

## **THE IMPACT OF TRAFFIC INFORMATION ON DRIVERS' ROUTE CHOICE-USING COMPETENCE SETS ANALYSIS**

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**Abstract:** Generally speaking, drivers' route choice is a fuzzy problem. However, if drivers' habitual domain becomes stable and without significant stimuli, route choice becomes a routine problem. Route choice can become fuzzy again if drivers perceive information stimuli. Intuitively, traffic information should help drivers to reach destination in an efficient way, but the abundant and complex information could overwhelm the drivers. In this work, a different and novel approach to complement the driver route choice decision models is exploited. The concept of habitual domains and competence sets proposed by Yu in 1980 is applied to the route choice problem. The effect of traffic information on route choice is isolated to analysis the behavior of route choice decision. Performance indexes of route choice decision are developed to help the drivers or the traffic information providers in expanding their competence sets to fully address the needs of route choice decision.

**Key Words:** route choice, traffic information, competence sets, habitual domain

### **1. INTRODUCTION**

There are usually more than one route between the origin and destination. Empirical research on route choice has shown that numerous factors are used by drivers to determine the final route, such as travel time, number of intersections, traffic safety, traffic lights and other factors. In addition, drivers' personal habits, cognitive limits and other behavioral considerations may also produce variations in route selection (Abdel-Aty et al, 1997). As a result, the route choice becomes extremely complicated.

Traffic information will definitely help drivers to reduce travel time and delay (Emmerink, et al., 1993; Koutsopoulos and Lotan, 1990; Jeffery, 1988), however it may cause the network over-saturation, over-reaction and concentration (Ben-Akiva et al., 1991). Recently, various traffic information has been developed increasingly to assist drivers to make efficient travel decision through static or dynamic traffic information. However, drivers' route choice depends on drivers' reaction to traffic information. Therefore, it is expected that different travel behavior and information supply strategy will have different impact on the traffic network.

Since habitual domains (Yu, 1980) and competence sets (Yu and Zhang, 1989; Yu, 1990) provide a general behavioral base of decision making, we can classify decision problems in to four categories: routine, mixed routine, fuzzy and challenging problems (Shi and Yi, 1987; Yu,

1990). The four problems could be corresponded to each stage of route choice decision model. Basically, drivers' route choice is a fuzzy problem (Lotan, 1992; Pang et al, 1995). Route choice will convert to routine problem when drivers' habitual domain becomes stable and without any significant stimuli. However, route choice will convert back to the fuzzy problem when drivers perceive information stimuli. Information technology (IT) will speed up the expansion of competence set; nevertheless, IT also increases the complexity of tasks and problems (Chiang, 2002). Traffic information, theoretically, will help drivers to reach destination in efficient way. However, when information sources are abundant, content may be numerous and overwhelmed, which may cause the driver to fall into an information labyrinth. As time goes on, the driver may gradually have a better grasp of the accuracy of traffic prediction and respond with possible alternate routes. In other words, the driver will select the most important information which could improve the previous driving experiences and come up with a route choice policy. In this case, the route choice is a routine problem. Another possibility is that part of the combination of traffic information quality may exceed the competence set of the driver in choosing the route such that he may not even know what route to take. This situation becomes a challenging problem.

This study is in an attempt to provide a different approach to complement the driver route choice decision models. The concept of habitual domains and competence sets is exploited to solve the route choice problem. The effect of traffic information on route choice is isolated and the relationship between what the driver has already acquired and the truly needed route choice competence sets is studied. Several useful indexes are developed using fuzzy measures in this study, including traffic information practicality, efficiency of acquired route choice, and traffic information acceptance. We proposed the competence set analytical model which can serve as a reference to assist drivers or traffic information providers in expanding their competence sets to satisfy the route choice decision needs.

## **2. HABITUAL DOMAINS AND COMPETENCE SETS**

### **2.1 Habitual Domains**

Yu proposed that people's thought, thinking, judgment, and reactions are dynamic, however, they become stable over time and stay within a domain unless unexpectedly stimulus. This domain is termed the habitual domain (Yu, 1980).

The knowledge and information that we learn and accumulate through our experiences are systematically stored in our brain and subsequently become our memory. In memory structure, everyone has a set of living goals. Each goal function has its own idea value or equilibrium point. When we perceive that the value for a goal has an unfavorable discrepancy from the ideal or equilibrium point, the particular goal will create a charge on our system and prompt us to take actions or make adjustments so that the perceived value can, ideally, coincide or be as close as possible to the ideal value. In order to reach our physiological and mental equilibrium point or self-suggested ideal value, whether it can be learned or innate, we must quickly and continuously allocate our attention to various events, subjects and activities. At any given time, we choose to pay attention to the event or activity which we subjectively perceive as the most important, and to develop an effective way to reduce or release the charge structure to its minimum so that the perceived value and the equilibrium point or value can be consistent. The message or information which has a great influence on our charge structure will more easily obtain or attention allocation, which in turn will change our

memory and charge structures (Yu, 1990).

