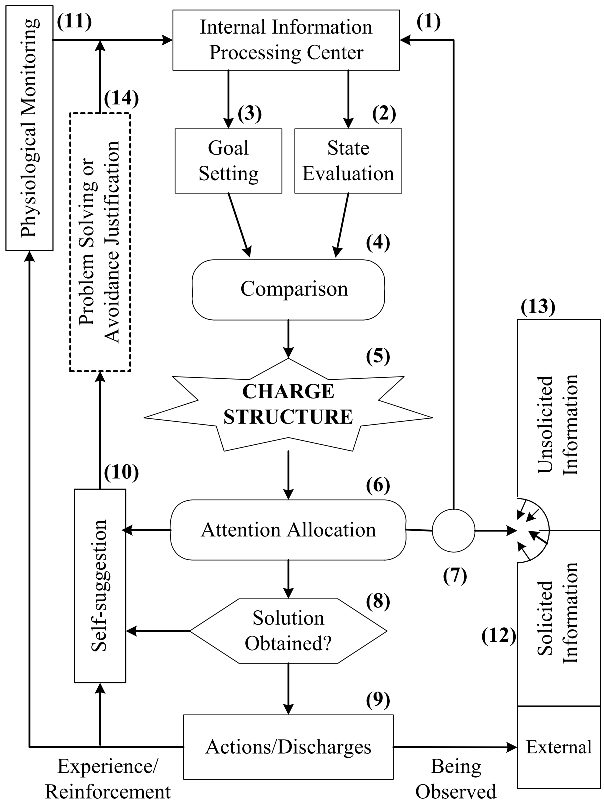
Although Fig. 1 is self-explanatory, let us briefly explain it as follows:

(i) Box (1) is our brain and its extended nerve systems. Its functions may be described by the four hypotheses (H1–H4) of Table 1.
(ii) Boxes (2)–(3) describe two basic functions of our mind. We use H5 of Table 2 to explain it.
(iii) Boxes (4)–(6) describe how we allocate our attention to various events. It will be described by H6 of Table 2.
(iv) Boxes (8)–(9), (10) and (14) describe a *least resistance principle* that humans use to release their charges. We use H7 of Table 2 to describe it.
(v) Boxes (7), (12)–(13) and (11) describe the information input to our information processing center (Box (1)). Box (11) is internal information inputs. Boxes (7), (12)–(13) are for external information inputs, which we use H8 of Table 2 to explain.

The functions described in Fig. 1 are interconnected, meaning that through time they can be rapidly interrelated. The outcome of one function can quickly become an input for other functions, from which the outcomes can quickly become an input for the original function.

Observe that the four hypotheses of Table 1 related to Box (1) which describe the information processing functions of the brain, are four basic summaries and/or abstractions

Fig. 1 The behavior mechanism



obtained from the findings of neuron science and psychology. The other Boxes (2)–(14) and the four hypotheses of Table 2 describe the input, output and dynamics of charges, attention allocation and discharge. They form a complex, dynamic multicriteria optimization system which describes a general framework of our mind. Note that the mechanism is an open system subject to the inputs of external information and internal information (including physiological monitoring) (Boxes (1), (7), (10)–(14)). With flexible interpretation, it can incorporate most human behaviors. For more detailed discussion, see Yu (1990, 2002).

3.2 Definition and elements of habitual domains

By the *habitual domain at time t*, denoted by HD_t, we mean the collection of ideas and operators that can be activated at time t. In view of Fig. 1, we see that HDs involve self-suggestion, external information, physiological monitoring, goal setting, state evaluation, charge structures, attention allocation, and discharges. They also concern encoding, storing, retrieving, and interpretation mechanisms (H1–H4). When the responses to a particular event are of interest, we can designate it as "HDs on the responses to that event". Note that conceptually HDs are dynamic sets which evolve with time.

Recall from H1 that each idea (thought, concept, and perception) is represented by a circuit pattern or a sequence of circuit patterns; otherwise, it is not encoded and not available for retrieving. From H2, we see that the brain has practical an infinite capacity for storing encoded ideas. Thus, $|HD_t|$, the number of elements in the habitual domain at time t, is a monotonic non-decreasing function of time t.

Table 1 Four hypotheses of brain operation

Hypotheses		Descriptions
H1	Circuit pattern hypothesis	Thoughts, concepts or ideas are represented by circuit patterns of the brain. The circuit patterns will be reinforced when the corresponding thoughts or ideas are repeated. Furthermore, the stronger the circuit patterns, the more easily the corresponding thoughts or ideas are retrieved in our thinking and decision making processes
H2	Unlimited capacity hypothesis	Practically every normal brain has the capacity to encode and store all thoughts, concepts and messages that one intends to
H3	Efficient restructuring hypothesis	The encoded thoughts, concepts and messages (H1) are organized and stored systematically as data bases for efficient retrieving. Furthermore, according to the dictation of attention they are continuously restructured so that relevant ones can be efficiently retrieved to release charges
H4	Analogy/association hypothesis	The perception of new events, subjects, or ideas can be learned primarily by analogy and/or association with what is already known. When faced with a new event, subject, or idea, the brain first investigates its features and attributes in order to establish a relationship with what is already known by analogy and/or association. Once the right relationship has been established, the whole of the past knowledge (preexisting memory structure) is automatically brought to bear on the interpretation and understanding of the new event, subject or idea

