AN APPROACH OF COLLABORATIVE COMMUNICATION WITH ETC TRAFFIC SIMULATION

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Abstract: The research of this paper is based on a simulation-based approach to the traffic problems at Electronic Toll Collection System (ETC) toll plazas of expressways in Japan. A process simulation-based approach using a general simulator is used in this research to offer some solutions for ETC traffic expressway problems. To do so, brief or detailed discussions are quite often required in a timely manner. However, it is not always possible to have those meetings in a timely manner because of the time and/or location constraints of the participating members. As a solution to this meeting issue, this paper proposes an approach of the collaborative communication based on the IP video conference system with a video streaming function, which is designed to support the remote audio/video communication along with the simulation-based video streaming, which can be shared among the participating members over the network. First, the paper describes the overview of the ETC traffic simulation, followed by the simulation model for the traffic analysis at ETC toll plazas as well as some basic background information of the research. Then, the paper shows the basic mechanism of IP video conference with the video streaming function, and discusses the validity of our approach using some experimental results.

Keywords: collaborative communication, ETC traffic simulation, audio/video conference system, simulator

1. INTRODUCTION

The problems of traffic congestions or traffic jams are the big issues not only in the general roads but also in the expressways in Japan. Considering the high toll charges of the expressways, the smooth traffic is strongly required from the users but heavy traffic occurs quite often. According to the survey conducted by the Japan Highway Public Corporation (JH), one of the major reasons for this congestion is caused by the congested toll plazas with toll booths. Under these circumstances, the Electronic Toll Collection (ETC) system was introduced as the core function of the intelligent transportation system (ITS), of which goal is to establish an intelligent transportation system for the next generation. The ETC system is expected to provide an effective solution to these traffic problems at the expressway toll plazas. However, the function of the ETC system does not work appropriately in the high traffic volume situation, which often occurs at the toll plazas of the Japanese expressways. The problems need to be studied in various respects including theoretical and practical points of view at various actual sites.

The author's research group has been studying the traffic congestion problems at the ETC toll plazas based on the simulation-based traffic model approach, and reported the feasibility of this approach based on the case studies. The study is still on-going and requires more case studies, about which the project members will discuss to find a better solution to the problems. To do so, the participating members of the project are scheduled to get together and have discussions. However, some of the members are located at a long distance and it is not always easy to get together in one place in a timely manner. Therefore, this research project uses a network-based collaboration approach using the IP-based video conference system.

The IP-based communication tool, such as the audio/video conference systems, is becoming popular these days (Kiyan, 2003; Johanson, 2002; Ponnekanti, 2003). These systems can be used quite effectively in our projects. Actually, this project uses the IP-based audio/video conference system called CELAVIS (Collaborative Engineering LAboratory VIdeo conference System), of which details will be described in the later section. However, it is not always easy to share the updated information of the simulation results, or in other words, to interactively update the information of simulation results during meetings over the network. The file sharing over the network could work quite effectively in the restricted conditions. However, the file sharing is not always available for security purposes. Some meetings are held with non-project members, with whom the files are not allowed to share. In these situations, only the some portion of the final simulation may be required. Under these circumstances, a video-on-demand function provides a solution. Therefore, in addition to conventional network-based communication function with audio/video communication, we have developed the video-on-demand-based (VOD-based) simulation function, in which we could review the simulation results during the meetings.

This paper first addresses the problems of the traffic jams at the ETC toll plazas in the expressways of Japan and clarifies the background of this research. Then the paper describes the overview of the approach using a simulation-based model, which was built by a general simulator called ARENA. Describing the basic modules of the collaboration system named CELAVIS, the paper shows the overview of the system using the video-on-demand simulation, and discusses the feasibility of this approach.

2. Research overview: ETC traffic simulations

The ETC system, which is the critical part of ITS in the Japanese highway systems, is strongly expected to reduce the congestions at the toll plazas in the expressways. If it works as an effective countermeasure to expressway congestions, as a result, it should dramatically reduce the traffic problems and enable the smooth traffic in the expressways. In practice, however, it is not working in such a way so far for various reasons. This section clarifies the actual problems which cause the traffic problems at the toll plazas, and shows the research approach based on the process simulation model, which is the basis of this research. The results of simulations are supposed to be shared in the audio/video conferences in this project.

