Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5, pp. 1557 - 1571, 2005

A STUDY ON INFORMATION ARCHITECTURE FOR THE FREEWAY/EXPRESSWAY REAL-TIME TRAFFIC INFORMATION WEBSITE IN TAIWAN

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Abstract: The paper presents some research findings from conducting an analysis on the information architecture of Freeway/Expressway real-time traffic information website, which established by Taiwan Area National Freeway Bureau (TANFB), Ministry of Transportation and Communications (MOTC), to provide travelers with pre-trip road and traffic information. First, a Continuous Time Markov Chains (CTMC) model with preliminary information architecture was constructed by collecting clickstream data in the web server. This model was then modified according to the change of information priority and hence the expected searching time under this new architecture was predicted by its modified model. The concept of constructing and using the Markov model is to substitute subsequent, lengthy usability testing. Ultimately, the findings of this research can highlight the directions for constructing similar travelers browsing model with results being used as inputs for communications network simulation on the web/Internet-based multimodal traveler information systems in Taiwan.

Key Words: Real-Time Traffic Information Website, Information Architecture, Continuous Time Markov Chains (CTMC)

1. INTRODUCTION

Taiwan-Area National Freeway and Highway Bureaus have been proactively constructing portions of 12 east-west expressways to connect two north-south freeways with West Coastal Highway, and with another 4 east-west freeways to form a complete freeway/expressway system in the country. This system has become vital to the so-called life circles of urban and rural areas, especially along the west coast of the island. The realization of some advanced traveler information systems (ATIS) services, founded on the existing traffic management system, is the first step toward developing a more comprehensive intelligent transportation systems (ITS) in Taiwan.

With the ultimate goal of a more comprehensive ATIS, the Freeway/Expressway real-time traffic information website has been established by Taiwan-Area National Freeway Bureau (TANFB), Ministry of Transportation and Communications (MOTC), to provide travelers with pre-trip road and traffic information, which can help travelers to plan their routes and avoid on-road congestions simultaneously. The homepage of this website is shown in Figure 1. Like other websites, its operation relies on client-server mechanisms under World Wide Web (WWW). Travelers, thus called website visitors, search for their needed traffic information by clicking serial hyperlinks from one web page to another, in which each hyperlink means a potential request from a client to the web server. After the web server receives the request message, the related contents are submitted to the client in the form of Hypertext Markup Language (HTML). They are then translated into web pages by client's browser software.

From the viewpoint of this type of ATIS operations, the number of browsing visitors will directly or indirectly affect the performance of traffic management strategy; however, the usage frequency of the website will in part depend on the friendliness of its web pages structure. Therefore, designing an excellent website with friendly interface to make travelers search traffic information more quickly and thus increase their use should be an important task for web page designers.

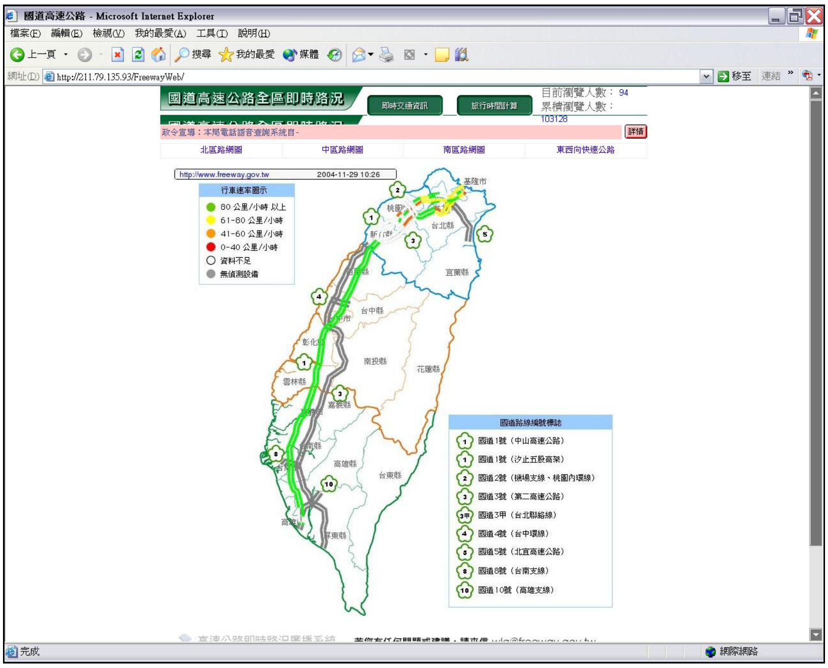

Figure 1. The Homepage of Taiwan's Freeway/Expressway Real-Time Traffic Information Website

The following second section will introduce some background issues in website design; the third section then explores some application studies on web page browsing prediction using Markov Chains. The fourth section will define the problem of interest, construct travelers' browsing performance Markov model, and conduct sensitivity analyses on the information priority changes. Finally, conclusions are summarized along with suggestions for future research.