The anatomy of our habitual domain is made up of these elements (Yu, 1990):

- (1) Potential Domain: all the ideas and operators that can potentially be activated in our brain.
- (2) Actual Domain: the ideas and operators that actually are being used at one time.
- (3) Activation Probability: the likelihood that particular ideas and operators will be activated.
- (4) Reachable Domain: new ideas and operators generated by the current or actual domain.

## 2.2 Competence Sets

Based on habitual domains, Yu and Zhang (1989) and Yu (1990) further employed the concept of competence set including ideas, knowledge, information and skills to assist us to solve problems (Yu and Zhang, 1989; 1990; 1992a, b; Yu, 1990). As time evolves, our competence sets will be limited unless we make more efforts to gain new knowledge. In general, these ideas, knowledge, information and skills can be considered the influential factors in associated with choice behavior.

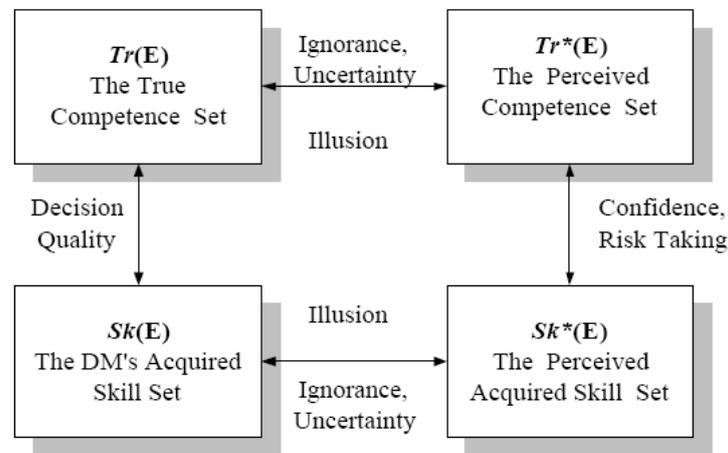
Depending on the perception of the availability of competence sets and the core of habitual domains, decision problems can be classified into four categories: routine, mixed routine, fuzzy and challenging problems (Shi and Yu, 1987; Yu and Zhang, 1992a, b).

- (1) Routine problems: the competence set that is needed to successfully solve the problem, which is well known to the decision-maker, and the decision-maker has acquired that set.
- (2) Mixed routine problems: a decision problem is termed a mixed routine problem if it consists of a number of routine sub-problems.
- (3) Fuzzy problems: the needed competence set is only fuzzily known to the decision-maker. Therefore, the decision-maker has not yet mastered the skills, concepts or capabilities necessary for successfully solving the problem.
- (4) Challenging problems: the needed competence set is unknown or only partially known to the decision-maker.

According to Chiang (2002), there are four basic elements of competence set for a given problem  $E$ . The four elements are interrelated as depicted in Figure 1.

- (1) The **true competence set** ( $Tr(E)$ ): consists of ideas, knowledge, skills, attitudes, information and resources that are truly needed for solving problem  $E$  successfully;
- (2) The **perceived competence set** ( $Tr^*(E)$ ): The true competence set as perceived by the decision maker;
- (3) The Decision Maker's **acquired skill set** ( $Sk(E)$ ): consists of ideas, knowledge, skills, attitudes, information and resources that have actually been acquired by the decision maker;

- (4) The **perceived acquired skill set** ( $Sk^*(E)$ ): the acquired skill set as perceived by the decision maker.



**Figure 1 Four Basic Elements of Competence Set and Their Relationships (Chiang, 2002)**

Note that the above four element are some special subsets of the habitual domain of a decision problem  $E$ , see (Yu, 1990) for details. In this study, we focus on the relationship between  $Sk$  and  $Tr$ , and explore two issues: (i) what is the  $Sk$  and  $Tr$ , for driver's route choice problem and (ii) how to expand the existent competence set to the needed competence to deal with the rout choice problem.

In summary, the main purpose of competence set analysis is to identify the truly needed competence set and the decision-maker's competence set for a decision problem (Yu and Zhang, 1990). Furthermore, competence set can help decision makers to expand their competence set effectively for making decision.

When a decision maker already acquired the needed competence sets and is proficient in it, he will be comfortable and confident in making decisions (Hwang et al, 2001; Li et al, 2000). When decision-makers consider the decisions to be fuzzy problems, they would first define and identify the truly needed competence and subsequently promote themselves to solve the decision problems by continuously practiced. However, when decision makers face the challenge problems, they should expand their potential domain and try to obtain the new competence sets. Otherwise, they could not solve the decision problem effectively.