2.1 The ETC solution and its problem

According to the surveys conducted by JH, the traffic jams in the expressways occur for several reasons, including toll gates, slopes, junctions, tunnels, constructions, narrowing of lanes, etc. The typical toll collection procedure at the toll gates is regarded as one of the major reasons. According to the survey of JH, 30% of expressway traffic jams occur around the toll plazas. This means that the introduction of the non-stop toll payment procedure could theoretically and effectively reduce expressway traffic jams. However, the reality is often different from what is expected.

Imagine the typical toll plaza traffic congestions occurring at an expressway toll plaza with four gates, where one of them is ETC gate and three of them are general gates. When the traffic is light, both gate systems work well and smooth traffic can be seen. However, when the traffic is heavy, all drivers will experience a negative impact from the toll gates. First, because the non-stop system is only available to the ETC drivers, the traffic can become relatively congested. Secondly, because the number of non-ETC toll booths has been reduced as the result of the introduction of the ETC gates, in this case, the non-ETC drivers experience longer delays.

As a result, the overall total travel time for both the ETC and the non-ETC vehicles at this toll plaza actually become longer due to the introduction of the ETC system. The system's success depends upon the cooperation of its users. The more the drives use the ETC system, the less the congestion would be. However, the congestion occurring at the expressway toll gates discourages drivers to start using the ETC system, which make the drives stay away from using the ETC system.

2.2 Simulation-based approach to the ETC

For the ETC systems, the basic infrastructure is required to both the expressways and the vehicles which run the expressway. As for the expressway infrastructure, at least one ETC gate has been installed in every toll gates in Japan as of 2004. As for the infrastructure on the part of vehicles, the number of vehicles with ETC units reached to 12.5% as of January 2004. However, this penetration ratio is still regarded as low, considering the estimation that at least 30% of penetration ratio should be achieved in order to take advantage of the ETC system. The issue here is to find how you urge drivers to purchase the expensive ETC unit for their vehicles when the advantage of the ETC system is not yet. Drivers are not willing to start using the ETC system when they see the congested situation at expressway toll plazas in heavy traffic. To address these questions, this project studies two kinds of solutions to the ETC traffic issue. One solution is gate management, which coordinates ETC/general switching to make the best use of the gates depending on the traffic situation. Even though this solution is employed at ETC toll plazas, the key issue here is how to find the best time for gate switching. The other solution is layout redesign, which employs an appropriate new layout design in toll plazas to reduce traffic congestion. Most of toll plazas were designed and operated before the introduction of the ETC system. The issue here is how to design/evaluate the layout to reduce the traffic and to achieve more efficient performance. Even though various kinds of layout redesign of toll plazas could be studied, the rebuilding of toll plazas is not always possible because of high construction costs. Therefore, both solutions are quite difficult execute on, that is, at toll plazas. Therefore, this project uses a simulation-based approach for these studies. Even though simulation-based approaches are often used in various applications including traffic problem solutions, this project uses the simulation-based approach in a different way. The next section covers the ideas about this approach in general and clarifies how this project uses this approach in a different way.

2.3 Comparison to other research approaches

In general, the simulation-based approaches have been applied to various application areas closely related to the transportation systems, and their feasibilities have been reported in various papers (Abbas-Turki et al., 2001; Fernandes et al., 1998; Gale et al., 2002; Krajzewicz, et al., 2002; Lucjan et al., 1999; Schwentke, 2000). For evaluating the impacts of ITS on the transportation networks covering traffic issues, which are the research areas of this paper, a number of simulation models have been developed. Several simulation models that are practically used in Japan and have been evaluated based upon the proposed verification processes. These models include NETSTREAM (Mori et al., 1998; Teramoto et al., 1997), AVENUE (Horiguchi et al., 1994 & 1995), SOUND (Yoshii, 1995; Tamamoto, 2004), tiss-NET (Kubota et al., 1995; Suzuki, 2001; tiss-NET, 2005). All of these models have been developed by the strenuous efforts to achieve the high quality of simulation and to perform the accurate simulation.