2. ISSUES ON WEBSITE DESIGN

Many literatures explore the issues with respect to the perception gap between users and designers. For instance, Nakayama *et al.* proposed a relevance analysis technique to discover the gap between website designers' expectations and users' behavior. Moreover, with the growth of web application users, web Quality of Service (QoS) has become an increasingly critical issue. Bhatti *et al.* presented experiments designed to estimate users' tolerance of QoS in the context of e-commerce; they also discussed contextual factors that influence these thresholds and show how users' conceptual models of web tasks affect their expectations. Lin *et al.* had even explored why users accept or reject a website, and how user's acceptance was affected by the features including information quality of a website, response time and system accessibility, etc. Undoubtedly, it is a fact that the usability of web pages will play an important role in the user's browsing behavior.

Earlier work on evaluating the web page usability for a website, using usability testing on user's clicking behavior, explores the existing disadvantages in these web pages. The contents or architecture of these web pages can thus be modified before uploading to the web server. Unfortunately, this method of online experiment requires a lot of time and effort, and can only provide testing and modification to web pages that are being designed. Furthermore, this process needs to be conducted repeatedly for various modifications. As a result, a preliminary concept of information architecture has been formalized to actively provide web page designers with design principles and orientation, which include information, structure, management and art, etc. Obviously, information architecture is a vital factor to the degree of web page usability, and some literatures have discussed on this topic. Broder *et al.* constructed the information architecture of web pages' hyperlinks by a graph to improve the searching effectiveness of web page algorithm. Li *et al.* analyzed the factors that impact the performance and scalability of a database-driven website; they also described several architectural design approaches for this particular type of website and presented experimental results on their performance under various conditions. Danielson *et al.* examined users' movement through hierarchically structured websites with sitemap and their behavioral effects.

The hierarchical web page design is often adopted in a website, in which the next hyperlink options are laid out from left to right, or top to bottom, to coincide with the habit of the general public. The web pages in such information architecture are linked by these designed hyperlinks. For websites with the function of information disseminating, such as a traffic information website, the information options on each web page will be the proper hyperlink options. Obviously, the ranking of information options should be an essential element of an information architecture, which affects travelers' searching speed and their usage, a major focus of the research.

As mentioned previously, a usability testing could be used to review the travelers' searching speed when influenced by the change of information options ranking; but it is a resource consuming process in each change. To overcome this, the research initially has proposed a Continuous Time Markov Chains (CTMC) model on travelers' browsing performance for the TANFB Freeway/Expressway traffic information website. Through adjustment on information priority and parameters simultaneously, this model was then used to predict the system's performance in terms of travelers' searching time. Thus, the time and effort can be greatly reduced regardless of how many alternative information priorities are.

3. RELATED WORK

Markov process model is a kind of stochastic process, which implies that the next state probability will only depend on the current state. For discrete state systems, there are two common styles: Discrete Time Markov Chains (DTMC) and Continuous Time Markov Chains (CTMC). Markov Chains has also been broadly applied to many academic fields. Travelers' information searching processes could be dealt with in serial hyperlinks from one to another, in which the time between two clicks is the so-called "think time", by ignoring transmission time via Internet. It is a vital parameter in analyzing website design problems in terms of searching time for such an information dissemination oriented website.

Recently, the majority of the researches on applying Markov Chains to web page applications focus on the issue of pre-sending mechanism, which sends the documents beforehand prior to the users' click on them. This will improve the users' browsing performance, reduce the transmission waiting time, and thus increase usage preference. Zukerman *et al.* had described several Markov models derived from the behavior patterns of many users, which predict the documents a user is likely to request next. They concluded the hybrid models generally have a greater predictive accuracy than the individual models, to be incorporated in a system for pre-sending WWW documents. In that research, the concept of discrete time was used to construct these models; but in fact, the continuous think time was more appropriate under our consideration of searching time. On the other hand, Sarukkai made an evaluation and suggestion on hyperlinks prediction and path analysis using Markov Chains, in which a Probabilistic Link Predictor, based on Markov Chains, is used as a framework for simulation analysis. There were four application layers to be proposed: Web Server HTTP Request Prediction, Adaptive Web Navigation, Tour Generation, and Personalized Hub/Authority.

