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先進旅行者資訊系統網站之網頁介面目錄選項排列可用性分析模式[1]

AN INTERFACE USABILITY ANALYSIS MODEL FOR MENU-ITEM PRESENTATION SEQUENCE IN WEB-BASED ADVANCED TRAVELER INFORMATION SYSTEMS IN TAIWAN

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摘　要

本研究係針對先進旅行者資訊系統網站，發展網頁介面目錄選項排列可用性分析模式，並以臺灣地區高速公路即時交通資訊網站為例，說明該模式之分析過程。首先蒐集國道高速公路局即時交通資訊網站網頁伺服器點擊流資料，構建原資訊架構下之連續時間馬可夫鏈使用者網頁瀏覽行為模式，並以平均使用者對話時間為網頁介面目錄選項排列可用性績效主要量化評估指標，不同排列順序之可用性績效，可由連續時間馬可夫鏈模式計算獲得。此外，由於行前交通資訊需求變化具不確定性，透過遺憾準則，可用以決定該網站資訊架構下之一般性目錄選項排列方案。實例分析結果顯示，無論有無改變網頁上目錄選項「即時交通資訊」與「旅行時間計算」之排列順序，其平均使用者對話時間

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與行前交通資訊需求變化均呈現線性關係。即使該可用性排列順序取決於行前交通資訊需求變化，分析後發現兩目錄選項交換排列順序後之可用性將優於原有排列順序。

關鍵詞： 先進旅行者資訊系統網站、介面可用性分析、目錄選項排列順序、連續時間馬可夫鏈、遺憾準則

ABSTRACT

The objectives of this study are to develop an interface usability analysis model for menu-item presentation sequence in web-based advanced traveler information systems (ATIS) and to conduct an empirical study of the freeway real-time traffic information website in Taiwan to illustrate the analysis processes of the model. The clickstream data collected from the web server were used for constructing a continuous time Markov chain (CTMC) model to represent users' web browsing behavior under a sequence of information architecture design. A major quantitative measurement of performance, expected time duration of user session (ETDUS), was estimated by the time-independent state probabilities obtained from CTMC model to show the results of menu-item sequence usability testing. To cope with the uncertain varying demands of pre-trip travel information (PTTI), a common sequence of menu-item alternative was determined by regret criterion. The empirical results indicate that there is a linear relationship between ETDUS and PTTI demands under a specific original as well as exchanged sequence of menu items for two text hyperlinks of real-time traffic information and travel time calculation shown on the relevant web pages. Although the appropriate sequence heavily depends on the variation of PTTI demands, it is found that the exchanged menu-item presentation sequence is better than the original one.

Key Words: *Web-based ATIS; Interface usability analysis; Menu-item presentation sequence; Continuous time Markov chains (CTMCs); Regret criterion*

I. INTRODUCTION

With the enormous growth of the World Wide Web (WWW), web-based advanced traveler information systems (ATIS) have become vital and popular media to provide travelers with various pre-trip travel information (PTTI) in the context of intelligent transportation systems (ITS) [1-4]. In order to make it easier for the users to search their needed PTTI, the WWW often adopts a top-down hierarchy organization to create a sensible, convenient and meaningful tree/network structure, so-called information architecture [5], to assist on classifying and arranging these complex and multiple PTTI contents into hierarchically categorized web pages [5-7].

Between these pages, the allowable paths are connected by their hyperlinks shown as menu items on each web page [6,8]. Users can browse their web pages by seeking and clicking the needed menu items. Therefore, investigating users' perceptions on the layout of the menu items has become essential for web interface design [6].

The choice of presentation sequence is an important issue on the layout of the menu items for human-computer interaction (HCI) interfaces [6]. Previous studies concerning presentation sequence have mainly focused on examining the reaction time for seeking target items in two aspects. Firstly, the items ranked by different sequenced strategies such as category, random or frequent usage were assessed using experiments [7,9-12]. Secondly, a relationship between the users' reaction time and the serial item position in the menu was modeled [13]. However, a systematic and correlative analysis on web page's menu item presentation sequence along with graphical user interface (GUI) has not been substantially carried out [5,14-17]. In addition, the item sequences were frequently explored on single interface; literatures on browsing multiple web pages are limited so far [18].

To investigate menu-item presentation sequence in web pages, the usability analysis is an effective way to do so [5,6,14-16,19,20]. Nevertheless, the traditional usability analysis is a time consuming, costing and iterative process to examine participants' perceptions using prototype tests [6,14]. Also, it can only reflect on the current condition at a time, unable to predict the variations in terms of slight changes on interface design. Consequently, some models were proposed to assist in analyzing human-machine interface usability [21,22], but only few attempts have so far been made on the usability analysis for web's menu-item presentation sequence [18].

Accordingly, this paper describes a study aiming at developing a usability analysis model for menu-item presentation sequence in a web-based ATIS in Taiwan. Following the introduction, in Section 2, the usability analysis process for ATIS web's menu item presentation sequence is further illustrated. In Section 3, we propose a model structure for this study, in which web browsing behavior model and mean think time versus serial position model (MTTSPM) are constructed to develop a usability analysis model using clickstream data. In Section 4, an empirical study is conducted to illustrate the analysis processes using this model. Finally, this paper concludes with some major findings and recommendations.

II. USABILITY ANALYSIS PROCESS

2.1 Web Usability Analysis and Design

The web interface usability is defined as the degree of effectiveness, efficiency and satisfaction on users' perceptions of web browsing [6]. It depends on the concept of user-centered design [14,19,20] that forces web designers to consider users' needs and experiences, but not permit users to passively accommodate the designed interface. Clearly, the web usability will affect not only users' perceptions but also the usage penetration [23,24].

To realize user-centered design, examining users' usability needs is designers' primary work during web design process [6], but these needs are difficult to be identified completely in advance [6,14]. This uncertainty will continuously lead to a gap between the web designers' expectations and users' perceptions [14,25]. Therefore, an iterative design process is proposed to compensate for these shortcomings, letting designers continually improve their designs. It is an ongoing cycle composed of three steps: design, prototype and evaluation [14]. In the design step, designers initially consider the users' needs to set measurable usability goals and its corresponding design concepts including information architecture, GUI design and so on. In the prototype step, designers develop prototype webs in accordance with design concepts. In the evaluation step, usability testing is executed to assess whether these prototypes meet the desired goals or not. If necessary, this iteration process might be repeated until the usability goals have been achieved [14,19].

Basically, the one-way process of the three steps without feedback from evaluation to design can be regarded as a usability analysis process in nature; the results can also be used as a redesigning clue for the next iteration design. Thus, web designers can completely analyze usability for a variety of alternatives following the three-step process. During every phase of web's life cycle such as designing, implementing or maintaining, this iterative method is useful for analyzing and developing usability. However, every step in this iteration is always time consuming and costing, especially when recruiting many participants for usability testing during evaluation step under multiple goals and prototypes [6,14-17,19,20].