The focus of this project is not on the higher accuracy of the simulation itself just like these studies pursue, but rather, focuses on how we can use a simulation-based approach to the ETC traffic problems mentioned in the previous section. Under these circumstances, this project decided to use a general simulator for the simulation-based analysis. The simulator is called Arena, which is commonly used for various simulation applications, including manufacturing, logistics, supply-chain, business process, etc. Based on the simulation-based analysis of traffic jams at toll plazas with ETC gates (Ito, 2004a; Ito et al., 2004c), this project focuses on these two issues to consider countermeasures to fully utilize the advantages of the ETC system.

3. SIMULATION MODEL FOR ANALYSIS OVER TRAFFIC JAMS AT ETC TOLL PLAZA

3.1 Model of toll plaza

The model in this study covers the traffic congestions with vehicles, ranging from the starting point of the congestion, all the way to the toll plaza which is the bottle-neck of the traffic, and until the exit of the toll plaza. This section briefly describes the definition of simulation model to represent the traffic congestions, and some of the critical parameters used in the model. Analyzing the process of traffic congestions based on the process oriented approach, the basic six processes starting from the vehicle generation to the toll gate exit are defined as follows.

(1) Generation of vehicle entities: Vehicle entities are generated at the starting point in the simulation either as ETC or non-ETC vehicles, of which attributes such as passenger vehicle or large commercial vehicles are assigned here to be used in the simulation process.

(2) Lane selection: One of the lanes is selected from several candidate lanes. Selection ratio is assigned to each vehicle based on predefined probabilities, vehicle types, traffic condition, etc.

(3) Vehicle travel time: The travel time for each vehicle is calculated according to the travel distance from the starting point to the end of traffic jams, which is up to the traffic condition.

(4) Selection of toll gates: Availability of gates to each vehicle is first made clear. For example, ETC-only gate is only available to ETC vehicles, which means non-ETC vehicle cannot take ETC-only gate. Then, one of the gates will be selected.

(5) Toll payment: Any vehicles arriving at the booth occupy the gate, which means other vehicles need to wait in a queue. Job queue is used to represent the line of vehicles.

(6) Gate exit: After toll payment, vehicles are regarded to leave instantly without any traffic jams because the model covers until the gate exit.

3.2 Input parameters for the model

3.2.1 Generation of vehicles

Interval of generation for vehicle entities is determined based on the assumption of the number of arriving vehicles per unit time, which is arbitrarily assigned beforehand.

$$t_i = \frac{T}{N} \qquad (1)$$

ti: interval of vehicle entity generation [sec]
T: arbitrary time [sec]
N: estimated number of arriving vehicles

3.2.2 Interval time

The interval time is determined based on exponential distribution curve to randomly generate initial vehicles at the starting point. Each vehicle type is assigned based on some initial parameters, or stochastically assigned.

3.2.3 Vehicles time

Vehicles travel from the initial point to toll gate under the restriction of traffics. The travel time for this movement is defined as Scheme 2.

$$T_d = \frac{[L-(L_s+L_t)]}{V_c} + \frac{L_s}{V_s} \quad (2)$$

Td: travel time using travel distance [sec]
L: distance from starting point to toll gate [m]
Ls: distance from traffic-end to toll gate [m]
Lt: traffic jam length [m]
Vc: ave. travel speed [m/sec]
Vs: ave. speed during deceleration [m/sec]

While all of the parameters with one exception of traffic jam length are determined in Scheme 2, the remaining parameter of traffic jam length is determined by the calculation of travel time in simulation. When a vehicle reaches the end of traffic jams, the expected travel time to the toll gate is calculated.

3.2.4 Service time

Service time at toll booth is determined for ETC/non-ETC vehicles respectively. The time is either set to a fixed value or derived from distribution curve.