Commonly accepted in the literatures, when using Markov Chains to predict users' browsing path, each web page is regarded as one state, and a serial hyperlink is a transition from one state to another. The same concept is adopted in the research modeling here to explore users' searching performance. Unlike the previous related works, we also focus on think time per page and its average searching time, thus the CTMC will be more appropriate for our analysis.

4. MODEL CONSTRUCTION

4.1 Information Architecture of Current Website

The information architecture structured by hyperlink options in the Taiwan's Freeway/Expressway real-time traffic information website shown in Figure 1 can be represented as in Figure 2, in which there are three major layers.

In this figure, there are five options laid on the homepage, in which Real-Time Traffic Information and Travel Time Calculation stand side by side in the first row of this page; the second row places four options: Northern Network, Central Network, Southern Network, and East-West Expressways. (The first three options in this row can also be accessed through direct clicks on the corresponding portion of the map below in Figure 1.) These six options are in Layer 2 of the information architecture. The four options of the second row have Layer 3 web pages; for instance, while in the Northern Network map page shown in Figure 3, one can click any of 75 sections on the map, and the surveillance camera and its information can be found as a web page on Layer 3. On the other hand, the Real-Time Traffic Information page that provides the travelers with real-time speed and incident information for individual sections has all the information in only one page. With respect to Travel Time Calculation, users retrieve the information on a particular Origin-Destination (O-D) by selecting a road, with a pair of origin and destination interchanges, respectively. In a while, a response web page will return the travel time result. These web pages are mainly written by JAVA, Active Server Pages (ASP) and FLASH jointly, and the database system is Oracle.

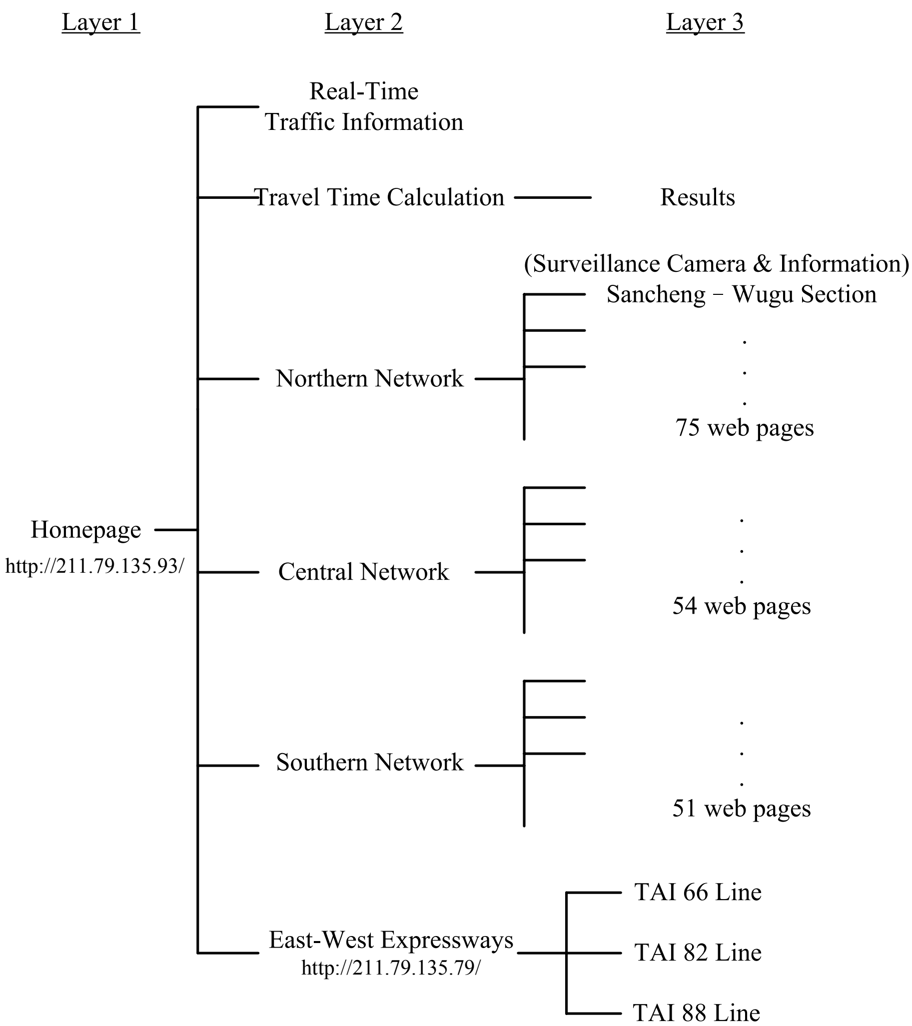

Figure 2. The Information Architecture for Taiwan's Freeway/Expressway Real-Time Traffic Information Website

Figure 3. The Northern Network Web Page (Layer2)

4.2 Problem Definition & Restrictions

For the information architecture of Taiwan's Freeway/Expressway real-time traffic information website under current use, the visitors' browsing performance model has been constructed, and used to analyze the effect of browsing performance in case of information priority changes. Here the browsing performance concentrates on the visitors' clicking process from homepage to the terminal web pages that they would like to search for; therefore, defining the terminal web pages is in place.