Table 2 Four hypotheses of mind operation

Hypotheses		Descriptions
H5	Goal setting and state evaluation hypothesis	Each one of us has a set of goal functions and for each goal function we have an ideal state or equilibrium point to reach and maintain (goal setting). We continuously monitor, consciously or subconsciously, where we are relative to the ideal state or equilibrium point (state evaluation)
H6	Charge structure and attention allocation hypothesis	Each event is related to a set of goal functions. When there is an unfavorable deviation of the perceived value from the ideal, each goal function will produce various levels of charge. The totality of the charges by all goal functions is called the *charge structure* and it can change dynamically. At any point in time, our attention will be paid to the event which has the most influence on our charge structure
H7	Discharge hypothesis	To release charges, we tend to select the action which yields the lowest remaining charge (the remaining charge is the resistance to the total discharge) and this is called the least resistance principle
H8	Information inputs hypothesis	Humans have innate needs to gather external information. Unless attention is paid, external information inputs may not be processed

From H4 (analogy and association), new ideas are perceived and generated from existing ideas. The larger the number of existing ideas, the larger the probability that a new arriving idea is one of them; therefore, the smaller the probability that a new idea can be acquired. Thus, $|\mathrm{HD}_t|$, although increasing, is increasing at a decreasing rate. If we eliminate the rare case that $|\mathrm{HD}_t|$ can forever increase at a rate above a positive constant, we see that $|\mathrm{HD}_t|$ will eventually level off and reach its steady state. Once $|\mathrm{HD}_t|$ reaches its steady state, unless extraordinary events occur, habitual ways of thinking and responses to stimuli can be expected. For more detailed derivation of the stability of HD_t, see Chan and Yu (1985) or Chap. 9 of Yu (1985).

Habitual domains at time t, HD_t, have the following four subconcepts:

(i) *Potential domain*, designated by PD_t, which is the collection of all ideas and operators that can be potentially activated with respect to specific events or problems by one person or by one organization at time t. In general, the larger the PD_t, the more likely that a larger set of ideas and operators will be activated, holding all other things equal.
(ii) *Actual domain*, designated by AD_t, which is the collection of ideas and operators which actually occur at time t. Note that not all the ideas and operators in the potential domain can actually occur. Also note that the actual domain is a subset of the potential domain. That is, $\mathrm{AD}_t \subset \mathrm{PD}_t$.
(iii) *Activation probability*, designated by AP_t, defined for each subset of PD_t, is the probability that a subset of PD_t is actually activated or is in AD_t. For example, people who emphasize profit may have a greater frequency to activate the idea of money. Similarly, people who study mathematics may have a greater frequency to generate equations.
(iv) *Reachable domain*, designated by $\mathrm{R}(I_t, O_t)$, which is the collection of ideas and operators that can be generated from the initial idea set (I_t) and the initial operator set (O_t). In general, the larger the idea set and/or operator set, the larger the reachable domain.

At any point in time, without specification, habitual domains (HD_t) will mean the collection of the above four subsets. That is,

$$\mathrm{HD}_t = \{\mathrm{PD}_t, \mathrm{AD}_t, \mathrm{AP}_t, \mathrm{R}(I_t, O_t)\}.$$

In general, the actual domain is only a small portion of the reachable domain, while the reachable domain is only a small portion of the potential domain, and only a small portion of the actual domain is observable. This makes it very difficult for us to observe other people's HDs and/or even our own HDs. A lot of work and attention is therefore needed in order to accomplish that. For further discussion, see Yu (1985, 1990, 2002) and quoted therein.

Note that the behavior mechanism is dynamic, from which stability of HDs is generated. Thus human behavior is dynamic, but the range of its change is bounded, and to certain degree the behavior is stable. More precisely, AD_t is varying with time and situations but the variation of AD_t is bounded with some stable AP_t, unless extraordinary event occurs or special effort is exerted.

4 Competence set analysis

In front of a challenging problem, how do we handle it? Recall Example 2, why was there no city other than Los Angeles willing to hold the 1984 Summer Olympics? Because they were threatened by the previous financial disastrous experience of Olympic Games at Montreal and Moscow (being affected by the corresponding circuit patterns), and they were afraid of not being able to bear the possible financial loss. Why could the Los Angeles Olympics be so successful and produced a profit of over $220 million? Because Peter Ueberroth, the Chief Executive Officer, effectively made use of all potential resources and integrated all competences in the potential domains.