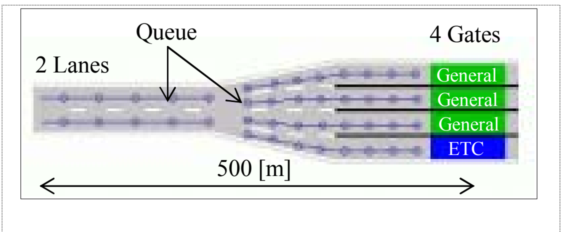

Figure 1: Example of ETC tollgate model

Table 1: Gates conditions of simulation

Case	The gate type to be used
Case-1	General gate*3 ETC gate*1
Case-2	General gate*3 Combined use gate*1

3.3 Simulation results

As for the simulation environment to implement the model presented in the sections 2.1 and 2.2, this study adopts the process simulation software called Arena 6.0 (Kelton, 1998) by Rockwell Software Co. Verification of simulation model was carried out based on some real traffic jams data, and significant results were obtained (Ito, 2005a; Ito et al. 2005b).

This section shows some of the comparative results using several conditions based on a simple simulation model as show in Figure 1. This model has four lanes, where three of them are connected to the general gates and one of them is connected to the ETC gate. The vehicles coming from the left side of the figure are moving in one of the two lanes until the lanes split into the four lanes, and change lanes to one of the four lanes based on the feature of the vehicles. Service time [sec] of ETC/non-ETC vehicles at the gate is determined by a triangular distribution of (14,16,18) and (3,4,5), respectively, for 1 hour simulation each. This comparison is based on the two kinds of scenario as show in Table 1. In Case-1, the ETC gate is open only for the ETC vehicles, whereas the ETC gate is open to both the ETC and non-ETC vehicles in Case-2, which is called the combined use gate as show in Table 1.

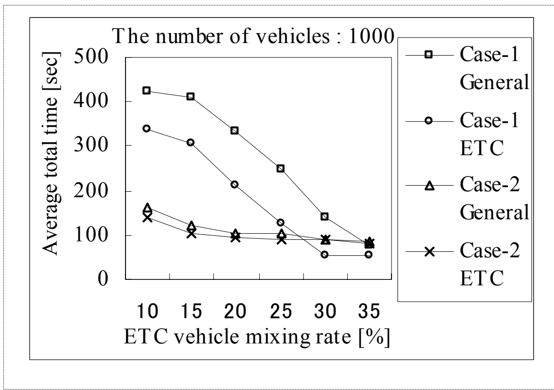

Figure 2: Comparison of average total time for the number of vehicles

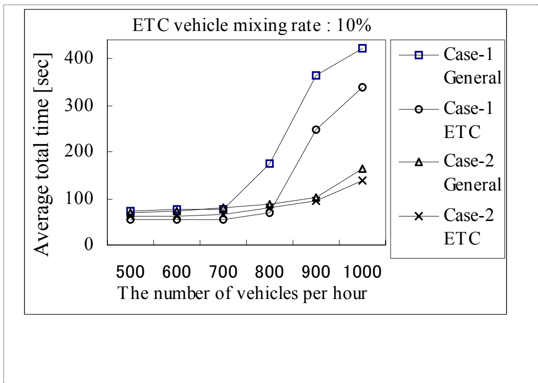

Figure 3: Comparison of average total time for ETC vehicle mixing rate

Figure 2 shows the change curve of average travel time according to the increase of traffic volume. It shows that the travel time of Case-1 using ETC-only gate by far exceeds that of Case-1 which adopts a combination gate to comply with the traffic condition. What does this means is that introduction of ETC gate indirectly decreases the availability for non-ETC vehicles, resulting the traffic jams which affect even ETC vehicles.

Figure 3 shows the affect of ETC penetration ratio to traffic jams. If the penetration ratio reaches to 35%, travel time of Case-1 with combination gate would become shorter than that of Case-2, which indicates that 35% is a target ratio to enjoy the benefit of ETC system. This result can give a good reference in designing toll plaza.

4 IP-BASED VIDEO CONFERENCE SYSTEM (CELAVIS)

The IP-based communication tool, such as the audio /video conference systems, is becoming popular these days. These systems provide the basic environment not only for the regular network-based conferences, but also work as the core system for the interactive information workspace for the next generation (Milne, 2003). In our project, the IP-based video conference system called CELAVIS (Collaborative Engineering LAboratory VIdeo conference System) (Ito, 2004b) plays the central role in the communication system presented in this paper.