2.2 Usability Analysis Process for this Study

During designing or implementing phases in ATIS web's life cycle, the menu item presentation sequence would be a final task after the web information architecture, composed of various PTTI or categorized items, and other related GUI designs have been properly determined. Although some intuitive guidelines suggest that the menu item presentation sequence, except natural sequence such as time, numerical ordering, physical properties and so on [6], can be ranked by category grouping or descending usage frequency [10,12], they are still unsuitable to completely apply to ATIS web for two reasons. Firstly, various PTTI for an ATIS web should be properly arranged by categorized and hierarchical information architecture to enhance interface usability, but problems still exist on presentation sequence for PTTI and categorized items themselves. Secondly, it is difficult to predict the usage frequency of every PTTI or categorized items since the travelers' PTTI demands will vary with their trip purposes [26], so the usage frequency would be uncertain for every item. Therefore, these guidelines for sequences should be used cautiously in ATIS web's usability design. Next in the maintaining phase, it is important that the sequences should be continuously reviewed to improve the original designs by usage frequency. Thus, an adaptive menu design has been proposed to dynamically change the sequences by current frequency [6,27], but this mechanism often leads to users' confusion and learning disorder [27] and affects their intention to use [28]. In any case, there is still no effective way to determine the sequence for ATIS web interface design so far during all phases in the life cycle. To ensure the sequence usability, it is necessary to establish a systematic and comprehensive usability analysis process for menu-item presentation sequence.

Similar with general web usability analysis process, understanding users' needs is the first step to analyze web-based ATIS interface usability. Several travelers' needs having been identified by research on characteristics of effective traveler information systems are as follows [2,29]:

1. Information that is timely, accurate, reliable and relevant to make travel decisions.
2. Information that is for the entire region.
3. Interfaces that are easy to use and easy to access by the traveling public.
4. Services are affordable to the end users.

However, only one need that interfaces are easy to use by the traveling public can be assessed by analyzing interface usability in web-based ATIS [2,29]. The term, easy to use, requires that travel information be easily sought for through the interface [29] since travelers consider the duration of user sessions as an additional time cost [29,30,31]. The duration of a user session is defined as the time period that a user spends on the whole browsing process from the first web page to the final one [31]. Thus, this time duration is exactly a measurable goal for ATIS web's usability analysis. It is almost consistent with the quantifiable performance measurement, the time that users take to complete a specific task, suggested in general usability testing [20]. Clearly, the ATIS web interface usability resulting from the menu-item presentation sequence can also be analyzed by measuring time duration of user sessions.

The usability analysis process for this study is shown as Figure 1. In the design step, the usability goal has been identified as above, and corresponding measurable goal has also been set as user session time. In addition, potential alternatives for menu-item presentation sequence are determined. In the prototype step, a prototype web should be constructed; the proposed sequence alternatives will be integrated into designed web pages. In the evaluation step, participants are recruited to conduct usability testing under trip scenarios generated by randomly combining varied trip characteristics (e.g., trip purpose, trip length and availability of transit systems, etc.).

Then, the participants' session time will be examined individually. That is, a potential sequence will have a corresponding prototype to be examined by usability testing; the results for all alternatives will be analyzed and compared to choose the best one. Although this process could be an effective way to analyze and design sequence usability, there are still two limitations:

1. Lack of efficiency: this method is basically a time consuming and expensive process, which is not economically sound and constrained by time and budgets.
2. Lack of generality: only current participants' usage can be considered; a common sequence is difficult to determine to satisfy all practiced users due to their varied PTTI demands.

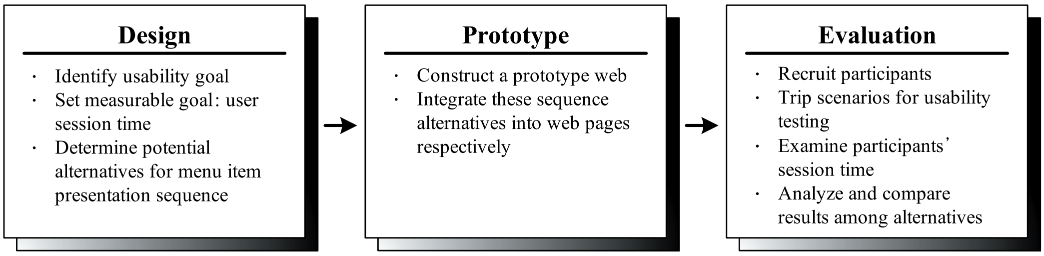


Figure 1　Usability Analysis Process for this Study

III. DEVELOPMENT OF USABILITY ANALYSIS MODEL

3.1 Model Structure

In order to overcome these shortcomings discussed above, it is necessary to develop an analysis approach that coincides with the usability analysis process for this study. As shown in Figure 2, this approach is mainly composed of a web browsing behavior model which is used to substitute for multiple usability testing in usability analysis process. For model construction purpose, a subject menu-item presentation sequence is configured to be involved in a prototype web to collect users' clickstream data under designed information architecture. During the data collection process for just one period of time, the mean think time versus serial position model (MTTSPM) is constructed to predict the mean think times for different item position using clickstream data. The web browsing behavior model can also be constructed to analyze potential sequence by MTTSPM with varied PTTI demands. These results can thus be regarded as measurements for determining the feasible sequence strategies by any decision making technique.

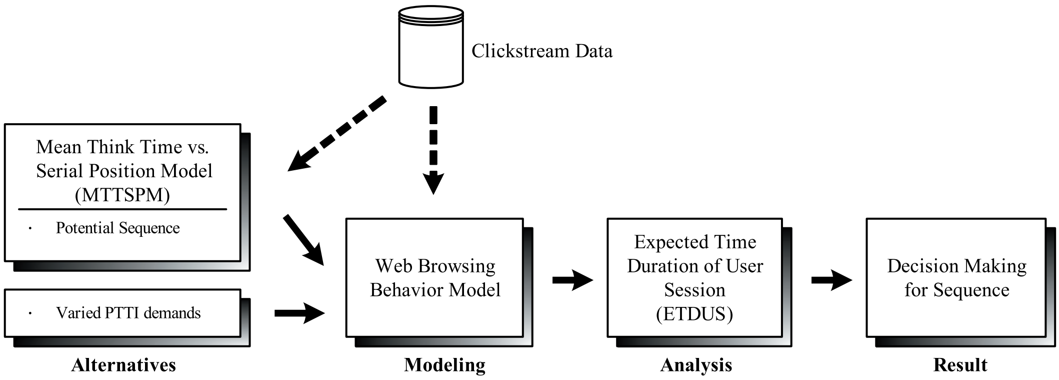


Figure 2　Model Structure for this Study

3.2 Clickstream Data

Under the request-response mechanism in WWW, a user clicks serial hyperlinks shown as menu items on every web page to go through their browsing process from one page to another until a user session has completed. The web server is requested to transmit corresponding graphics and texts to the user in the form of Hypertext Markup Language (HTML) documents. Most of web server software, Apache, Tomcat or Windows Server for example, automatically record these events occurred in web server by creating an Access Log file composed of clickstream data. These data are useful for analyzing users' browsing and purchasing behavior in e-commerce web by using individual choice behavior model or data mining techniques [32-36].