The study on Competence Set Analysis began with Yu (1989), as a derivative of HD theory. Its mathematic foundation was built by Yu and Zhang (1989, 1990, 1993). The competence set (CS) for a given decision problem is defined as a collection of ideas, knowledge,

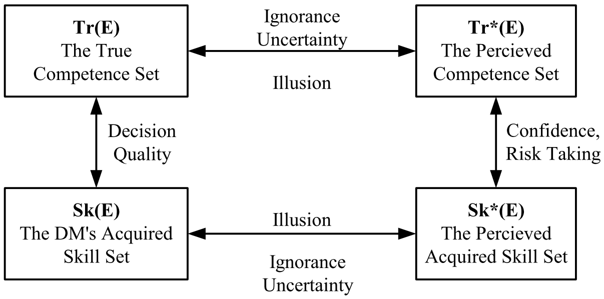


Fig. 2 The interrelationships among four elements of CS

skills and resources for its effective solution. Such a set, like HD, implicitly contains potential domain, actual domain, reachable domain, and activation probability as discussed in Sect. 3. When the decision maker thinks he/she has already acquired and mastered the CS as perceived, he/she would feel comfortable making the decision and/or undertaking the challenge.

In order to more precisely understand CS, we shall distinguish "perceived" and "real" CS, and "perceived" and "real" skill set (Sk) that we have acquired. Thus, there are four basic elements of CS for a given problem E, described as follows:

(i) *The true competence set* (Tr(E)): consists of ideas, knowledge, skills, information and resources that are truly needed for solving problem E successfully;
(ii) *The perceived competence set* ($Tr^*(E)$): The truly needed competence set as *perceived* by the decision maker (DM);
(iii) *The DM's acquired skill set* (Sk(E)): consists of ideas, knowledge, skills, information and resources that have actually been acquired by the DM;
(iv) *The perceived acquired skill set* ($Sk^*(E)$): the acquired skill set as *perceived* by the DM.

Note that each of the above sets inherently involves with actual, reachable and potential domains, and activation probabilities. This fact makes CS analysis rich, interesting and complex. Without special mention, in the following discussion we shall focus on actual domains of the CS. The interrelationships of the above four elements are shown in Fig. 2.

Note that the above four elements are some special subsets of the HD of a decision problem E. Without confusion, we shall drop E in the following general discussion. According to the different relations among the four elements, we have the following observations:

(i) The gaps between the *true* competence set (Tr or Sk) and *perceived* competence set (Tr^* or Sk^*) are due to ignorance, uncertainty and illusion;
(ii) If Tr^* is much larger than Sk^*, the DM would feel uncomfortable and lack of confidence to make good decisions; conversely, if Sk^* is much larger than Tr^*, the DM would be fully confident in making decisions;
(iii) If Sk is much larger than Sk^*, the DM underestimates his own competence; conversely, if Sk^* is much larger than Sk, the DM overestimates his own competence;
(iv) If Tr is much larger than Tr^*, the DM underestimates the difficulty of the problem; conversely, if Tr^* is much larger than Tr, the DM overestimates the difficulty of the problem;
(v) If Tr is much larger than Sk, and decision is based on Sk, then the decision can be expected to be of low quality; conversely, if Sk is much larger than Tr, then the decision can be expected to be of high quality.

Let us use Example 1 to illustrate Fig. 2 further.

In Example 1, from the Woodlawn ghetto organization's point of view, perceptively they thought "demonstration" could solve their problems (refer to Tr* in Fig. 2), and they did own this capability (see Sk* in Fig. 2), so they were confident to fight against the city authority. But apparently the true CSs (Tr) to win over the city authority was more than demonstration (Tr is greater than Tr*), the organization underestimated the difficulty of the problem. So, to solve their problems, they had better look for other solutions (or competence) in the potential domains. They turned to Alinsky, and realized they could expand their CSs by integrated that of Alinsky's.

Alinsky, who observed the charge structure of the city authority, proposed the solution to legally occupy all the toilets in the famous international airport (the needed skill is in the Sk of every human being). This solution effectively created charge to the city authority because their perceived CSs to deal with the subsequent problems is much larger than their Sk*.

As for the city authority, at first they thought they were powerful and could control the situation (Sk* is larger than Tr*), so they ignored the organization's requests. After they learned Alinsky's strategy, they realized there is a big gap between the true CSs (Tr) and their perceived CSs (Tr*), between Sk and Sk*, between Tr* and Sk*, and between Tr and Sk. The city authority perceived that they were unable to handle the chaotic situations generated by the travelers, press, media, and people excited by the news around the world. To release their charge, the best way (H7 of Table 2) is to prepare special budget to meet the organization's request.

CSs, as projections of HDs, can be changed dynamically with new skill, resources, information inputs, and new situations. It will gradually become stable after a period of time. In Example 2, at the very beginning, being influenced by old experiences (the old circuit pattern), "raising money from the government" constitutes the important part of the CS. During that period of time, the CS was fairly stable. However, when the LA government refused to support the Game, the situation changed. To raise fund, the organizers had to expand their CSs by getting into the potential domains to find solutions. During the time, when they were actively rethinking the alternatives, criteria, preferences, etc., the states of decision situation, their CSs and their HDs could change rapidly. Once they came out the idea of operating the Game as a commercial product, the decision situations became relatively stable, at least in the direction of their search effort. They looked into the potential domains as to find the potential players, their interest, potential products and services. This allows them to expand and transform their CSs as to increase incomes, decrease expenses, solve their challenging financial problem and have a successful Olympics.