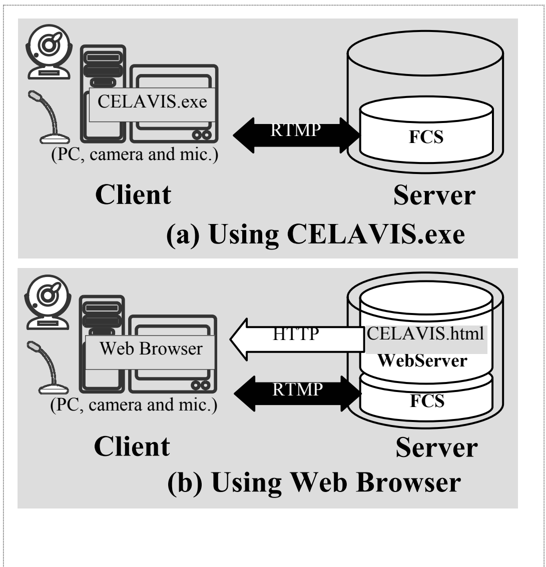

Figure 4: Client connection methods

CELAVIS is a custom-made IP-based video communication system which has been developed in CE lab (Collaborative Engineering Laboratory) at the University of Tokushima. Using CELAVIS server along with the Flash Communication Server MX (FCS) of Macromedia Co., the custom-made client software for CELAVIS enables audio/video communication based on the RTMP (Real Time Messaging Protocol) protocol developed by Macromedia. The Client PC requires the Flash Player (Plug-in) software to use CELAVIS system but no other special requirements are needed. This section covers the overview of the CELAVIS system.

One of the advantages of the CELAVIS architecture is that a custom-made configuration or modification can be applied to the system based on the needs of users. For our research purposes, the commercial systems are not suitable for this reason. As for some of the implemented features of CELAVIS, user/client authentication, bidirectional distribution of video images, two-way audio conversation, text chat, etc are implemented.

The user/client authentication makes it possible to keep the CELAVIS system secure and available only to our research community. The accessible client machines are controlled by the CELAVIS server to make it secure as well. The two-way audio and video functions provide the basic communication tool but they also enable the users to attend the conference communication from multiple sites.

The users can use the services either with locally installed software or via the web access. Figure 4-a shows the client program access, whereas Figure 4-b shows the web browser access. In either access, the CELAVIS users can communicate using on-demand video streaming function as well as audio/video functions using standard Laptop/PC.

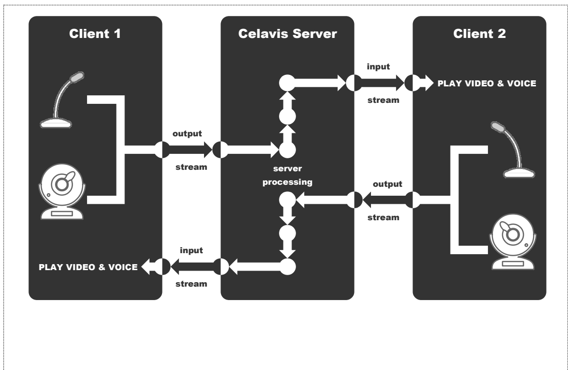

Figure 5: Workflow of server side and client side for video streaming

Figure 5 shows an example for the former access, which means the locally installed software access. Upon authentication, the client machine loads audio/video data from the microphone and CCD camera, and perform an internal process to communicate with the CELAVIS server. The active user information is managed by the server, and it will be displayed to the user's terminal. Selecting an active user from the list, a communication line will be established. For an audio/video conference, each user makes peer-to-peer connection to the corresponding users, which could also establish a conference connection for multi-users from different sites.