Figure 3 shows the relationship between user browsing behavior and clickstream data for a single user in a request-response round. While user starts by clicking to enter the website at time t_0, the server will receive the request at time t_1 caused by a lag of upload transmission time. After its processing time, the server starts sending corresponding documents at time t_2; user receives and starts to browse the web page at time t_3 caused by another lag of download transmission time. During the user think time, the user views the web page until he/she has decided, sought and clicked the menu item for the next request. Then, the next request-response round will occur at time t_0' and the server receives the next request at time t_1' and so on. Under the conditions of minimal delay on the communications network (i.e. $t_0 \approx t_1$, $t_2 \approx t_3$ and $t_0' \approx t_1'$) and a speedy web server (i.e. $t_1 \approx t_2$), the time duration between two requests ($t_1' - t_1$) can be regarded as the user think time of ($t_0' - t_3$) that reflects on the actual browsing time. Obviously, this approximate relationship also exists in clickstream data collected from off-line testing without communications networks.

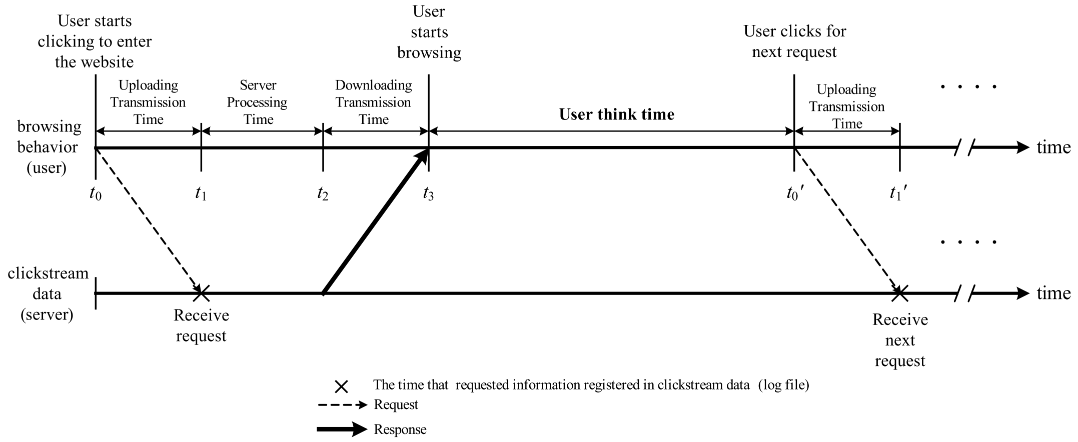


Figure 3 Sketch on the Relationship between Browsing Behavior and Clickstream Data for a Single User in One Request-Response Round

Clearly, multiple requests and contents transferred between the clients (users' computer) and the web server can be completely registered by clickstream data, in which each row of data represents for a request including user's Internet protocol (IP) address, receiving time and the web page he/she is to browse. For the later model construction purpose, samples collected from clickstream data need to be further dealt with and illustrated as follows:

1. IP address can be a representation of individual user to sort the clickstream data into a set M of m user sessions, in which each session is consisted of several request activities invoked by a user. Also, each user session has been simplified as a process consisted of requests and think times.
2. There are two dummy starting and terminating requests to be added for a complete user session.
3. All web pages including dummy pages of starting and terminating requests are defined as a set P of p web pages. Also, each potential link generated by a request of web page i with next web page j is expressed as a pair $(i, j) \in P^a$, where P^a is a set of all potential links generated by requests.
4. As shown in Figure 4, the two dummy starting and terminating requests need to be simultaneously added into every user session. The starting request is used to overcome the difficulty for modeling due to the different accessing web pages in the first request of each session. While the terminating request is used not only to compensate for the missing user think time for final request in the clickstream data, but also to represent for the egress activity of this user session. Thus, two corresponding dummy web pages are also created to be used for modeling.
5. The time duration of each session (m^{th}, $m \in M$) is consisted of several user think times

(thk_{ij}^{mr}) that represent for time spent on web page i until clicking the next request of web page j, in which a set of R of r requests represents for the total numbers of requests (starting and terminating requests included) in m^{th} user session. The two dummy think times are arbitrarily assigned as 1 sec for starting and final browsing requests respectively. Even though the time duration of user session is not completely real due to dummy think times, it is still sufficient for characterizing an information seeking task in this study.

The above-mentioned characteristics involved in clickstream data would be useful when constructing web browsing behavior model. Also, the Access Log file can be obtained by off- or on-line usability testing during the designing or maintaining phase.

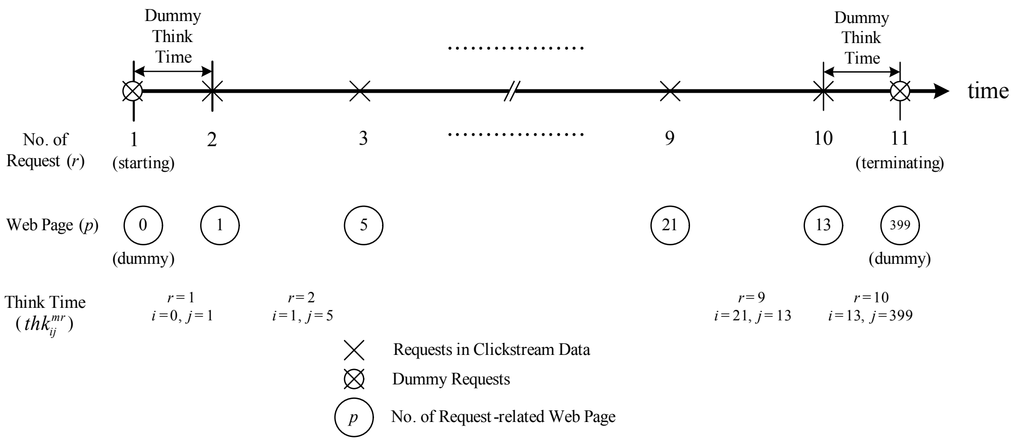


Figure 4　Sketch on a Example of the mth User Session with 11 Requests

3.3 Web Browsing Behavior Model

In previous studies on web browsing behavior, the discrete time Markov chains (DTMCs), characterizing a system by discrete state transitions occurred at discrete time instants, had been broadly utilized to predict the probability of which a user browses a particular web page. Later on, they were embedded in web servers to pre-send web page documents to the user with the purpose of reducing waiting time. [37-41]. Although the DTMCs model is a simple and effective way to predict user's browsing behavior on link/path choice, it lacks the continuous time domain that can reflect on the random characteristics of time duration resulting from user browsing, a vital concern on interface usability in a web-based ATIS. To overcome this, a continuous time Markov chains (CTMCs) model with the domain of discrete state and continuous time is adopted to characterize browsing behavior. The usability analysis model for this study is thus expressed as a web browsing behavior model constructed by continuous time Markov chains (CTMCs) using clickstream data.

Prior to utilizing CTMCs, two assumptions need to be further examined as follows:

1. The numbers of order that represent the numbers of previous browsing pages addressed on a web page for modeling CTMCs should be determined in this study. That is, so-called Markovian property, the probability of the next web page requested do not depend on all previous browsing pages, only rely on the past ones within the numbers of order. Although the higher order could lead to higher accuracy on web page access predictions, some limitations such as high-state complexity might occur to decrease its practical applications. The trade-off resulting from selecting the numbers of order is thus a vital and complex issue on Markov predictive model [38,42]. In order to avoid these unnecessary issues on higher-order model, a simplest but not the most accurate model, first-order CTMCs, is adopted to interpret the web browsing behavior in this study [43]. That is, we assume that the probability of requesting the next one (path) only depends on the current browsing web page, independent of the past.
2. The think time sojourned in one web page is a random variable with exponential distribution, a characteristic to be further validated in the empirical study.