Example 3 (Disguising as a swine to hunt tigers) The Chinese have a saying, "hunting the tiger by disguising as a swine." It is based on an ancient hunting technique in which the hunter disguises himself in the hide of a swine and mimics its grunting. When the hunter approaches, the tiger thinks: "Easy meal, I love fresh pork," and so it comes near the fake swine without any vigilance. Upon the last moment, the hunter casts off his disguise and reveals himself to be a much more dangerous creature: a hungry man with a pointy stick. It is then too late for the tiger to escape from being hunted.

Being unaware of whom the real opponent is, the tiger thinks its perceived skill set is much greater than perceived CS needed (i.e. Sk* is much larger than Tr*). So it is full of confidence when facing the opponent (the disguised swine). Of course, the tiger's perceived opponent (a swine) is far different than the real opponent (a hunter), and the true skill set of the tiger (Sk) against the opponent is far less than that of the really needed competence set (Tr) against the real opponent, the hunter. The tiger, without sensing its inadequate CS, becomes the victim of the hunter who manipulates the CS cunningly.

5 Innovation dynamics

CS analysis contains two inherent domains: competence domain and problem domain. Like HD, each domain has its actual domain, reachable domain and potential domain. As depicted in Fig. 3, there are two major kinds of problems in CS analysis:

(i) Given a problem or set of problems, what is the needed CS? How to acquire it efficiently and effectively? Some mathematical models can be found in Chen (2002), ChiangLin and Yu (2007), Feng and Yu (1998), Huang et al. (2004, 2006), Lai et al. (2007), Li and Yu (1994), Li et al. (2000), Lin (2006), Shee (2006), Shi and Yu (1996), Yu and Zhang (1989, 1990, 1993) and quotes therein.

(ii) Given a CS, how to locate a set of problems to solve as to maximize the value of the competence? There are lots of studies of CS analysis working in this direction, please see Chen (2001), ChiangLin et al. (2007), Hu et al. (2002, 2004).

Recall the decision problems in Example 1, for solving the problems, the Woodlawn ghetto organization turned to Alinsky to acquire their needed CS; the solution proposed by Alinsky contained resources from diverse parties, whose CSs were utilized to achieve the goal. In Example 2, the Chief Executive Officer Peter Ueberroth acquired the needed CSs from the potential players (corporations, TV viewers, ordinary people, volunteers, etc.) in the potential domains to solve his problem of raising fund and cutting cost. He made good use of these players and products to create values. Eventually he produced a profit of over $220 million for the 1984 Olympics and changed people's impression of hosting Olympic Games.

According to the HD theory and CS analysis, all humans and things can release pains and frustrations for certain group of people at certain situations and time. Thus, all humans and things carry the competence (in broad sense, including skills, resources, functionalities, even attitudes). If we regard all humans and things as a set of different CSs, then producing new products or services can be regarded as a transformation of the existent CS to a new form of CS. Based on this, we could depict a comprehensive and integrated framework, called the *Innovation Dynamics* (see Fig. 4), to help people understand corporate innovation and creation of maximal values for the targeted customers and themselves.

The dynamics can be interpreted clock-wise, according to the indices of Fig. 4, as follows:

(i) According to HD Theory, when there exists unfavorable discrepancies between the current states and the ideal goals of individuals or organizations (for instance, the corporations are losing money instead of making money, or they are technologically behind,