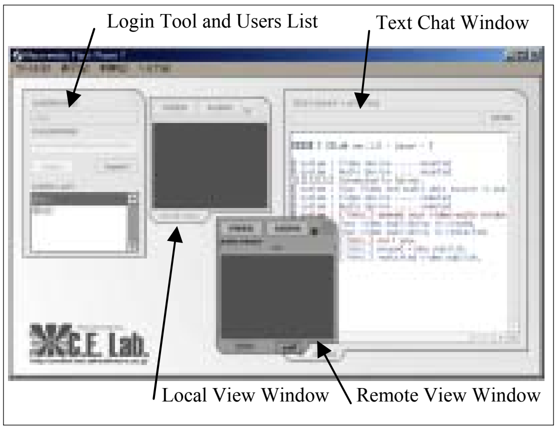

Figure 6: User interface of CELAVIS

Figure 6 shows a snapshot of the user interface in a typical interaction case. The Login tool and user list tool shown on the upper-left of Figure 6 show an active user list. The figure also shows the local and remote view windows, and the text chat window is show on the right.

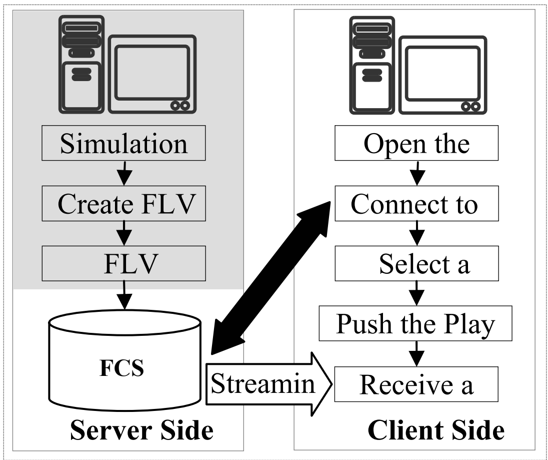

Figure 7: Workflow of server side and client side for video streaming

5 SIMULATIONS WITH VIDEO STREAMING

5.1 Overview of video streaming function

To propose the best solutions to the traffic congestion problems at the expressway toll plazas, various kinds of simulation need to be carried out and reviewed by the project members. Technical audio/video meetings which share the on-demand simulations could play a critical role for better interactions among the members. For this study, the on-demand video streaming function was implemented in the CELAVIS system using the FCS server. Currently, streaming function is implemented as a separate function to CELAVIS. However, integration of the function to CELAVIS is also under development as a part of this research, which will be reported elsewhere. This section covers how the video streaming function has been implemented.

Figure 7 shows the workflow of video streaming procedures to set up the video streaming function in CELAVIS. The left-hand side shows the workflow on the server side and the right-hand side shows the workflow on the client side. The video streaming data are prepared on the FCS server as follows. After the video streaming of traffic simulation was recorded from simulation processes by video capturing, the capturing data are converted to FLV format and are uploaded to FCS server. Once the simulation model is implemented and its parameters are appropriately assigned, these video capturing procedures are simple procedures, which can be processed as a routine work.

Figure 7 also shows the workflow of the client side. During the CELAVIS conference, the CELAVIS users launch the client software of streaming player or activate it from the web site of CELAB to play the streaming video. When the player software is launched, the RTMP connection to the FSC server is automatically established based on the secured network connection between the client and the server. The CELAVIS users select of the available video streaming by the selection menu of the player software and manipulate the video streaming. The player software provides the basic functions to review the streaming data, for example, monitoring, video selection, play/rewind/forward/stop, and etc.