After visitors enter the homepage, they will choose one of the Layer 2 options during think time; then the Layer 3 web pages will appear, except the option for Real-Time Traffic Information. Most visitors can reach their goals (terminal web pages) on this Layer 3. The results of Travel Time Calculation depend heavily on the calculation in Oracle database, which provides visitors with custom-oriented travel time information. It is difficult to single out think time from the calculation time due to technique restrictions. Consequently, the Travel Time Calculation web page in Layer 2 will be regarded as a terminal one.

With regard to the information on West-East Expressways, accessible from another website at http://211.79.135.79, it still only provides travelers with limited information on the twelve expressways due to insufficient advanced equipments. Currently, only three expressways TAI 66, 82, & 88 Lines are linked. The information scarcity will lead to low clicks on this web page by visitors. Therefore, the path to East-West Expressways pages has been ignored.

4.3 Web Pages Browsing Performance Model (CTMC model)

A traveler's browsing behavior can be regarded as serial hyperlink clicks from homepage to terminal web pages; however, for the purpose of Continuous Time Markov Chains (CTMC) model construction, some assumptions have been made as follows:

- Each web page is regarded as a state in CTMC model, the behavior of travelers' serial hyperlink clicks are regarded as state transitions in CTMC model.
- The sojourn time at one web page, i.e. the intervals between starting time of the current web page and the next one, should be a random variable with exponential distribution.
- The next web page (state) probability depends only on the current one, independent of the past ones.

The proposed CTMC's state transition diagram of this research is shown in Figure 4; the shaded states are the terminal states, totaled to 182 states. The mathematics formula can be represented as the following conditional probabilities

$$P[X(t+\Delta) = j \mid X(t) = i] = q_{ij}\Delta \tag{1}$$

$$P[X(t+\Delta) = i \mid X(t) = i] = 1 - \sum_{j \neq i} q_{ij}\Delta \tag{2}$$

where

Δ	:	an infinitesimal time step size
$X(t)$	:	the web page of the browsing process at time t
q_{ij}	:	transition rate from web page i to j, as indicated on the arc in Figure 4.
i	:	number of web pages, from 1 to 186