The CTMCs web browsing behavior model is constructed by defining the states and their transitions. Consider a web information architecture with a set P of p web pages (including dummy pages of starting and terminating request), each one (p^{th}) is given a corresponding state. Also, the potential hyperlinks between web pages $(i, j) \in P^a$ are defined as state transitions for model construction. Thus, the web browsing behavior is regarded as state transitions in a CTMCs model (see Figure 5).

In order to construct the CTMCs model, the samples collected from clickstream data were used to estimate some needed parameters as explained below [44]:

1. Transition Probability

The transition probability (TP_{ij}) is defined as the probability that a transition occurred from state i to j. It is measured as the ratio of the total numbers of (i, j) pairs to the total numbers of (i, j) pairs departing from state i in clickstream data, as indicated in Equation (1):

$$TP_{ij} = \frac{n_{ij}}{N_i} = \frac{\sum_{m \in M} x_{ij}^{mr}}{\sum_{m \in M} x_i^{mr}} \tag{1}$$

in which

n_{ij} : total numbers of (i, j) pairs;

N_i : total numbers of (i, j) pairs departing from state i;

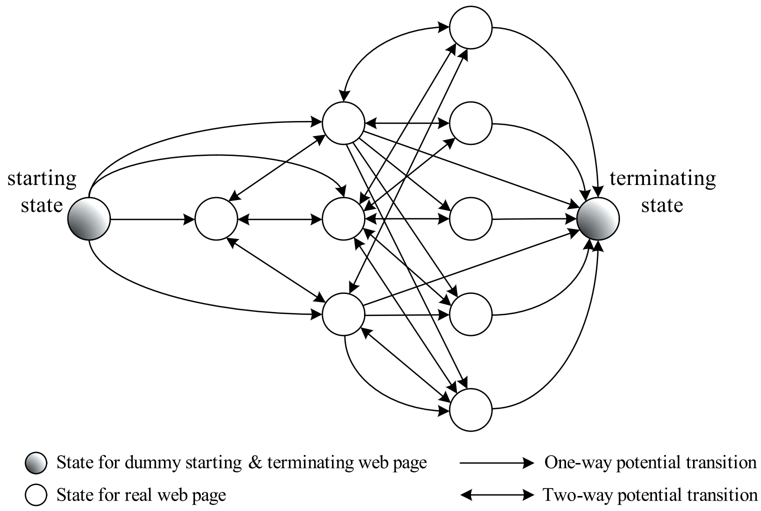


Figure 5　Sketch of States and Transitions in a CTMCs Model

$x_{ij}^{mr}, x_i^{mr} \in \{0,1\} \qquad \forall (i, j) \in P^a;\ m \in M;\ r \in R;$

$x_{ij}^{mr} = 1$, if the sample of pair for the r^{th} request in the m^{th} user session equals to the estimated (i, j) pair; $x_{ij}^{mr} = 0$, otherwise. $x_i^{mr} = 1$, if the sample of requesting page for the r^{th} request in the m^{th} user session equals to the estimated web page i; $x_i^{mr} = 0$, otherwise.

2. Departure Rate

The departure rate (ν_i) is defined as the rate that the transitions occurred per unit time from state i. It is measured as the ratio of the total numbers of (i, j) pairs departing from state i ($\sum_{m \in M} x_i^{mr}$) to the total sojourn times (total think times in the samples of clickstream data) starting state i, as indicated in Equation (2):

$$\nu_i = \frac{\sum_{m \in M} x_i^{mr}}{\sum_{\substack{m \in M \\ j \in P}} x_{ij}^{mr} thk_{ij}^{mr}} = \frac{N_i}{N_i \times mthk_{ij}} = \frac{1}{mthk_{ij}} \tag{2}$$

in which

$x_{ij}^{mr} \in \{0,1\} \qquad \forall (i, j) \in P^a;\ m \in M;\ r \in R;$

thk_{ij}^{mr} : the time spent on browsing web page i until clicking the next request of web page j for the r^{th} request in the m^{th} user session;

$mthk_{ij}$: the mean think time of (i, j) pairs; it is measured as the ratio of the total sojourn times (total think times in the samples of clickstream data) from state i to j

($\sum_{\substack{m\in M \\ j\in P}} x_{ij}^{mr} thk_{ij}^{mr}$), to the total numbers of (i, j) pairs (n_{ij}).

3. Transition Rate

The transition rate (q_{ij}) is defined as the rate that the transitions occurred per unit time from state i to j. It is measured as the product of the transition probability (TP_{ij}) and departure rate (ν_i), as shown in Equation (3):

$$q_{ij} = TP_{ij} \times \nu_i \qquad \forall (i, j) \in P^a, i \in P \tag{3}$$

For the CTMCs model calculation purpose, a $p \times p$ Rate Matrix ($\Re$) with the elements (r_{ij}) that are defined as Equation (4):

$$r_{ij} = \begin{cases} q_{ij} & i \neq j \\ -\nu_i & i = j \end{cases} \qquad \forall (i, j) \in P^a, i \in P \tag{4}$$

in which $r_{ij} = 0$, if $(i, j) \notin P^a$.

Thus, the state probability ($SP_i(t)$) for state i at time t can be calculated by a vector of differential equations derived by Chapman-Kolmogorov, as indicated in Equation (5):

$$SP'(t) = SP'(0) \times e^{\Re t} \tag{5}$$

in which

$SP'(t)$: a vector for probabilities of all states at time t ($SP'(t) = [SP_0(t)\ SP_1(t)\ .....SP_i(t)]$; $i \in P$), the sum of total state probabilities equals 1;

$SP'(0)$: a vector for initial probabilities of all states at time 0 ($SP'(0) = [SP_0(0)\ SP_1(0)\ .....SP_i(0)]$; $i \in P$), the sum of total state probabilities equals 1;

$e^{\Re t}$: a matrix exponential defined as $e^{\Re t} = \sum_{k=0}^{\infty} \frac{(\Re t)^k}{k!}$.

Based on the state probabilities calculated through Equations (1) to (5), some measurements of performance can be estimated as follows:

1. Expected Time Duration of User Session (ETDUS)

The expected time duration of user session (ETDUS) is defined as the mean time that users spend on their sessions, the users' mean time interval during their transitions from starting to terminating state. In the CTMCs model, a user session is explicitly defined by the occurrence of terminating state to show its completion, so the time-dependent probability distribution of the terminating state should be further illustrated to derive the ETDUS.

Suppose a probability density function $f(t)$ is defined as the time-dependent variation of cumulative probability at terminating state. Therefore, the probability of a completed session occurring at time t is represented as Equation (6):

$$F(t) = \int_{-\infty}^{t} f(t)dt = \int_{0}^{t} f(t)dt \tag{6}$$

in which

F(*t*): the time-dependent state probability at terminating state.