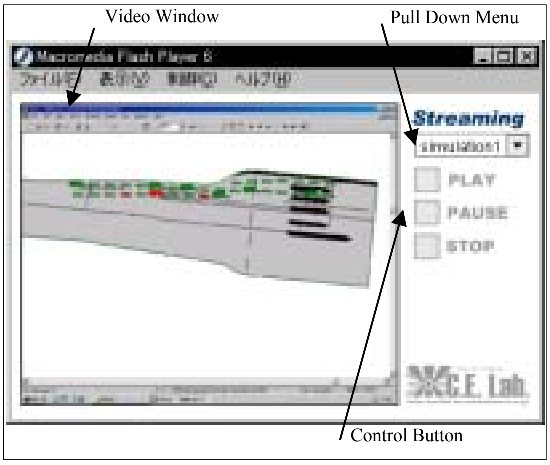

Figure 8: User interface of video streaming tool

Figure 8 shows an example of the user interface of video streaming tool which is invoked in CELAVIS. The video window in Figure 7 shows the streaming of the simulation result based on the traffic jams occurred at the toll plaza with ETC gate. The system allows users to manipulate basic operations to review the video streaming during video conference. To modify the parameters in the simulation result requires rerunning of another simulation, which means that the interactive parameter change is not allowed here. However, the preparation of simulation results based on several parameters can make it possible to review the different results during the video conference. The video streaming is provided to the users distributed over the network based on the on-demand basis. Therefore, users have control over the streaming to review them on each site, which is one of the big advantages of the system.

5.2 Evaluations and open issues

Using the video streaming function in CELAVIS, several experimental video conferences were held over the network. The video conference users could share the video streaming which shows the simulation results, during the conferences. The usability of the software was recognized high because of its basic functions which allow the users easy manipulation without any help of the operation manuals. The users on each site can easily review the simulation results anytime during the conference. What is more, the video streaming runs without any delay, which works very effectively for the conferences.

Some practical issues should be pointed out here. As for the resolution of video streaming provided by CELAVIS, the range of 72-144dpi video images was used in this study. This resolution is quite low; however, the sharing of simulation information did work quite effectively for the video conferences to discuss the traffic issues. This is because that the discussion was not based on the quality of the image in our case studies. However, if the topic of discussion was more image quality-oriented, for example, the image processing to generate high quality images, or the high level of color reproduction in the generated images; much higher resolution of the images may be required in some applications.

6 RESULTS AND DISCUSSION

This paper described the overview of process simulation model to study the traffic congestions which occurs at the toll plaza with ETC gates in the high traffic volume conditions. To verify the model, data collection at a real traffic congestion site was conducted and used in this study. This paper presented a brief overview of the simulation. The details for the simulation model have been reported in other papers (Ito, 2005a).

Then the paper described the overview of the audio/video conference system developed by the Collaborative Engineering Lab., which is called CELAVIS. The video streaming function presented in this study was developed in the CELAVIS system. The CELAVIS system itself is a general communication tool with audio/video function based on a Java platform, which allows us to modify the system based on the requirements. .

The paper then presented the integrated test environment including CELAVIS video conference and video streaming function, where simulation results can be shared for video conference participants who may be distributed over the network. As for the conversation using audio/video communication, the results were quite favourable in most of the cases of video conferences held so far, in terms of quality-wise of video image and audio sound. In the meantime, the image quality of the streaming was not good enough to share the detailed information of the reference materials on video screen, such as the detailed view of the physical object including vehicles, traffic lane change, etc. However, the low resolution of the video streaming images not only worked effectively in our study, but also allows us to manipulate the streaming in a very timely manner. A few seconds of time delay was observed during the conferences depending upon the time of the day because of network traffics. However, the interaction with the video streaming was so smooth and no complaint was observed in the experiments, even though some international sites were included in the test.

The use of the video streaming to distribute the information was timely and effective, and accelerated the feeling of information sharing for most of the participants in the experiments. The detailed information could be more effectively shared by some alternative method, such as the file sharing by the file server. However, as the timely and effective means of information sharing, the use of the video streaming function worked fine. Further study need to be conducted to find a better solution regarding the process of video streaming preparation and their management on the web.

7 CONCLUDING REMARKS AND FUTURE WORKS

The paper described the approach of collaborative communication environment using the IP-based video conference system with the video streaming function. As the case study, the simulation-based approach to the problem solving for traffic jam issues, which occurs at the expressway toll plazas with ETC gates, was presented. On one hand, the face-to-face communication is more natural for us than the network-based communication. On the other hand, the latter provides us more extension of communication environment than the former does. To do so, not only the standard communication with audio/video information, but also some additional usages of the tool can be discussed, for example, introduction of physical devices, additional information such as smell or texture, etc. The idea of interactive simulation was introduced and reviewed in this research. The video conference experiments using the video streaming communication showed good results. Considering the results presented in this paper, the author would like to further continue the research to enhance the collaboration in the communication over the network, which would play a critical role in the near future.

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