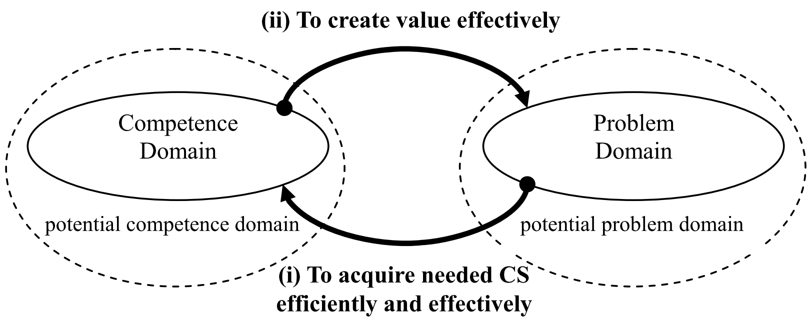


Fig. 3 Two domains of competence set analysis

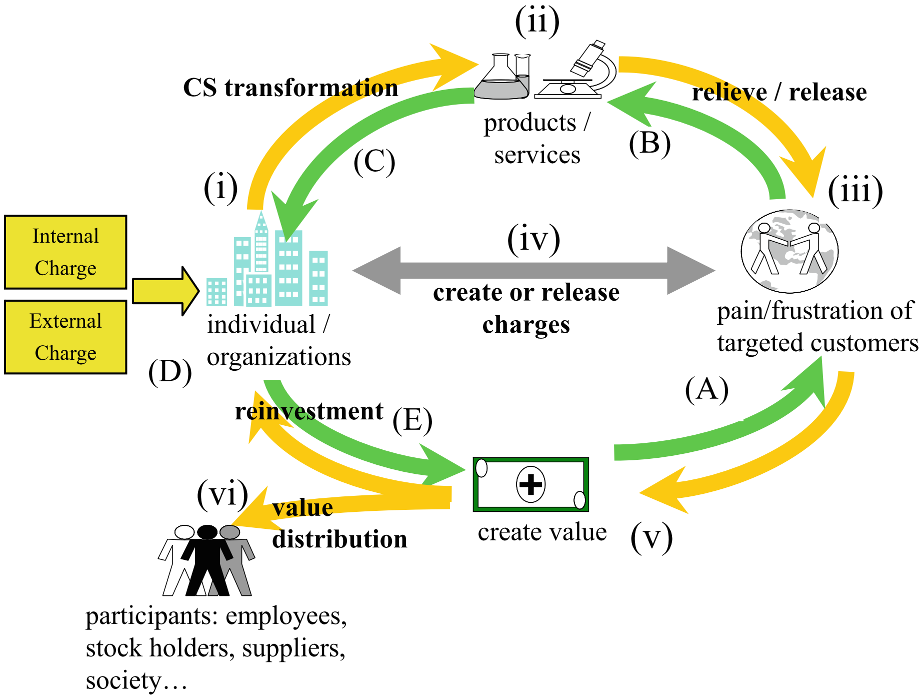


Fig. 4 Innovation dynamics

instead of ahead of the competitors), it will create charges which can prompt the individuals or corporations to work harder to reach their ideal goals.

(ii) The transformation of CSs will be presented in visible or invisible ways, which results in a new set of the products or services produced by the corporations.

(iii) The products or services produced by corporations must carry the capability to relieve/release the pain and frustration of targeted customers. Note that there are actual domains, reachable domains, and potential domains for the targeted customers, and for their pains, frustrations, and problems.

(iv) Besides discharge, corporations or organizations can create charges to the targeted customers by means of marketing, advertisement or promotion, and vice versa.

(v) The targeted customers will experience the change of charges. When their pains and frustrations are relieved, the customers become happy. By their buying the products or services, the products and services create their value.

(vi) The value will be distributed to the participants such as employees, stock holders, suppliers, society, etc. In addition, to gain the competitive edge, products and services have to be continuously upgraded and improved. The reinvestment therefore is needed in order to develop and produce new products and services.

In contrast to the clockwise cycle, the Innovation Dynamics can be interpreted counterclockwise, according to the indexing of Fig. 4, as follows:

(A) To create values, the corporations must consider who will be the targeted customers, and what kind of pain and frustration they have, both in actual and potential domains.

(B) In order to ease the pains and frustrations for the targeted customers, what products or services, in actual and potential domains, are needed? Competitiveness becomes an important issue in the final selection of the products and services to produce.
(C) How do the corporations transform their internal and external competence and resource to develop or provide the selected products and services effectively and efficiently?
(D) When the transformation of CSs succeeds, the corporation's internal and external charge will be released, at least partially.
(E) New goals as to create new values can be reestablished. The innovation cycle: (A) → (B) → (C) → (D) → (E) → (A) will go round and round.

The concept of Innovation Dynamics describes the dynamics of how to solve a set of problems with our existent or acquired competence (to relieve the pains or frustrations of "targeted customers or decision makers" at certain situations) as to create value, and how to distribute this created value so that we can continuously expand and enrich the CS to solve more challenging problems and create more value. Observe that each links, clockwise or counterclockwise, in Fig. 4 involves dynamic MCDM in changeable spaces.

Note, while we describe innovation dynamics in terms of corporation, it can also be applied to individual person as to continuously expand and enrich his/her HDs and maximize the value of his/her life.

Let us use the following case study to illustrate Innovation Dynamics further.

6 Case study of dynamic MCDM: from HD to innovation dynamics

6.1 Case review: Wii—an innovative product that rewrote the game history (Data Source: Nintendo official website; Business Next Issue 148, 2007/2/15)

Wii, the fifth home game console released by Nintendo, is the direct successor to the Nintendo GameCube. A distinguishing feature of Wii is its wireless controller, the Wii Remote, which can be used as a handheld pointing device and detect movement in three dimensions. Another distinctive feature of the console is WiiConnect24, which enables it to receive messages and updates over the internet while in standby mode. Wii belongs to the 7th generation home game console; at the same time, its competitors are Xbox 360 (from Microsoft) and PlayStation 3 (from Sony).