j : number of web pages, from 1 to 186

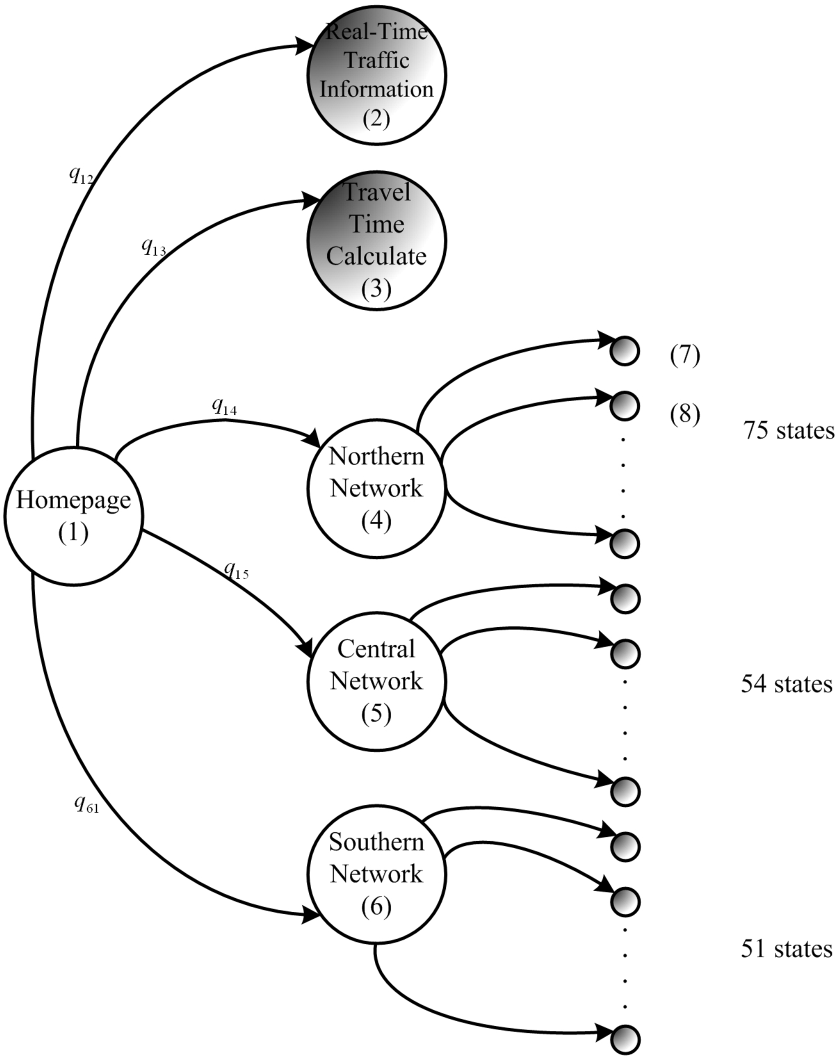

Figure 4. The State Transition Diagram of the Preliminary Model

To obtain the transition rate, we define the departure rate of web page *i*, which is a parameter for an exponential random variable as

$$\nu_i = \sum_{j \neq i} q_{ij} \tag{3}$$

where

ν_i : the departure rate of web page *i*

When the browsing process is at web page *i*, the time until a transition being made is an exponential (ν_i) random variable. Given the event D_i that the browsing process departs web page *i* in the time interval $(t, t+\Delta]$, the conditional probability of the event D_{ij} that the browsing process will go to web page *j* is

$$P[D_{ij} \mid D_i] = \frac{P[D_{ij}]}{P[D_i]} = \frac{q_{ij}\Delta}{\nu_i \Delta} = \frac{q_{ij}}{\nu_i} = P_{ij} \tag{4}$$

where

D_i : the event of staying at web page *i*

D_{ij} : the event of departing from web page *i* to *j*

P_{ij} : a conditional probability that transits from D_i to D_j

If we ignore the time spent in each web page, the transition probabilities P_{ij} can be viewed as the transition probabilities of a Discrete Time Markov Chains (DTMC). Combine these two equations (3) and (4), we can obtain the transition rate

$$q_{ij} = P_{ij} \times v_i \tag{5}$$

For subsequent calculations of probabilities, it will be useful to define a rate matrix $\Re$ with *i*, *j*th entry

$$r_{ij} = \begin{cases} q_{ij} & i \neq j \\ -v_i & i = j \end{cases} \tag{6}$$

Furthermore, the probabilities of the next web page $p_j(t)$ can be obtained according to the probabilities of the current web page $p_i(t)$, for the preliminary model, formulated by differential equations

$$\frac{dp_j(t)}{dt} = \sum_i r_{ij} p_i(t), \qquad j = 1, 2, ..., 186 \tag{7}$$

where

P_i : the probability of the current web page

P_j : the probability of the next web page

Thus, some performance index, such as mean browsing time, can be calculated using $p_j(t)$ obtained from equation (7).

5. ANALYSIS EXAMPLES

5.1 Clickstream Data Collections

This study uses the clickstream data, ***localhost.access.log*** file, collected by the web server software Tomcat within the TANFB real-time traffic information web server, which provides the following information:

- the visitors' IP addresses
- the time when the visitor sends his/her request to the server
- the serial web page files being clicked, thus the path used by each visitor

IP addresses can be used to track where the visitor is located. For a single visitor, the time between two requests can be regarded as think time, plus some negligible transmission time, and the path refers to state transitions in the model.

One entire week's clickstream data made by 6084 records were collected from October 5th to 11th, 2004. Unfortunately, some of the data are not very useful for model construction. For instance, several visitors paused on some web pages for unreasonably long period of time, without visiting any terminal pages, and thus ignored for the analysis. To simplify our model, the Homepage is regarded as the initial state. Many visitors accessed the website through "Favorite" to Layer 2 or Layer 3 pages directly, without going through the Homepage, were also eliminated. In order to have a more homogeneous group of website-familiar or frequent visitors, a person could be considered as first-time visitor if he/she spent time at the homepage for too long (50 sec) or repetitively requested same type of information, and thus treated as outliers and excluded from further analyses. The resulting sample size consists of 1622 data. Through goodness-of-fit testing, we can see that the think times, or sojourn times at one state, fit the exponential distribution significantly well, as summarized in Table 1.