Another major issue of competence set analysis is to explore how to expand competence set in the most effective and efficient way and to help decision makers to expand their competence set in favor of better quality decisions (Yu and Zhang, 1992b, 1993). Competence set is a crucial element of solving the problem, and competence set expanding is an important factor to impact decision process and quality (Yu and Zhang, 1992c; 1993). Several models have been proposed to increase competence sets. Yu and Zhang (1992a) have addressed the problem of optimally expanding competence sets using the concept of minimum spanning tree. If a suitable numerical function (such as a cost function, utility function, etc.) can be specified, we can use the next-best method to acquire the optimal expansion process. Yu and Zhang (1990) defined an expected reward based on a random set decomposition of competence sets to measure the benefit of an expansion. Furthermore, Yu and Zhang (1993) explored the selection of the optimal competence set for the maximal expected net return and conducted a

marginal analysis for set expansion. The earlier results of competence set expansion are extremely useful for us in exploring the expansion process of competence sets for the route choice problem.

The focus of earlier application of competence sets analysis is business management support decision, consumer decision behavior (Chen, 2001; 2002), and model choice behavior. In this work, the habitual domains and competence sets are applied to the problem of route choice. This novel approach expands the application of competence set. The traffic information set is isolated to develop a decision model for driver route choice which can be used operationally and practically to investigate the behavior of route choice decision.

### **3. THE COMPETENCE SET OF THE ROUTE CHOICE PROBLEM**

#### **3.1 Types of Route Choice Problems**

As defined in 2.2, decision problem can be generally classified into four categories: routine, mixed routine, fuzzy and challenging problem. The four problems could be related to each stage of route choice decision model. The application of the competence sets to route choice analysis is described in the following:

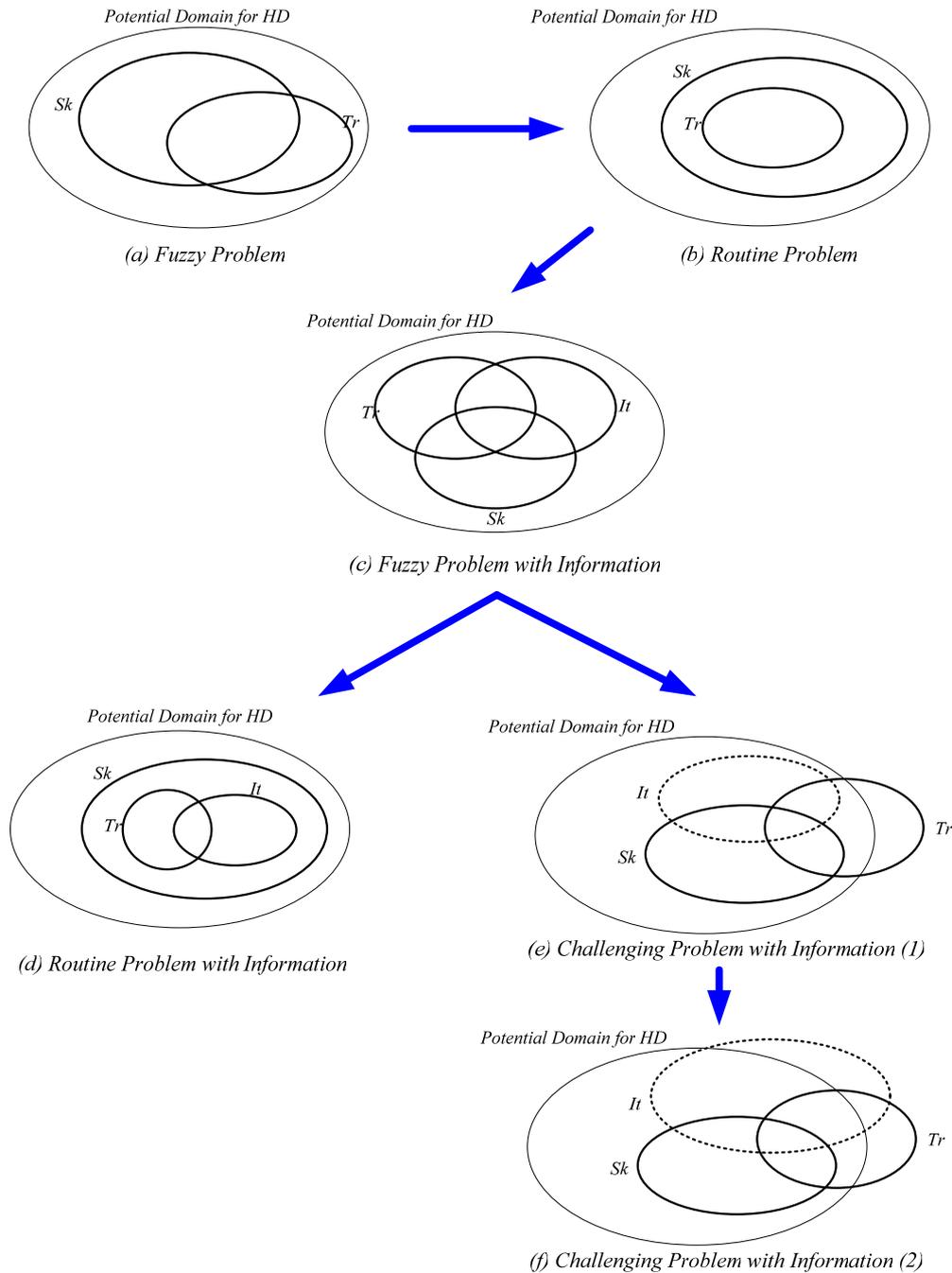
A driver selecting a route is essentially a fuzzy problem (Figure 2(a)). For a driver's habitual domain that is gradually stabilizing and without any major happenings, route choice becomes a routine problem (Figure 2(b)). Typically, the origin-destination of a trip is composed of a combination of a series of several road segments; thus, to complete one trip, many decision points have to be passed through in order to decide the best route. This is defined as a mix routine problem. On one hand, when traffic information is considered by the driver as various events, route choice will revert back to the fuzzy problem (Figure 2(c)). Availability of traffic information to the driver is the expansion of the actual domain and the extension of the competence set. When the driver receives more traffic information, theoretically, this should assist the driver with his decision of the best route. However, the abundant information can be complex such that the driver is overwhelmed to make efficient and effective decisions. Typically, the driver can gradually learn the accuracy of traffic prediction over time and select possible alternate routes. In such a case, the driver will preferably choose the information which is relevant to improve early driving experiences and develop a route choice policy. It will become a routine problem (Figure 2(d)). Another possibility is that part of the combination of traffic information quality may exceed the competence set of the driver in choosing the route or he may not even know what route to take. This time, the situation becomes a challenging problem (Figure 2(3) or 2(f)).