As a result of summing of all state probabilities at time *t* equal to 1, the state probability exclusive of terminating state can be indicated as Equation (7):

$$G(t) = 1 - F(t) = 1 - \int_{0}^{t} f(t)dt = \int_{t}^{\infty} f(t)dt \tag{7}$$

in which

G(*t*): the sum of state probabilities at time *t* exclusive of terminating state.

By differentiating *G*(*t*) with respect to time *t*, we can obtain the relationship as indicated by Equation (8):

$$\frac{dG(t)}{dt} = \frac{d}{dt}\int_{t}^{\infty} f(t)dt = f(\infty) - f(t) = -f(t)$$

in which

$f(\infty) = 0$: an absorbing characteristic for terminating state at time $t = \infty$.

Thus,

$$f(t) = -\frac{dG(t)}{dt} \tag{8}$$

The ETDUS is calculated by substituting Equation (8) into the mean of continuous probability distribution, as indicated in Equation (9):

$$ETDUS = \int_{0}^{\infty} tf(t)dt = -\int_{0}^{\infty} t\frac{dG(t)}{dt}dt = -\int_{0}^{\infty} tdG(t) = \int_{0}^{\infty} G(t)dt \tag{9}$$

2. Expected Number of Departures

The expected number of departures ($D_i(t)$) from state *i* at time *t* is calculated as Equation (10):

$$D_i(t) = \int_0^t \omega_i(x)dx \tag{10}$$

in which

$\omega_i(x)$: the frequency of departures from state i at time x; it is calculated using $\omega_i(x) = \sum_{i \in P} SP_i(t)q_{ij} \qquad \forall (i, j) \in P^a$.

3. Expected Number of Transitions

The expected number of transitions ($N_{ij}(t)$) from state i to j at time t is calculated as Equation (11):

$$N_{ij}(t) = \int_0^t \nu_{ij}(x)dx \tag{11}$$

in which

$\nu_{ij}(x)$: the frequency of transitions from state i to j at time x; it is calculated using $\nu_{ij}(x) = SP_i(t)q_{ij} \qquad \forall i \in P; (i, j) \in P^a$.

4. Expected Number of Visits

The expected number of visits ($V_i(t)$) into state i at time t is calculated as Equation (12):

$$V_i(t) = \int_0^t vis_i(x)dx \tag{12}$$

in which

$vis_i(x)$: the frequency of visits into state i at time x; it is calculated using $vis_i(x) = \sum_{i \in P} SP_i(t)q_{ji} \qquad \forall (j, i) \in P^a$.

5. Expected Time Spent in a State

The expected time spent ($T_i(t)$) in a state i at time t is calculated as Equation (13):

$$T_i(t) = \int_0^t SP_i(x)dx \tag{13}$$

3.4 Mean Think Time versus Serial Position Model (MTTSPM)

In order to predict the time duration of user sessions affected by various sequence of menu items in this study, it is necessary to construct another behavior model with respect to different choices of menu-item sequence for usability analysis using CTMCs. The serial position of menu items reflects on different users' behavior for their reaction time [13] included in user think time.

Therefore, modeling the relationship between user think time and serial position is essential for analyzing usability using CTMCs model.

As for searching behavior on menu items in terms of serial position, a computer menu had been experimented by Somberg & Picardi (1983) in the past [13]. That is, the participants were given a word (prompt) and then had to search a numbered list of categories (menu) to find one which described the word. A linear function was thus proposed to describe the relationship between mean reaction time and serial position, in which the reaction time was the time interval from a prompt till the correct category was chosen. Also, the intercept of the linear function indicated the time needed to complete a cognitive process, and the slope was treated as a scan rate for each category during scanning process [45].

Similar to searching computer menu, the web-user browsing behavior during think time can also be reasonably divided into two processes. Firstly, users in a cognitive process start browsing the content of web page, identify the potential web page (path) and then determine the next tentative web page. Next in the scanning process, they seek out the corresponding menu item and click it to reach the next web page. Therefore, there also exists a linear regression function ($MTTSPM_i^{pos}$) of mean think time versus serial position on web page i obtained from click-stream data, as shown in Equation (14):

$$MTTSPM_i^{pos} = \beta_0 + \beta_1 pos \tag{14}$$

in which

β_0, β_1: coefficients of linear regression model;

pos: the serial position of menu items on a web page ($pos \in N$), which is ranked from left to right in horizontal sequence, from top to bottom in vertical sequence.

As the sequence changes, the departure rate should be recalculated using Equation (2) by substituting the mean think time obtained from Equation (14). For example, the web page of state 1 shows three menu items in serial positions 1, 2 and 3 linking to web pages of states 2, 3, and 4, respectively. Suppose the menu items linking to web pages of states 2 and 3 in positions 1 and 2 are exchanged to 2 and 1, the new sequence of menu items is then linked to web pages of states 3, 2 and 4 in serial position. Using MTTSPM as indicated in Equation (14), the mean think times $mthk_{12}$ and $mthk_{13}$ in Equation (2) can be substituted by $MTTSPM_1^2$ and $MTTSPM_1^1$ respectively to obtain new departure rate (ν_1'). Following Equations (3) to (5), the new CTMCs model can be reconstructed; the corresponding measurements of performance are thus calculated.

3.5 Decision Making under Uncertain PTTI Demands

Under various uncertain PTTI demands, the minimax regret criterion [46] that considers the concept of opportunity cost is used to conduct decision making on sequence of menu items in this study. The potential scenarios are thus considered by changing the corresponding transition probabilities under pessimistic and optimistic situations. The CTMCs model can then be reconstructed from Equations (3) to (5) to calculate the measurements of performance. Based on these values, the minimax regret criterion is finally employed in sequence decisions. These processes are further illustrated in the empirical study.

IV. EMPIRICAL STUDY

4.1 Description

In principle, the usability analysis model is applicable to any web-based ATIS during any phase of its life cycle. An empirical study was proposed on the freeway real-time traffic information website, which was established by Taiwan Area National Freeway Bureau (TANFB), Ministry of Transportation and Communications (MOTC), to show how the usability of menu-item presentation sequence can be analyzed by this model in implementation of this website.

The version of the research website was implemented in April of 2004 through June of 2005, providing travelers with various PTTI which include freeway traffic flow map (northern, central and southern areas), traffic camera, event, roadwork, travel time and so on. These contents were arranged into web pages by the information architecture shown in Figure 6. In addition, the PTTI and menu items (potential hyperlinks) shown on each web page are illustrated in Table 1.

Most of web pages in this website adopt both of text and graphic hyperlinks. For instance, there are five items of text hyperlinks along with a graphic hyperlink of Taiwan traffic flow map laid on the homepage. The text hyperlinks, real-time traffic information and travel time calculation, stand side by side in the first row of this page (Type I). The second row places three options: Northern Network, Central Network and Southern Network, which are also accessible through direct clicks on the corresponding portion of the Taiwan traffic flow map below. The issue on menu-item presentation sequence should only occur in the menu items of text hyperlinks, but not in the map row of natural sequence. As for the menu items shown on other web pages in Level 2 or 3, their layouts are almost similar to the one of homepage (Type II); the designed menu-item presentation sequences on every web page are also illustrated in Table 1. The major purpose of this study is to examine whether the designed sequence is suitable for these menu items in terms of interface usability along with different PTTI demands. Following the exchange of menu-item sequence of real-time traffic information and travel time calculation shown on homepage (Type I), the sequence for the same items on other web pages (the last two items in Type II) are exchanged simultaneously by parameter adjustments to analyze the interface usability using CTMCs model.