Table 1. The Results of Testing Sojourn Time Distribution by Departure States

Departure State (i)	Sample Size	Mean (sec)	Std. Dev. (sec)	Exponential Distribution Goodness-of-Fit Test	
				χ^2 Test	K-S Test
				p-value	p-value
Homepage (1)	**1622**	16.2	11.2	<0.005	<0.01
Northern Network (4)	800	27.5	25	<0.005	<0.01
Central Network (5)	167	27.9	20.9	0.285	<0.06
Southern Network (6)	174	30.7	24	<0.005	<0.01

5.2 Model Construction under Existing Information Architecture

Then we calculated each transition rate in the model by using equation (5); for instance, the transition rate departing from the homepage is shown in Table 2. We then constructed browsing performance model using software Relex 7.7 Markov Chain Module, in which states and transition rates were assigned, as those shown in Figure 4. Furthermore, we calculated the Mean Time to Terminal Web Pages (MTTWP), defined as follows

$$MTTWP = \int_0^\infty R(t)dt \tag{8}$$

where

$$R(t) = \sum_i P_i(t) \qquad i = 2, 3, 7, 8, ..., 186$$

$P_i(t)$: individual probability of non-terminal web pages

MTTWP refers to the visitors' mean browsing time from the homepage to terminal pages. The result calculated by Relex 7.7 Markov Chain Module shows that the MTTWP is 35.96 seconds, comparable with the mean browsing time of 36.03 seconds from the 1622 sample data. It is obvious that this CTMC model performs validly.

5.3 Sensitivity Analysis of Information Architecture on Information Priority Changes

Exploring the effect of information priority changes on the browsing performance is the focus of this study. As mentioned in section 4.1, the information architecture of the homepage can be regarded as two sets: one has States 2 and 3, and the other has States 4, 5 and 6 (even through direct clicking on the map), with different features of options in the two sets. We can reasonably assume that the browsing performance in one set is independent of the other. Thus, two scenarios are designed to conduct the sensitivity analysis of information priority and probability changes. If one uses map hyperlink as information array to reach the next layer, there exist no information priority problems at all.

Table 2. Example Transition Rates Calculation in the Model (Departure from Homepage)

Departure State (*i*)	Homepage (1)				
Arrival State (*j*)	Real-Time Traffic Info. (2)	Travel Time Calculation (3)	Northern Network (4)	Central Network (5)	Southern Network (6)
Average Think time (ATT_{ij})	18.53	20.26	13.59	18.41	18.18
Sample Size (n_{ij})	310	171	800	167	174
Probability (P_{ij})	0.1911	0.1054	0.4932	0.1030	0.1073
Departure Rate (γ_i)	0.0616				
Transition Rate (q_{ij})	0.01178	0.00650	0.03040	0.00635	0.00661

5.3.1 Scenario I: Information Priority Change in Set 1

When the order of information options changes, it will influence the transition rate in the model. Assuming the average think time and information priority on each path is positively related, the further to the left of the information options in a row, the shorter the average think time, and vice versa. The second row shows some deviation due to relatively small sample size for Central and Southern Networks. For example, if we exchange State 2 with State 3, the average think times for State 2 and State3, respectively, are

$$ATT_{12}' = ATT_{13} \tag{9}$$

$$ATT_{13}' = ATT_{12} \tag{10}$$

Through the recalculation of total browsing time, probability and departure rate on each path, the revised transition rates of Scenario I were obtained, as shown in Table 3.

It can be seen from Table 3 that the average think times of State 2 and State 3 of 18.53 sec and 20.26 sec for Real-Time Traffic Time Information and Travel Time Calculation respectively, after entering the homepage. In addition, both State 2 and State 3 are terminal states, thus the transition rates were obtained, as if they were exchanged with each other. Accordingly, the MTTWP is 36.12 sec, a little larger than 35.96 sec obtained before exchange.
This can be attributed to the fact that the larger sampler size comes after the smaller one, hence associated with longer think time.

Here we further explore the effects of information probability changes between options. Following the Scenario I above, suppose the demand from homepage to Travel Time Calculation doubles to 0.2108, other probabilities will be proportionally decreased to 0.1648, 0.4669, 0.0767 and 0.081 respectively. Thus the calculated MTTWP is fairly close to the original one without exchanging options of 33.72 sec.