On the basis of habitual domain theory, this study adopts and expands the basic concept of competence set analysis; through this, a logical and applicable concept framework is developed, which can provide drivers another analytical method to affect route choice decision behavior. Using the competence set concept, a conceptual framework and analytical procedure for driver's route choice problem is described in the following sections.

#### **3.2 The Basic Definition of Competence Set**

For a driver's route choice problem, denoted by  $E$ , there exists a set of objective functions which satisfy the driver. Based on the requirements of the topic of this study, we use  $Sk(E)$  to

define the existing competence set, which consists of the capabilities that the driver has acquired. Next, we use  $Tr(E)$  to define the driver's truly needed competence set, which consists of the capabilities that are truly needed by the driver for a satisfactory solution. We use  $It(E)$  to define the traffic information set which consists of the collections of available or possible traffic information, such as radio broadcasting, navigation systems, variable message system.



**Figure 2. Relationship between Competence Sets and Route Choice**

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Let  $HD$  be the discussion universe containing the competence sets. It is valid to assume that the three competence sets  $Sk(E)$ ,  $Tr(E)$ ,  $It(E)$  are fuzzy subsets of  $HD$ , where  $HD = \{x_1, x_2, x_3, \dots, x_n\}$ . The membership function is defined by

$$\mu_{Sk(E)}(x_i), x_i \in HD;$$

$$\mu_{Tr(E)}(x_i), x_i \in HD;$$

$$\mu_{It(E)}(x_i), x_i \in HD;$$

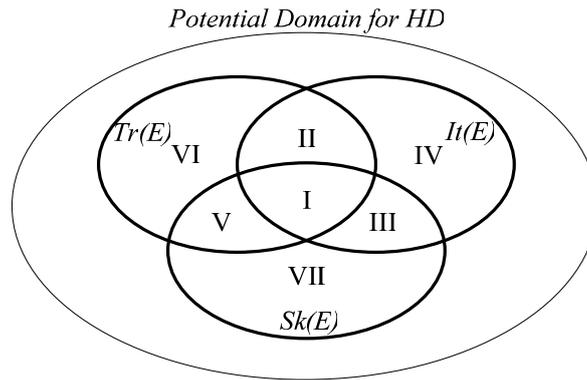
Note that larger value of membership function denotes higher degrees of set membership.

### 3.3 Fuzzy Problem vs. Route Choice

Under the conditions that a driver meets traffic congestion and there is no traffic information available, he does not have enough control over the best route choices. It is because he only has a fuzzy understanding of the route choice competence set that he really needs. Thus, this is considered as a fuzzy set problem as shown in Figure 2(a).

As mentioned above, when a drivers' habitual domain becomes steady and there are no significant stimuli, the route choice becomes a routine problem. If the traffic information given to the driver is enough stimuli, then the route choice reverts back to a fuzzy set problem (Figure 2(c)). In this case, the traffic information may be different from the situation that the driver had originally predicted. The previous driving experience is inadequate to grasp the truly needed competence to select the best route. Moreover, it is not possible to verify the reliability of the traffic information and consequently the route choice becomes a fuzzy set problem.