4.2 Data

The clickstream data consists of a total of 6,390 user sessions, generated by the web server software Tomcat within the TANFB freeway real-time traffic information web server, were collected for one entire week from October 5th to 11th of 2004. Although these clickstream data are precious [33], preprocessing tasks are still required to obtain meaningful data sets for model construction [34]. Firstly, approximately 16% of user sessions were eliminated resulting from routine testing using specific IP addresses by web managers. Next, approximately 28% of users appeared to have sojourned in a specific web page exceeding 5 minutes without any activities. This kind of behavior can be easily detected by several successive requests of the same web page separated by 5 minute-intervals, resulting from Java server page (JSP) embedded in HTML, which is designed to automatically renew the PTTI shown on the web page. Therefore, these user sessions were also eliminated from clickstream data. Finally, the user sessions with exces

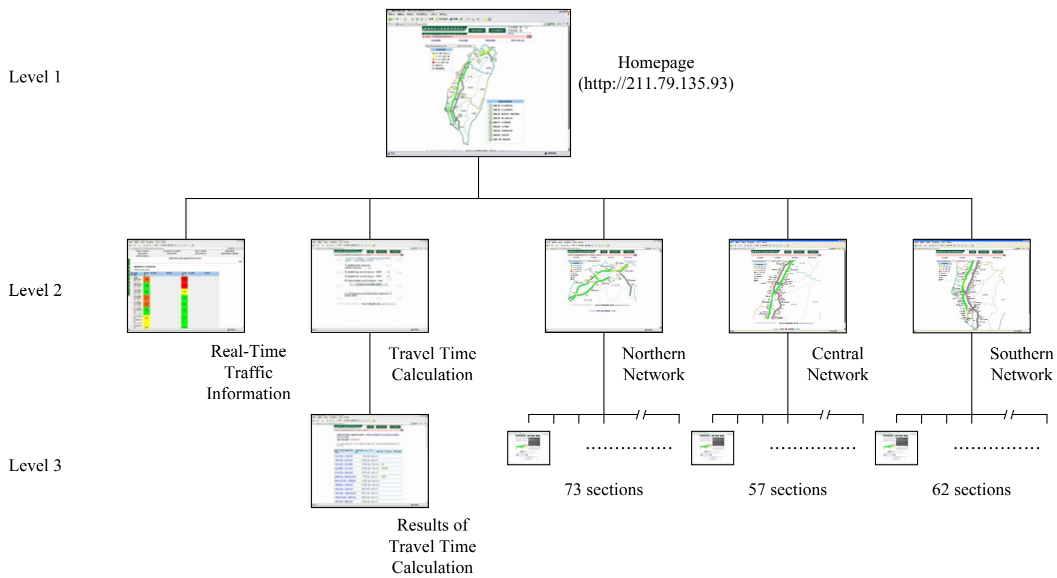


Figure 6 The Information Architecture for the Freeway Real-Time Traffic Information Website

Table 1　Illustration on PTTI and Menu Items for each Web Page

Web Page	Level	Contents of PTTI	Sequence Style	Permitted Web Pages to Link								
				Home-page	Real-Time Traffic Informa-tion	Travel Time Calcula-tion	North-ern Net-work	Central Net-work	South-ern Net-work	73 Sections in North-ern Network	57 Sections in Central Network	62 Sections in South-ern Network
Homepage	1	Taiwan area traffic flow map	Type I		◎	◎	◎	◎	◎			
Real-Time Traffic In-formation	2	Event & roadwork in-formation	None	◎								
Travel Time Calculation	2	Travel time calculation by inputting Ori-gin-Destination (O-D)	Type II	◎	◎	◎						
Northern Network	2	Northern Network traffic flow map	Type II	◎	◎	◎	◎	◎	◎	◎		
Central Net-work	2	Central Network traffic flow map	Type II	◎	◎	◎	◎	◎	◎		◎	
Southern Network	2	Southern Network traffic flow map	Type II	◎	◎	◎	◎	◎	◎			◎
Results of Travel Time Calculation	3	Results of travel time calculation	Type II	◎	◎	◎						
73 Sections in Northern Network	3	(1) the traffic camera for a specific section; (2) the traffic flow map of adjacent sections	Type II	◎	◎	◎	◎	◎	◎	○		
57 Sections in Central Network	3	(1) the traffic camera for a specific section; (2) the traffic flow map of adjacent sections	Type II	◎	◎	◎	◎	◎	◎		○	
62 Sections in Southern Network	3	(1) the traffic camera for a specific section; (2) the traffic flow map of adja-cent sections	Type II	◎	◎	◎	◎	◎	◎			○

Notes:

Type I: Real-Time Traffic Information | Travel Time Calculation

Type II: Total Area Map | Real-Time Traffic Information | Travel Time Calculation

Type I means the two menu items, Real-Time Traffic Information and Travel Time Calculation, are horizontally sequenced from left to right side. Type II means the three menu items, Total Area Map, Real-Time Traffic Information and Travel Time Calculation, are also horizontally sequenced from left to right side.
◎: indicates the potential linked web page.
○: indicates the web pages of adjacent sections only.

sive time durations generated by web crawlers, web spiders or web surfers should be reasonably eliminated; thus, an approach was proposed to determine the appropriate range of time duration to screen the remaining 56% of samples. As shown in Table 2, a time increment of 60 sec is used to define the range of time duration of user session for elimination, and the errors of estimates were calculated. By comparing their 95% maximum error of estimates, the smallest one (2.93 sec) is chosen with the eliminating time duration of more than 720 sec. Therefore, the final samples are comprised of 3,266 user sessions; that is, approximately 51% of the original 6,390 user sessions are meaningful for model construction. Based on the analysis of these 3,266 user sessions with dummy requests and think times, Figure 7(a) shows the relative frequency distribution of time duration and Figure 7(b) shows the relative frequency distribution of number of requests, respectively.