Table 3. Example Transition Rates Calculation in **Scenario I** (Departure from Homepage)

Departure State (i)	Homepage (1)				
Arrival State (j)	**Travel Time Calculation** (2)	**Real-Time Traffic Info.** (3)	Northern Network (4)	Central Network (5)	Southern Network (6)
Average Think time (ATT_{ij}')	18.53	20.26	13.59	18.41	18.18
Sample Size (n_{ij})	**171**	**310**	800	167	174
Probability (P_{ij})	**0.1054**	**0.1911**	0.4932	0.1030	0.1073
Departure Rate (γ_i)	**0.0610**				
Transition Rate (q_{ij})	**0.00643**	**0.0117**	**0.03**	**0.00628**	**0.00655**

5.3.2 Scenario II: Information Priority Change between Two Rows

Basically, the information in the two rows, thus called Set 1 and Set 2 here on, has different characteristics. This Scenario II was designed to explore the browsing performance with changes between these two rows. The initial model doesn't serve the purpose, therefore it has to be decomposed; Set 1 and Set 2 have their own CTMC models, called S1 and S2, respectively. Their calculated MTTWPs are used as the parameters for this new model, as shown in Figure 5. This new model consists of only State 1, S1, and S2. The transition rates from respective homepages for S1 and S2 are summarized in Table 4. The respective MTTWPs of 19.16 sec and 43.08 sec obtained for S1 and S2 can thus be treated as their respective average think times in the new model. Through the same calculation, the transition rates and the corresponding MTTWP of 36.02 sec were obtained, as shown in Table 5. This new, simplified model is validly equivalent to the original model of the same 1622 sample size.

Through simplifications, the original complicated CTMC model has been transformed into a new CTMC model with only three states and two transition rates. Furthermore, States S1 and S2 inherently imply the browsing performance in Set 1 or Set 2. An exchange between Set 1 and Set 2 goes beyond the capability of the original model of only being able to exchange options within a set. The average think times from Homepage to their respective Layer 2 within each set are quite different and only Set 2 has transitions from Layer 2 to Layer 3. Therefore, exchanging these two rows can only induce think time difference from Homepage to Layer 2, which is estimated to be about 4 sec. Following the same analysis method in Scenario I with the average think time plus or minus of this 4 sec, the transition rates and MTTWP with an exchange between two rows are shown in Table 6. The average browsing time of 34.36 sec thus obtained shows some slight improvement, with Set 2 for providing real-time traffic information in individual networks being put in the top row. This reduction in MTTWP can be attributed to the fact that entering Layer 2 through individual networks consumes less time than the other two original top-row options.

Table 4. Example Transition Rates Calculation from Layer 1 to Layer 2 in the Decomposed Model (Departure from Homepages)

	S1		S2		
Departure State (i)	Homepage (H1)		Homepage (H2)		
Arrival State (j)	Real-Time Traffic Info. (2)	Travel Time Calculation (3)	Northern Network (4)	Central Network (5)	Southern Network (6)
Average Think time (ATT_{ij})	18.53	20.26	13.59	18.41	18.18
Sample Size (n_{ij})	310	171	800	167	174
Probability (P_{ij})	0.64	0.36	0.7	0.1464	0.152
Departure Rate (γ_i)	0.522		0.0667		
Transition Rate (q_{ij})	0.0334	0.0188	0.04669	0.00976	0.01013

Table 5. Transition Rates Calculation and MTTWP in the New Simplified Model

Departure State (i)	Homepage (1)	
Arrival State	Row 1 Set S1 (2)	Row 2 Set S2 (3)
Average Think time	19.16	43.08
Sample Size	481	1141
Probability	0.297	0.703
Departure Rate	0.0278	
Transition Rate	0.0083	0.0195
MTTWP	36.02 sec	

Table 6. Transition Rates Calculation and MTTWP with Exchange between Two Rows in the New Simplified Model

Departure State (i)	Homepage (1)	
Arrival State	**Original Row 2 Set S2 (2)**	**Original Row 1 Set S1 (3)**
Average Think time	**39.08**	**23.16**
Sample Size	1141	481
Probability	0.703	0.297
Departure Rate	0.0291	
Transition Rate	0.0205	0.0086
MTTWP	34.36 sec	