To further analyze the route choice fuzzy competence set, a series researches by Chen on consumer decision problem using competence sets will be sued and the union of  $Sk(E)$ ,  $Tr(E)$  and  $It(E)$  defined in section 3.2 is decomposed into I-VII segments. A simplified illustration of the three competence sets is presented in Figure 3.



**Figure 3. Decomposition of Competence Sets.**

Part I ( $Tr(E) \cap Sk(E) \cap It(E)$ ): Represents the route choice competence set that the driver already acquired, the driver truly needed and the traffic information can provide.

Part II ( $Tr(E) \cap It(E) \setminus Sk(E)$ ): Represents the route choice competence set that the driver truly needed and the traffic information can provide, but not the driver already acquired.

Part III ( $It(E) \cap Sk(E) \setminus Tr(E)$ ): Represents the route choice competence set that the driver already possesses and the traffic information can provide, but the driver doesn't think that is conducive to route choice.

Part IV ( $It(E) \setminus (Tr(E) \cup Sk(E))$ ): Represents the route choice competence set is not in the driver's actual domain, however, perhaps the driver is unfamiliar or does not know the traffic information set and thus doesn't think that is conducive to route choice.

Part V ( $Tr(E) \cap Sk(E) \setminus It(E)$ ): Represents the route choice competence set that the driver already acquired and he thinks that is conducive to route choice, but is not the competence set that the traffic information can offer.

Part VI ( $Tr(E) \setminus (Sk(E) \cup It(E))$ ): Represents the route choice competence set is not in the driver's actual domain and is not the traffic information can offer, but the driver thinks that is conducive to route choice.

Part VII ( $Sk(E) \setminus (Tr(E) \cup It(E))$ ): Represents the route choice competence set is in the driver's actual domain. However, the competence set is not the traffic information can offer and the driver doesn't think that is conducive to route choice.

Parts I, III, V, VII are the competence sets which the driver already acquired. Parts I and V are the competence sets which the driver already has acquired. Part I represents the competence set acquired from traffic information. Part V may be previous experience of the driver or how familiar he is with the road network. Moreover, Parts II and VI are the competence sets which the driver truly needs but have not been acquired. Part II is the traffic information that the driver thinks is conducive to route choice. When Part II has a larger proportion in  $Tr(E)$ , then the driver would be more dependent on traffic information. The traffic information provider has to expand the traffic information competence set  $It(E)$  in a efficient way to include the competence set of  $Tr(E) \setminus It(E)$  (which are Parts V and VI).

On the other hand, the competence sets outside  $(Tr(E) \cup Sk(E))$  represent attributes that the driver is unaware of. Although Part VI (i.e.,  $(It(E) \setminus (Tr(E) \cup Sk(E)))$ ) is not in the driver's

actual domain, nevertheless, this part is frequently the traffic information provided by recent technology but the driver is unfamiliar or unaware of. Thus, the driver will think that these information will not help in choosing routes. For example, automobile navigation systems are currently scarce. The driver perhaps does not have enough experience in using these systems or he may not understand what functions the systems can provide. If the traffic information can be combined with the driver's objective function, then it can assist the driver with choosing a route, making  $Tr(E)=It(E)$ . In other words, if the driver subjectively thinks the competence set which is conducive to route choice is exactly what the traffic information has, it will be tremendous helps when the driver buys or uses this type of traffic information.

### 3.4 Routine Problem vs. Route Choice

Route choice becomes a routine problem when the driver's habitual domain gradually stabilizes (Figure 2(b)). In the routine decision stage, usually the driver is already familiar with the roadway characteristics in the road network, traffic flow conditions, and traffic compositions, aside from knowing how to respond to current traffic congestion. In this case the driver has already acquired enough grasp of the competence set for all competence sets which are truly needed.  $Tr(E)$  is a subset of  $Sk(E)$ ; which is  $Tr(E) \subset Sk(E)$ . In the routine decision stage, the driver's route choice behavior follows a fixed model or is based on certain rules made from daily or weekly repetitive habitual routes. For this type of driver, traffic management authorities can resort to transportation demand management such as signal timing plans, lane allocation management, assign some roads one way during peak hours or block passage, or even build up new roads to stimulate this type of driver's route choice habit. When the road network shows a significant difference in terms of traffic conditions exceeding what the driver thinks of, he will start to consider changing his choice of route.