Table 2 Parameters of Remaining Samples of User Session Using Every Eliminated Range

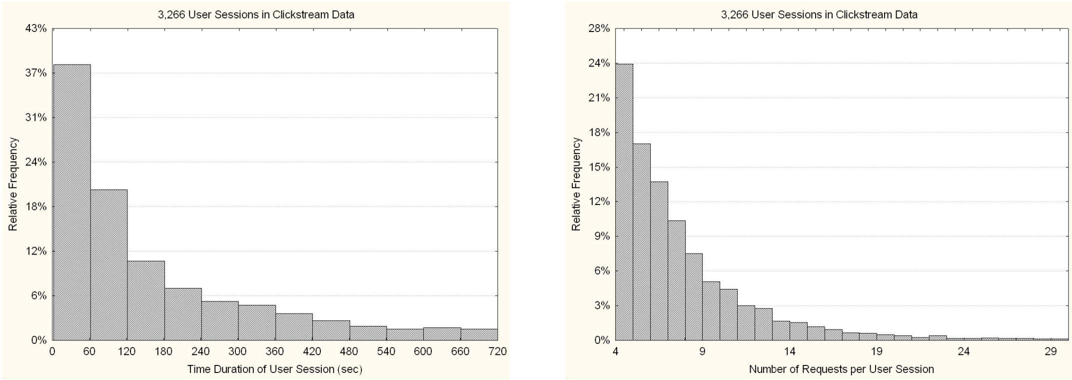
The Range of Time Duration of User Session for Elimination	Mean (sec)	Standard Deviation (sec)	Remaining Samples of User Sessions	95% Maximum Error of Estimate	95% Confidence Interval
>840 sec	165.33	179.09	3,310	6.10	[159.23, 171.43]
>780 sec	161.24	172.16	3,289	5.88	[155.36, 167.12]
>720 sec	157.08	85.50	3,266	2.93	[154.15, 160.01]
>660 sec	148.80	152.68	3,216	5.28	[143.52, 154.08]
>600 sec	140.30	139.89	3,160	4.88	[135.42, 145.18]
>540 sec	133.30	129.82	3,109	4.56	[128.74, 137.86]
>480 sec	125.36	118.89	3,045	4.22	[121.14, 129.58]

[a,b]: the range of a to b.

4.3 CTMCs Model

For CTMCs model construction purpose, the definitions of 400 states are illustrated in Table 3. The original 201 states are generated from 199 physical web pages adding 2 dummy ones to show the events a user can browse on that web page. Other duplicated 199 states resulted from the user browsing the next web page exactly the same way as the current one, that is by clicking refreshing button to manually renew the contents in 5 minutes.

In order to examine the sequence of menu items on real-time traffic information and travel time calculation, it is necessary to pick the samples of sessions that users had passed through these two web pages from the final samples of 3,266 user sessions; thus, a total of 869 samples were filtered to construct the CTMCs model. By using the goodness-of-fit test, it was found that the think times at each state fit the exponential distribution significantly well, a characteristic hypothesized by CTMCs model. Table 4 shows the example results on this test for departure states 1, 4, 5 and 6.



(a) (b)

Figure 7 The Relative Frequency Distribution of (a) Time Duration of User Session; (b) Number of Requests per User Session (3,266 User Sessions)

Table 3 Definitions on 400 States in CTMCs Model

Web Page	Corresponding State No.		Numbers of States
	Original	Duplication	
Starting Web Page (Dummy)	0		1
Homepage	1	200	2
Real-Time Traffic Information	2	201	2
Travel Time Calculation	3	202	2
Northern Network	4	203	2
Central Network	5	204	2
Southern Network	6	205	2
Results of Travel Time Calculation	7	206	2
73 Sections in Northern Network	8-87 197-199	207-276 396-398	146
57 Sections in Central Network	88-134	277-333	114
62 Sections in Southern Network	135-196	334-395	124
Terminating Web Page (Dummy)	399		1
Total Numbers of States	201	199	400

The CTMCs parameters, transition probability (TP_{ij}), departure rate (ν_i) and transition rate (q_{ij}), can be estimated to obtain a 400×400 rate matrix ($\Re$) that is consisted of elements r_{ij}. Table 5 shows these estimated parameters departing from state 1. By substituting the state prob-

Table 4　Example Results of Testing Think Time Distribution (States 1, 4, 5 and 6)

State	Number of Transitions	Mean (sec)	Standard Deviation (sec)	Goodness-of-Fit Test for Exponential Distribution	
				χ^2 Test	K-S Test
				p-value	*p*-value
1 (Homepage)	1,315	28.82	50.44	> 0.005	> 0.05
4 (Northern Network)	522	37.59	55.15	> 0.005	> 0.05
5 (Central Network)	329	32.37	45.47	> 0.005	> 0.05
6 (Southern Network)	304	35.43	43.43	> 0.005	> 0.05

ability obtained from Equation (5) into Equation (9), a ETDUS with stationary state probabilities (at $t \to \infty$) can be calculated as 201.76 sec. This value falls within the 95% confidence interval of [195.64, 207.8] obtained from the 869 samples of user sessions. It is a sufficient evidence to show that the CTMCs model performs validly for web browsing behavior.

Table 5　Example Transition Rates Calculation from State 1

State	1 (Homepage)						
Next State	2 (Real-Time Traffic Information)	3 (Travel Time Calculation)	4 (Northern Network)	5 (Central Network)	6 (Southern Network)	200 (Duplicated Homepage)	399 (Terminat-ing State)
No. of Transitions	250	192	318	172	152	110	121
Transition Probability (Equation(1))	0.19	0.15	0.24	0.13	0.12	0.08	0.09
Departure rate (Equation(2))	0.035						
Transition Rate (Equation(3))	0.0067	0.0053	0.0084	0.0046	0.0042	0.028	0.0032

4.4 Menu-Item Sequence Analysis

The menu items, real-time traffic information and travel time calculation, shown on the homepage (Type I) and other web pages (Type II), are the only two items that could be examined on their sequences. In order to predict the choice behavior on serial positions of the two menu items, the MTTSPM should be modeled by clickstream data to fit a linear regression model indicated by Equation (14) for each state with transitions linked to states 2 and 3. Thus, Table 6 shows the examples of the MTTSPM for states 1, 4, 5 and 6, in which $pos = 1, 2$ represent the serial position of two items on real-time traffic information and travel time calculation respectively on state 1; $pos = 2, 3$ represent the serial position of these two on states 4, 5 and 6 respectively. By using MTTSPM, the mean think time of requesting states 2 and 3 on each state can be measured as menu-item sequence analyses while the position of these two items are exchanged. For example in homepage, the new mean think time for requesting states 2 and 3 ($mthk_{12}'$ and $mthk_{13}'$) can be recalculated by the linear regression model with $MTTSPM_1^2$ and $MTTSPM_1^1$ respectively. The new departure rate can thus be obtained by substituting $mthk_{12}'$ and $mthk_{13}'$ into Equation (2); the transition rate will also be recalculated by Equation (3). Similarly, the position sequence changes on other states will lead to the recalculation of transition rates. These recalculated transition rates will form a new rate matrix by Equation (4); the state probability at any time t can then be obtained from Equation (5). Therefore, the ETDUS resulting from the positions exchange of the two items is 202.11 sec, approximately the same as 201.76 sec in the original sequence.

Table 6　The MTTSPM of Requesting states 2 and 3 for States 1, 4, 5 and 6

	$MTTSPM_1^{pos}$ (Homepage)	$MTTSPM_4^{pos}$ (Northern Network)	$MTTSPM_5^{pos}$ (Central Network)	$MTTSPM_6^{pos}$ (Southern Network)
Intercept (β_0)	22.86	39.08	18.44	14.26
Coefficient of pos (β_1)	3.47	1.38	5.65	9.69
R^2	0.6933	0.6037	0.5832	0.5794

4.5 Analysis on Varied PTTI Demands

Basically, the graphical traffic flow information shown on the web homepage, Northern Network, Central Network, Southern Network and their related sections are considered as travelers' primary PTTI demands. Other traffic information including event, roadwork, travel time calculation and its results are regarded as secondary ones. Therefore, it can be reasonably assumed that travelers' primary PTTI demands are fixed, but the secondary ones may vary by their trip purposes. Thus, travelers would have different demands on secondary PTTI between weekdays and holidays, a scenario on varied demands of secondary PTTI is to be analyzed in this study.