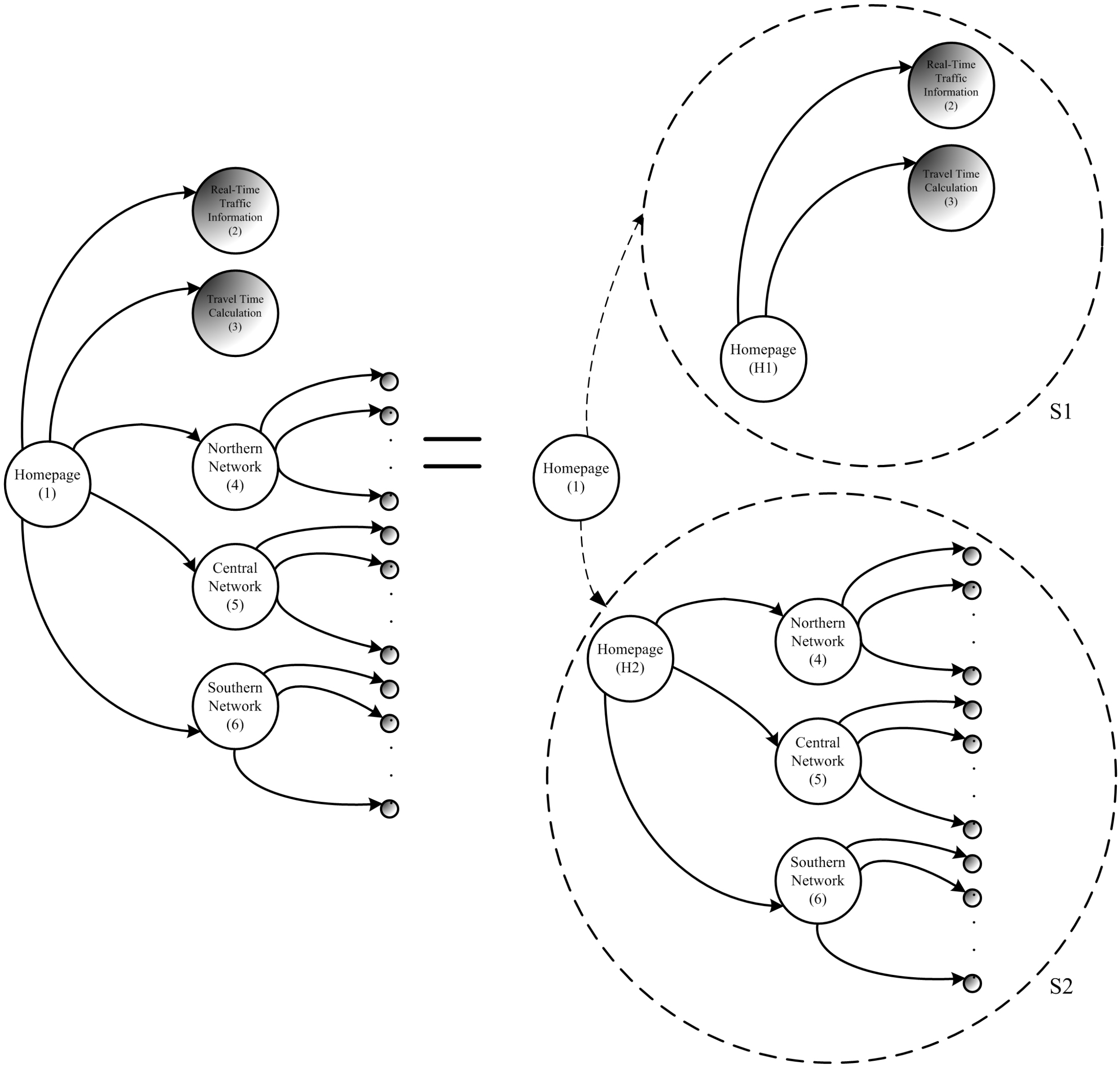

Figure 5. Decomposed Model Diagram

6. CONCLUSIONS & RECOMMENDATIONS

The research has analyzed the travelers' browsing performance for the TANFB Freeway/Expressway real-time traffic information website, and built a model using Continuous Time Markov Chains (CTMC). First, a Markov model with preliminary information architecture has been constructed using data available from the web serve. Then, after validation, this model has been modified in accordance with the exchange of option orders in the information architecture and the probability changes in options. The Mean Time to Terminal Web Pages (MTTWPs) of these two scenarios have also been predicted by their modified models as well, and it shows that the current information architecture can be improved by different information priority arrangement.

Furthermore, it can be concluded that the model constructed using CTMC, as proposed in this study, can resemble the real situation more closely than DTMC in theory. The research findings do suggest some general guidelines for webpage designers. The improvement in website browsing performance by exchanging rows has been predicted by this CTMC model, however, it needs to be validated by usability testing, including additional information such as weather conditions. The important area of future research should also concentrate on the browsing behavior of a person, e.g., how many information needed per visit, not just performance related to individual information obtained. The CTMC model thus constructed will define any state as terminal state and include some backward (upward) transitions, plus some paths of accessing the website through "Favorite" feature to any layers as well as paths of leaving any layers. This will pave the way to explore the web/Internet-based real-time travel information demand for travelers using the service, and thus to be used as input for communications network simulation.

ACKNOWLEDGEMENTS

This paper is part of achievements made possible by the grant provided by National Science Council (Project No. NSC 93-2211-E-006-049-), executed in 2004, Taiwan, the Republic of China. We are indebted to NSC for this study.

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