Since 1970s, Nintendo has engaged in the video game console industry. In 1996, Nintendo launched the first ever 64-bit video game console N64; in 2000, Game Boy, its handheld video game console has reached the record of selling 100 million units globally. At that time, Nintendo entered the markets both in US and Japan, its ADR price in Nasdaq Composite Index has once reached the peak of 28 USD. However, N64 failed to compete with the PlayStation series game console manufactured by Sony. In order to gain its market share, Nintendo has then launched the GameCube to contend with Sony's PS and Microsoft's Xbox. Unfortunately, Nintendo's game products were still unable to compete with its opponents; as a result, its ADR stock price was downgraded since 2002, and even less than 9 USD in May 2003, which created a high level of charge on the management. Please see Fig. 5 and Table 3 for Nintendo's price and earnings history.

Being surrounded by major competitors, since late 1990s, Nintendo lost its leading position in video game console products, and fell behind to be the third place. In mid 2006, Wii with the code of "Revolution" has launched, and it has made Nintendo become the market leader in worldwide console sales. Wii's success brought Nintendo with astonishing profits, and its ADR stock price also reflected the popularity for such product. In 2007, the

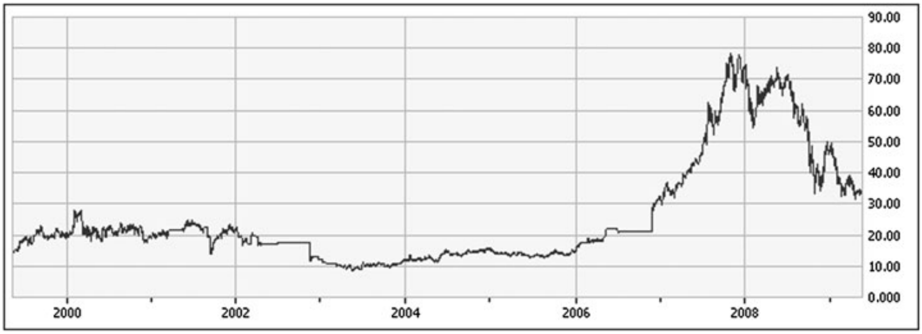


Fig. 5 10-year trend of Nintendo Co Ltd ADR price (from May 1999 to May 2009)

Table 3 Nintendo price and earnings history (data from Standard & Poor's)

Year	2001	2002	2003	2004	2005	2006	2007	2008
Calendar year EPS ($US)	0.69	0.71	0.51	0.68	0.69	0.96	2.13	2.38
Change in earnings vs. previous year	N/A	2.90%	–28.17%	33.33%	1.47%	39.13%	121.88%	11.74%
Price/Earnings	0.0x	20.2x	44.1x	17.7x	22.6x	25.0x	25.7x	–

stock price of Nintendo has hit the mark of 35 USD in the Nasdaq Composite Index which achieved the highest peak for past 6 years (see Fig. 5).

6.2 Case analysis

Satoru Iwata, the president of Nintendo, stated that Wii is "the disruptive innovation product". He set up the goals as "to expand the game population and make people who never played games play." In other words, Nintendo was trying to get into the potential domain to expand its target customers, and to find out their need and interests in potential domains so that these potential customers would like to use their products. In the following subsections, we discuss its CS analysis and charge structure, and explore how it fits in with the framework of Innovation Dynamics.

6.2.1 Competence set analysis

The expansion and transformation of CSs play a vital role to Wii's success. Personnel's brainstorming, information and communication technology, even the bravery and enthusiasm are all important elements in its CS.

Idea of designing Wii Remote was started with Satoru Iwata's interest in TV remote controller. "People are willing to take TV remote controller for interaction, but not every family member would like to touch the remote controller of video game console." Satoru Iwata gave the problem to his R&D colleagues and requested them to make a video game console which should be as popular as TV remote controller. Thus, in order to reach such conceptual idea, Miyamoto Shigeru, Senior Managing Director and General Manager of Entertainment

Analysis and Development of Nintendo, gathered designers and engineers together to think over various opinions and ideas, and created a video game console that can easily pursue those family seniors to have the willingness to buy it. Moreover, the result of personnel's brainstorming has gradually formed the basic goal and concept for Wii, including simple, fast start on, power saving, quiet, etc., and there occurred many important suggestions to influence the design of Wii in the process of brainstorming, such as "new video game console should not have too many lines, otherwise it may be easily messed up and made mom to be mad". Finally, it has made Wii successfully aimed at the female and senior groups who have never played video games before.

In terms of IT and communication technology, Wii has successfully integrated wireless communication technology, sensor bar and infrared pointer, etc., into its CSs. Wii's console has embedded the standard wireless networking function, which allows users to access to the internet and to subscribe the Nintendo DS build-in services, including "Nintendo WiFi Connection" and "WiiConnect24".

Besides, there are some intangible but extremely important elements to support enterprise's innovation activities, such as bravery and enthusiasm. Based on the idea of "amusement is more important than visual attraction", Wii does not support higher definition, thus its visual effect has been greatly overpassed by its opponents, PS3 and Xbox 360. It really needs great courage and enthusiasm to do something that departed from the traditional track.