For drivers, traffic information is also a type of habitual domain stimulus which helps in choosing a route ( $It(E) \cap Tr(E) \neq \emptyset$ ). When the traffic information content is different from what the driver himself had predicted, such as announcing a non-recurrent traffic congestion ahead (caused by an accident or roadwork), the driver will start thinking of the reliability of the information, and considering the familiarity with the present road network and the urgency of reaching the destination. As a result, the driver can make the route choice. At this point, from being a routine problem, the route choice becomes a fuzzy problem. Nevertheless, as time goes by, the driver will gradually have a better grasp of the accuracy of traffic information predictions and the possible alternate routes to respond to the road conditions. In other words,  $It(E)$  has already been incorporated by the driver to his route choice competence set ( $It(E)$  is a subset of  $Sk(E)$ ; that is,  $It(E) \subset Sk(E)$ ). When the number of information sources is large and the contents become complicated, in order for the driver to avoid getting lost in the information labyrinth, the driver will select the most important or what he most believes to be the needed information. This will complement his past driving experience to choose a route. This becomes a routine route choice stage as in Figure 2(d).

### 3.5 Challenging Problem vs. Route Choice

Since the road network the driver confronts with is dynamic, the competence set which the driver truly needs  $Tr(E)$  will likewise vary over time. If  $Tr(E)$  is unknown to the driver or he only knows a part, in other words, part of the competence to solve the problem exceeds driver's potential domain ( $Tr \setminus PD \neq \emptyset$ ), then this is a challenging problem, as shown in Figure 2 (e). Traffic information theoretically should effectively help the driver make the best route choice. Nevertheless, drivers have their own acceptance level and absorptive capacity

regarding traffic information. If the information is too much or is too complicated for the driver to absorb, the driver could be overwhelmed to make effective decision. Thus,  $It(E)$  will exceed  $Sk(E)$  ( $It(E) \setminus PD \neq \emptyset$ ) and become another challenging problem (Figure 2(f)).

In the challenging decision stage, part of  $Tr(E)$  has already exceeded the driver's habitual domain, which can be thought of driver is lost in an unfamiliar city. Thus, the driver has to expand his competence set or habitual domain in order to quickly reach the destination. In this case, using traffic information is a simple and effective method through expanding from  $It(E)$  towards  $Tr(E)$  or expanding from  $Sk(E)$  towards  $It(E)$ . The challenging problem could become either a fuzzy problem or a routine problem. For example, when the driver gets lost, he can stop the car and ask people for directions or he can use a navigation system. Based on the traffic information collected, the driver can expand his potential domain and reach his destination.

#### 4. PERFORMANCE MEASURE INDEXES OF ROUTE CHOICES

The goal of competence set analysis in this study is to decompose Parts I to VII into segmented competence sets. This will assist  $Sk(E)$  to expand towards Parts VI, II, and VI segmented competence sets. In addition, it pushes  $It(E)$  towards expanding to Parts V and VI segmented competence sets. Based on various competence set expansion directions, a fuzzy measure is used to develop three indexes of route choice performance, including traffic information practicality  $Pc(It(E))$ , route choice acquisition efficiency  $Pf(Sk(E))$ , and traffic information acceptance  $Ac(It(E))$ .

##### 4.1 Traffic Information Practicality

From the traffic information provider point of view, making the driver accept traffic information, acknowledging the reliability and accuracy of traffic information, and bringing information into  $Tr(E)$  of route choice are of primary interest. For the traffic information equipment company, if the driver does not know automobile navigation system or he does not use it, then the market opportunity for traffic information equipment is limited. Furthermore, for the firms which providing value-added traffic information services, if drivers do not know about the electronic maps or they think that the electronic maps' information is inaccurate, the firms will not be attracted to provide better map contents and to update information more frequently. For those operating traffic management centers, if the traffic information announcements or roadside variable message system are not correct or cannot sent to road users in real time, then the goal of traffic management by using traffic information cannot be achieved.

Assume that  $g(\cdot)$  is a fuzzy measure satisfying

$$g(\emptyset) = 0 \text{ and } g(Tr(E)) = 1;$$

$$\text{if } A \subset B, \text{ then } g(A) \leq g(B)$$

and

$$g(\{x_i\}) = 0 \text{ for } x_i \in HD \setminus Tr(E).$$

According to the above definitions, we know that  $g(A) = g(A \cap Tr(E))$ , which indicates that

$Tr(E)$  is the truly needed competence set. Assume that  $\mu_{It(E)}(x_j)$  is monotonically non-increasing with respect to  $j$ .

$$\mu_{It(E)}(x_1) \geq \mu_{It(E)}(x_2) \geq \mu_{It(E)}(x_3) \geq \dots \geq \mu_{It(E)}(x_n)$$

Thus, we can define traffic information practicality, to drivers for  $Pc(It(E))$  concerning the consumer decision problem E.

$$Pc(It(E)) = \frac{\|Tr(E) \cap It(E)\|}{\|Tr(E)\|} \dots\dots\dots (1)$$

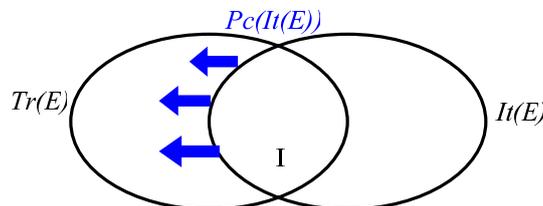
Where  $\| \quad \|$  is a measure on HD.