A further assumption that the varied demands of secondary PTTI would only occur at homepage is proposed for the focus analysis mainly because most transitions to the web pages of secondary PTTI (states 2 or 3) are from homepage (state 1). The two secondary PTTI demands departing from state 1 can be roughly estimated by the transition probabilities TP_{12} and TP_{13} as indicated in Table 5. By varying the two transition probabilities TP_{12} and TP_{13} under their fixed sum of probabilities of 0.34, the varied PTTI demands resulting from adjusting TP_{12} and TP_{13} are both substituted into Equation (3) to obtain the corresponding rate matrices and state probabilities through Equation (4) and (5), respectively. In case of the exchange of sequence being considered, the parameters adjustments as indicated above would be added to this model.

To cope with the uncertain PTTI demands, the sensitivity of ETDUS on adjusting transition probabilities TP_{12} and TP_{13} resulting from varied PTTI demands is measured as shown in Figure 8. There are two critical conditions ($TP_{13} = 0.05$ and 0.3) to be considered as the minimum and maximum demands of TP_{13}. Counteractively, the transition probabilities of 0.29 and 0.04 are the maximum and minimum demands for TP_{12} respectively. Obviously, a positively linear relationship between ETDUS and varied PTTI demands TP_{13} can be found for a specific sequence. It can also be stated that the original sequence is no longer better than the exchanged one beyond a certain point with continuously increasing TP_{13}; that is, the appropriate sequence will heavily depend on the variation of PTTI demands. Next, the minimax regret criterion is utilized for making sequence decisions under the uncertainty of PTTI demands to minimize the opportunity loss. A regret matrix is thus shown in Table 7, in which the regret value for alternatives under per PTTI demand is calculated by subtracting the minimum from the ETDUS to represent for the regret resulting from choosing the minimum ETDUS. For example, considering the transition probability of $TP_{12} = 0.29$ and $TP_{13} = 0.05$, the minimum ETDUS (189.82 sec) should be chosen to calculate the regret value; that is, the values for original and exchanged sequenced are calculated as 189.82-189.82 = 0 and 192.54 − 189.82 = 2.72 respectively. By this way, the maximum regret can then be determined for each alternative and the minimum of maximum regret (2.72 sec) shows that the exchanged menu-item presentation sequence is better than the original one. Besides, Table 8 shows the measurements of performance for exchanged sequence under varied PTTI demands. It can be seen that the expected time spent in state 1 always stays in high values with the varied PTTI demands. Obviously, the homepage is the most important web page in usability design.

Table 7 The Regret Matrix and Maximum Regret for Two Sequences

	Variation of PTTI Demands						Maximum Regret (sec)
TP_{12}	0.29	0.24	0.19	0.14	0.09	0.04	
TP_{13}	0.05	0.1	0.15	0.2	0.25	0.3	
ETDUS of Original Sequence (sec)	0	0	0	0.84	2.06	**3.3**	3.3
ETDUS of Exchange Sequence (sec)	**2.72**	1.54	0.35	0	0	0	2.72

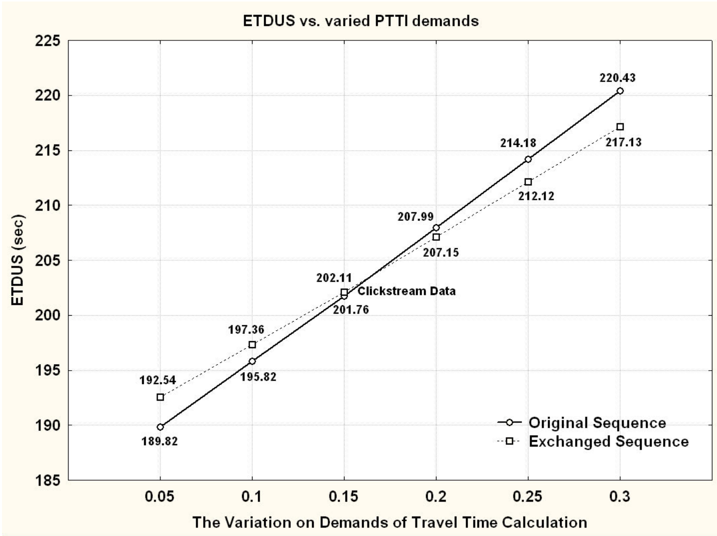


Figure 8　ETDUS versus Varied PTTI Demands Diagram under Original and Exchanged Sequence

Table 8　Measurements of Performance for Exchanged Sequence under Varied PTTI Demands

Exchanged Sequence	Variation of PTTI Demands					
TP_{12}	0.29	0.24	0.19	0.14	0.09	0.04
TP_{13}	0.05	0.1	0.15	0.2	0.25	0.3
Expected Number of Departures from State 1	1.49	1.5	1.51	1.53	1.54	1.55
Expected Number of Transitions from 1 to 2	0.43	0.36	0.29	0.21	0.14	0.06
Expected Number of Transitions from 1 to 3	0.07	0.14	0.22	0.3	0.38	0.46
Expected Number of Visitors into State 1	1.49	1.5	1.51	1.53	1.54	1.55
Expected Time Spent in State 1 (sec)	43.75	43.82	43.88	43.95	44.02	44.08
Expected Time Spent in State 2 (sec)	44.25	38.26	32.22	26.11	19.95	13.72
Expected Time Spent in State 3 (sec)	14.89	20.5	26.17	31.88	37.66	43.5

V. CONCLUSIONS AND RECOMMENDATIONS

From the analysis process and results in the empirical study, it can be concluded that the development of an analysis model with CTMCs provides a sensible and systematic way to examine the usability of menu-item presentation sequences in web-based ATIS. Although it might be difficult to make decisions for the choice of menu-item sequences under uncertain PTTI demands, a minimax regret criterion is also proposed to determine the best sequence alternative in terms of ETDUS. These results can contribute to web designers for reviewing and modifying the menu-item serial positions shown on web pages.

Unlike the past studies on menu-item presentation sequence concerning the micro-level performance for single interface [9-13], this study has proposed a macro-level measurement of performance [47] characterized by the time duration that a user completes a web browsing task through multiple web page interfaces to seek for his/her needed PTTI. In this model, it is found that the higher usage frequency (PTTI demands) is suitable for the priority sequence. This result is consistent with that of Mitchell (1989) [27], but designing a common sequence under varied usage frequency occurred in PTTI demands is still questionable. Furthermore, the proposed model can predict the usability of sequence alternatives on web pages to avoid time-consuming, costing and iterative process in traditional usability analysis, a first attempt on this issue.

In summary, this study has offered an effective method to analyze the usability on menu-item presentation sequence. It will also pave the way to explore the impact of communications demand for web-based ATIS on its performance. The proposed model could easily be employed to analyze the design of web renewal options with and without cache or pre-sending mechanism. It is also recommended that future research should consider more comprehensive users' requests information obtained from ATIS web server with cookie program in order to analyze the website usability more precisely.

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