6.2.2 Charge structure in potential domains

Video game industry has been developed for decades. In the past, producers believed that players' requirement for playing game lied on the sensuous gratification of eyes and ears; therefore, the game's image/sound effect has to be exquisite and vivid.

However, with the development of "physical experience design", Wii has made players physically move their body while playing games. Besides enjoying the fun and excitement of playing games, in players' potential domains, they would like to "win" (the strong circuit patterns of "Social Comparison"). For example, the moment when the physical-experience designed remote controller hit the ball in the screen image, it will have the vibration and sound effect on hitting the tennis ball and make players believe that they had hit a beautiful shot. Moreover, when players stroke an ace ball and scored, the reachable domains triggered by the actual physical movement may possibly accelerate players' heartbeat and make players have feelings of glory and excitement as if they are really in a tennis court to play, and win.

In this busy and tense modern society, the real purpose for many people to take exercises and leisure activities is to relieve physical and mental charge, suffering and problem. However, not everyone has time or opportunity to go to the stadium or leisure spots. These are the charge and suffering in people's potential domains. The emergence of Wii turns the living room into a virtual stadium, or a car racetrack, or a fishing pond. Players can obtain the mentally pleasant feeling and excitement through the virtual reality, as a consequence, the charge in their potential domains can then be relieved.

6.3 Nintendo's innovation dynamics

In Sect. 6.1, we have described the charge structure of Nintendo, which can be regarded as the motivation for Nintendo to innovate. With hard work and persistence on effective integrating of the creative thinkings of human resources, the IT environment and communication technology, in 2006, Nintendo officially announced the latest generation of home video game console, Wii. Nintendo successfully expanded and transformed the CSs (as shown in (i) of Fig. 4).

As mentioned in Sect. 6.2.2, Wii's physical experience design allowed players to enjoy the movement of their body while playing, departing from the traditional "sit and play" way of playing the game console. The players got excited, they tell their friends. Thus more and more people are attracted to the product. Therefore, the target customers have greatly expanded as to include women and seniors. As Wii has released the charge, pain and frustration in the potential domains for a large targeted group of people, many people buy and use Wii and its service. As a consequence, it earned a great profit for Nintendo. Please refer to (ii) to (iii) of Fig. 4.

To continuously upgrade its product and service, Nintendo reinvested its earned value (resource) to develop new product and service. In December 2007, Nintendo further promoted a new generation software, Wii Fit, which is an exercise game consisting of activities using the Wii Balance Board peripheral. The balance board measures players' weight and center of balance. The software can then calculate players' body mass index when told of his or her height. As most people are concerned about their health condition, Wii Fit was very popular and became the fifth best selling videogame in history (among games not packaged with a console) with 18.22 million copies sold as of March 31 2009. As a result, Nintendo has been far more than a game console provider in the industry; it also connects to communication-related, network-related and health-related industries. The reinvestment, continuous transformation of the ever growing CS to relieve more customers more pains to create even more value and resource keep on going, which is consistent with innovation dynamics, see Fig. 4 (vi) → (i) → (iii) → (v) → (vi). Being limited by space, for the counter-clockwise cycling of Fig. 4, we encourage the readers to explore it.

6.4 Discussion and implication

Nintendo's innovation process is consistent with Innovation Dynamics. They might not have Innovation Dynamics in their minds, but unwittingly, they follow the pattern of Innovation Dynamics. If a corporation is aware of Innovation Dynamics, it can avoid stepping into decision traps. By examining the operations of each link in Innovation Dynamics, corporations can understand if each and all links are properly developed, so that they can continuously upgrade their products/services and maximally create value by releasing pains and frustrations for the customers in the potential domains. The Innovation Dynamics can help them to be as successful and competitive as Nintendo.

Without Innovation Dynamics, people can easily get into decision traps. They may focus on some activities in certain links and neglect those on other links (decision making in changeable spaces), which could lead to serious problems. As an example, suppose corporations emphasize on all the links except that of pains and frustrations of the customers in the potential domains, they may not be able to provide the products/services which could really satisfy customers' need and release their charge. In the case, Nintendo's opponents (Sony and Microsoft) focused their product design for video game console on the game's image/sound effect to satisfy people's gratification of eyes and ears. They pay little attention to the gratification of physical movement and emotional excitement of winning in playing video games. As a consequence, they lose their market competitiveness to Nintendo. The case clearly shows that if companies can not create value, they can not survive. To create value, companies need to reduce or remove the pains and frustrations for potential customers in the potential domains.