Since the Choquet integral can provide more reasonable results than that using the fuzzy integral in many cases (Wang and Wang, 1997; Chen, 2001, 2002), we used the Choquet integral to calculate  $Pc(It(E))$  (Ishii and Sugeno, 1985)::

$$\begin{aligned} Pc(It(E)) &= (c) \int \mu_{It(E)}(x) dg \\ &= \mu_{It(E)}(x_n)g(X_n) + [\mu_{It(E)}(x_{n-1}) - \mu_{It(E)}(x_n)]g(X_{n-1}) + \dots \\ &\quad + [\mu_{It(E)}(x_1) - \mu_{It(E)}(x_2)]g(X_1), \end{aligned} \dots\dots\dots(2)$$

where ,  $X_i := \{x_1, x_2, x_3, \dots, x_i\}$ ,  $i = 1, 2, 3, \dots, n$  .

Traffic information providers have to expand from  $It(E)$  towards  $Tr(E)$ ; while they should lead drivers to extend from  $Tr(E)$  to  $It(E)$  (Figure 4), in order to improve the possible benefits of traffic information on route choice. Since drivers do not necessarily fully understand or recognize the traffic information from Advanced Traveler Information System (ATIS), the increase of the competence set will allow for integration with driver cognition (included in the potential domain) and obtain recognition (included in  $Tr(E)$ ) in order to avoid that traffic information technology be neglected or refused by drivers. Therefore, whether or not traffic information is considered by drivers as useful in route choice, it can be determined by the extent of intersection of  $It(E)$  and  $Tr(E)$ . The larger the intersection of  $It(E)$  and  $Tr(E)$ , the higher practicality of traffic information. The reverse is true only when the driver thinks that the traffic information does not help in choosing a route.



**Figure 4. Expansion of Traffic Information Practicality**

**4.2 Route Choice Acquisition Efficiency**

If  $Sk(E)$  cannot fully encompass  $Tr(E)$ , then it becomes the previously mentioned fuzzy problem. Thus, the driver has to further improve acquired route choice competence to increase the efficiency of route choice competence.

Similarly, assume that  $g'(A)$  is a fuzzy measure satisfying

$$g'(\phi) = 0 \text{ and } g'(Tr(E)) = 1;$$

$$\text{if } A \subset B, \text{ then } g'(A) \leq g'(B),$$

and,

$$g'(\{x_i\}) = 0 \text{ for } x_i \in HD \setminus Tr(E);$$

$$g'(A) = g'(A \cap Tr(E)).$$

Let  $Sk(E)$  be a fuzzy subset of  $HD$ . Assume that, without loss of generality,

$$\mu_{Sk(E)}(x_1) \geq \mu_{Sk(E)}(x_2) \geq \mu_{Sk(E)}(x_3) \geq \dots \geq \mu_{Sk(E)}(x_n)$$

Thus, route choice acquisition efficiency for  $Sk(E)$  concerning the driver route choice problem  $E$  is given by

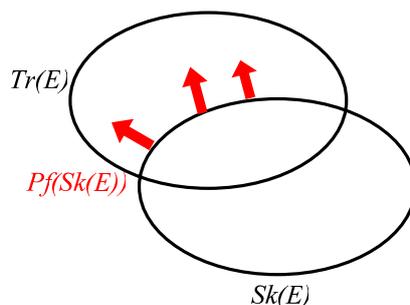
$$Pf(Sk(E)) = \frac{\|Tr(E) \cap Sk(E)\|}{\|Tr(E)\|} \dots\dots\dots(3)$$

Additionally,

$$\begin{aligned} Pf(Sk(E)) &= (c) \int \mu_{Sk(E)}(x) dg' \\ &= \mu_{Sk(E)}(x_n) g'(X_n) + [\mu_{Sk(E)}(x_{n-1}) - \mu_{Sk(E)}(x_n)] g'(X_{n-1}) + \dots \\ &\quad + [\mu_{Sk(E)}(x_1) - \mu_{Sk(E)}(x_2)] g'(X_1), \end{aligned} \dots\dots\dots(4)$$

where ,  $X_i := \{x_1, x_2, x_3, \dots, x_i\}$ ,  $i = 1, 2, 3, \dots, n$  .

When the driver’s acquired competence set  $Sk(E)$  which tends to expand towards  $Tr(E)$  (Figure 5), it indicates improved competence to acquire route choices. Thus, the efficiency of route choice for the driver can be evaluated based on the size of the intersection of  $Sk(E)$  and  $Tr(E)$ . The larger the intersection of  $Sk(E)$  and  $Tr(E)$  means that the acquired competence set tends to be closer to the truly needed competence set. In other words, the decision quality of route choice will be improved and the possibility the driver finds the optimal route will increase.