Table 4 Innovation dynamics and fields of management

Processes in innovation dynamics	Descriptions	Related management fields
Transforming of competence sets (refer to (i) and (D) in Fig. 4)	• Acquiring, adjusting and allocating resources (human resources, skills, technologies, etc.); transforming resources into products/services • The corporation's internal and external charge will be released when the transformation of CSs succeeds	• Human resource management • Organization management • Production management • Research and development (R&D) • Procurement management • Logistics management • ...
Producing of products/services (refer to (ii) and (C) in Fig. 4)	• The outcome of CS transformation and expansion • How to transform the internal and external competence and resource to develop or provide the selected products and services effectively and efficiently?	• R&D • Production management • Inventory management • Logistics management • ...
Releasing pains and frustrations for target customers (refer to (iii) and-(B) in Fig 4)	• Discovering of target group and exploring of their needs in actual and potential domains • What products or services are needed in order to ease the pain and frustrations for customers?	• Marketing management • Services management • Customer relationship management (CRM) • ...
Creating charge/releasing charge (refer to (iv) in Fig. 4)	Besides discharge, corporations or organizations can create charges to the targeted customers by means of marketing, advertisement or promotion, and vice versa	• Marketing management • CRM • ...
Creating/distributing values and reinvestment (refer to (v) and (vi) ; (A) and (E) in Fig. 4)	• Releasing of charge of the target customers and create values; how to distribute and share the created value effectively as to keep the stakeholders in unity for growth prosperity and competitiveness • To create values, the corporations must consider who will be the targeted customers, and what kind of pain and frustration they have, both in actual and potential domains	• Financial management • Compensation management • Investment management • Public relation management • ...

The Innovation Dynamics also points out that each and all links must be properly examined and developed. Missing one of them could lead to serious mistakes. For instance, if the distribution of the created value is unfair or ineffective, the stakeholders can be disintegrated or lose the morale for continuous upgrading the products/services.

Note that activities over each link of the Innovation Dynamics involve decision making in changeable spaces. Let us sketch their relations to various fields of management in the following Table 4. The table may serve as a list of new directions for the various fields of management to develop and research.

7 Conclusion and remarks

In this article, we introduce the dynamics of human behavior, the concepts of HDs, CS analysis, and Innovation Dynamics. We first explore the dynamics of human behavior through eight basic hypotheses, which is a dynamic MCDM in changeable spaces. The stability of this behavior dynamics leads to the concept of HD. The stability of HD on one hand makes us to be more efficient for routine problems; on the other hand, it can hinder our innovation.

Decision problems, like human beings, have their HDs. Some of the related parameters, such as alternative sets, criteria sets, outcome sets, etc., are observable and existed in actual domain, but some of them are invisible and hidden in the reachable domain and potential domain. The interaction of these visible or invisible parameters forms a changeable space. In fact, CSs of a problem is a projection of the HDs of the decision makers on the problem. To obtain better solutions for dynamic MCDM in changeable spaces, decision makers need to look into the depth of potential domains to acquire and master their needed CSs. Recall in Example 1, being affected by their old HD, the Woodlawn ghetto organization would like to demonstrate against the Chicago city authorities but it was in vein until Alinsky came up with new HD. He could see through the depth of potential domains and induced new decision parameters and CSs into the decision problem, and eventually discovered the great solution for the challenge problem.

Based on CS analysis and HD theory, a framework of Innovation Dynamics is introduced. The dynamics describes how we can expand and enrich our CSs on one hand and maximize the value of our CSs on the other hand. In the aspect of business management, corporations are not just facing one single decision problem but a sequence of problems in changeable spaces. Innovation Dynamics provides a framework to show systematically the cycling processes including transforming CSs, developing products/services, releasing pains and frustrations for targeted customers, creating and releasing charge, creating and distributing values, etc. It allows us to examine key management problems in potential domains in the dynamics. Nintendo's innovation on its product, Wii, is used as an example to illustrate our discussion.

Many research problems remain open. For instances, in CS analysis, the interaction among Tr, Tr*, Sk and Sk* and their impact on decision making in changeable spaces need to be further explored. In second order games, relevant parameters and players' state of mind can change with time and situation, how to restructure the games so that each player can declare a victory? Some significant results based on HD theory can be found (Yu and Larbani 2009; Larbani and Yu 2009). Mathematical analysis for specific cases would be of great interest to study. How to early detect decision traps and decision blinds, and to locate effective methods to deal with them certainly would bring value to practical decision making in changeable spaces and to academic research as well.

If we are willing to look into the depth of the invisible potential domains of the players, problems, and relevant parameters, Table 4 of Sect. 6.4 can provide abundant research opportunity. These are illustrated by Examples 1–3 and Nintendo's innovation on Wii. Take the first item of the second column of Table 4 (acquiring, adjusting and allocating of resources; transformation of resources into products/services) for an example. If we, like most operation researchers and industrial engineers, consider only tangible and visible resources, products and services in the actual domains or reachable domains, and do not look into those items hidden and invisible in the potential domains, we most likely could not solve problems such as posted by Examples 1–3 and Nintendo case. A very important direction for research is then how to systematically analyze the invisible potential domains as to find effective method to acquire, adjust and allocate resources in potential domains; and how to effectively transform the hidden resources in potential domains into products/services to effectively release the pains and frustrations of the people concerned. We have been working on these topics and encourage the readers to do the same. Together, we could make some important break through in the related management fields as listed in Table 4.

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