**Figure 5. Expansion of Route Choice Acquisition Efficiency**

### 4.3 Traffic Information Acceptance

When the driver is willing and tends toward  $It(E)$  contained in  $Sk(E)$ , it means higher capabilities with regards to applying traffic information on route choice. Moreover, the driver will not rely solely on previous driving experience to choose what route to take.

Similarly, let the driver acquired competence set of route choice  $Sk(E)$  be a fuzzy subset of  $HD$ . Its membership function is denoted by  $\mu_{Sk(E)}(x'_i)$ ,  $x'_i \in HD$ , Assume that  $g''(\cdot)$  is a fuzzy measure satisfying without loss of generality,

$$g''(\phi) = 0 \text{ and } g''(It(E)) = 1;$$

$$\text{if } A \subset B, \text{ then } g''(A) \leq g''(B),$$

And,

$$g''(\{x'_i\}) = 0 \text{ for } x'_i \in HD \setminus It(E);$$

$$g''(A) = g''(A \cap It(E)).$$

Assume that

$$\mu_{Sk(E)}(x_1) \geq \mu_{Sk(E)}(x_2) \geq \mu_{Sk(E)}(x_3) \geq \dots \geq \mu_{Sk(E)}(x_n)$$

Thus, traffic information acceptance for  $It(E)$  concerning the driver route choice problem  $E$  is given by

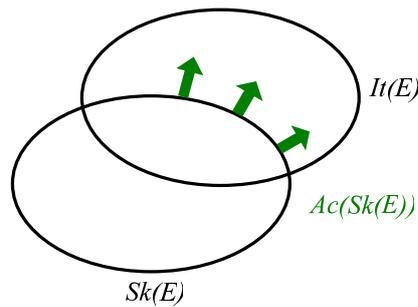
$$Ac(Sk(E)) = \frac{\|It(E) \cap Sk(E)\|}{\|It(E)\|} \dots\dots\dots(5)$$

Additionally,

$$\begin{aligned} Ac(Sk(E)) &= (c) \int \mu_{Sk(E)}(x') dg' \\ &= \mu_{Sk(E)}(x'_q)g'(X_q) + [\mu_{Sk(E)}(x'_{q-1}) - \mu_{Sk(E)}(x'_q)]g'(X'_{q-1}) + \dots \\ &\quad + [\mu_{Sk(E)}(x'_1) - \mu_{Sk(E)}(x'_2)]g'(X'_1), \end{aligned} \dots\dots\dots(6)$$

where ,  $X'_i := \{x'_1, x'_2, x'_3, \dots, x'_i\}$ ,  $i = 1, 2, 3, \dots, q$  .

When the driver expands from  $Sk(E)$  to  $It(E)$  (Figure 6.), the capability of applying traffic information is improved and the competence sets of route choice is increased. The degree of acceptance of traffic information can be measured by the intersection of  $Sk(E)$  and  $It(E)$ . A smaller intersection  $Sk(E)$  and  $It(E)$  indicates that the driver may incline to use primarily the previous driving experience habits. The contrary is true if the driver has a better grasp and processing of traffic information.



**Figure 6. Expansion of traffic information acceptance**

## 5. CONCLUSION AND SUGGESTIONS

An operational and practical driver route choice analytical model was developed based on competence set analysis as a conceptual framework. The effect of traffic information on route choice is investigated independently and the relationship between what the driver has already acquired and the true need route choice competence are studied and used to solve the problem of competence set and decision habit domain of the core concepts. Furthermore, the competence set is expanded to establish a adequate competence set when driver faced with the problem of route choice. In addition, we develop related route choice performance measures, including traffic information practicality  $Pc(It(E))$ , route choice acquisition efficiency  $Pf(Sk(E))$ , and traffic information acceptance  $Ac(It(E))$ . The analytical model of competence set proposed in this work can serve as a framework to be used by traffic information equipment suppliers or traffic information providers. This model can used to define the competence set of the route choice problem, to help suppliers expand  $It(E)$  that is suitable for driver's needs in choosing routes. In addition, drivers can examine the effect of traffic information on route choice. Given limited time and costs, it will help them design an effective competence set expansion process and explore related issues regarding efficient expansion processes.

In this work, preliminary results of applications of competence set expansion were shown and performance measures for route choice were developed. However, the measures of  $Sk(E)$ ,  $Tr(E)$ ,  $It(E)$  are differed by individuals, future work should include the detailed investigation of route choice competence set expansion process for developing related case studies.

Effectively expanding the competence set is an important issue in competence set analysis and an important factor affecting the quality of the decision process. For this reason, the way of competence sets expanding is unidirectional or interactive is another issue and is worth exploring further. Further studies will focus on exploring competence set expansion, including asymmetric costs and effects of experience, in order to go deeper into the effect of competence set expansion on route choice.

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