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The purpose of the MINDER program is to create the common simulation resource for human factors and safety researchers in respect to Minnesota Department of Transportation (Mn/DOT) programs. To accomplish this, we have created a simulation capability to re-create part of the I-35W Metropolitan area corridor from the Cross-town commons to just south of downtown Minneapolis. Our purpose in creating this was to allow researchers on different programs to use a common simulation environment. This was the first element of MINDER which was proposed as a larger program to include other segments of the freeway systems of the Twin City Metropolitan region. This corridor is extensively instrumented for traffic flow simulation and control. Successful development and validation of such a simulation environment has allowed a number of particular advantages. It represents, to our knowledge, the first interactively simulated portion of specific urban freeway on any high fidelity simulator. It allows parallel testing of simulation versus actual driving conditions. It is capable of integration with a number of ongoing Mn/DOT, university, and commercial research projects. It provides a human factors testing facility that exceeds most capabilities that currently exist world-wide.

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MINNESOTA INTELLIGENT DRIVING ENVIRONMENT RESEARCH (MINDER) PROGRAM

Final Report

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MINNESOTA INTELLIGENT DRIVING ENVIRONMENT RESEARCH (MINDER) PROGRAM

EXECUTIVE SUMMARY

The critical word in Intelligent Vehicle-Highway Systems is systems. To be successful from conception through implementation Intelligent Vehicle Highway Systems must employ a systems-based approach. The central facet of a systems approach is the ability for individuals to exchange views and information with respect to a common resource. The purpose of the MINDER program is to create that common simulation resource for human factors and safety researchers in respect to Minnesota Department of Transportation programs. To accomplish this, we have created a simulation capability to re-create part of the I-35W Metropolitan area corridor from the Cross-town commons to just south of downtown Minneapolis. Our purpose in creating this was to allow researchers on different programs to use a common simulation environment. This was the first element of MINDER which was proposed as a larger program to include other segments of the freeway systems of the Twin City Metropolitan region. This corridor is extensively instrumented for traffic flow simulation and control. Successful development and validation of such a simulation environment has allowed a number of particular advantages. It represents, to our knowledge, the first interactively simulated portion of specific urban freeway on any high fidelity simulator. It allows parallel testing of simulation versus actual driving conditions. It is capable of integration with a number of on-going Minnesota Department of Transportation, university, and commercial research projects. It provides a human factors testing facility that exceeds most capabilities that currently exist world-wide. Specifically, the project consisted of creating software objects to represent the landscape, roadway, roadside objects, downtown skyline, and moving objects of the I-35W corridor. Second, it consisted of a 'levels of detail' manipulation of those objects to maximize the efficient use of graphics resources available. Third, it required the synthesis of programming with a software representation of the target simulation vehicle, the 1990 Honda Accord. Fourth, it required post-processing software to reduce the outflow of information from the vehicle into meaningful data concerning driver performance. Finally, it required on-road validation of the eye points chosen and the objects represented in situations. The completion of this project has allowed the use of a realistic surrogate world in many other support research projects and programs. The following represents a detailed report of the completion of the work tasks as specified in the contract.

TABLE OF CONTENTS

WORK TASKS

WORK TASK 1. AUTOCAD DEVELOPMENT OF OBJECTS

One component of simulation creation is the designation of graphic objects which are made to represent real-world equivalents. In the XTAR system, this is accomplished by using AutoCad version 10, but can be enacted using other equivalent graphics plotting packages dependent upon the graphics computer system under consideration. After these initial descriptions in AutoCad, we used the XTAR translation facility to convert the graphics objects from the AutoCad object (the .dxf file) to an XTAR runtime format (the .dlo files). To aid in the creation of graphic objects, we created several utilities to create AutoCad files automatically via a direct description of the desired object. This was accomplished using a LISP program that created objects representing roadways and buildings in the I-35W environment. With the appropriate parameterization (for characteristics such as length, height, and other details, such as windows for buildings), the LISP program automatically generated the AutoCad.dxf files. Without this creation of the first work task of the project, programmers would have been forced to enter each vertex point for each object in the environment. Therefore, creation of the automated programming element in this component of the program saved several man-months of programming effort. It also facilitates future creation of objects in all XTAR programmed environments and has been used extensively in other supported work. Once the initial .dxf files are created and entered into runtime format, the simulation capability is enabled.

1

WORK TASK 2. LEVELS OF DETAIL PROGRAMMING

The limitation of the XTAR system, as it is in all graphics computation systems, is the number of polygons that can be projected. In essence, polygons represent the currency of simulation. While additional graphic characteristics can be used. e.g., such as texturing which is examined below, polygons still remain the basic unit of simulation. To render an increasingly valid visual scene it is necessary to use polygons. The more polygons available, the more realistic the visual scene can appear. The most obvious way of increasing polygon availability is to increased hardware computing power. That is, the capability to present complex visual scenes in real-time co-varies with the size, hence, the cost of the computer. However, for the present project we are restricted to the XTAR system which present 2000 flat-shaded polygons per second. If we cannot have more polygons available, an alternative for improvement is to use what we have in a more efficient manner and this process is enacted in 'Levels of Detail Programming.' Levels of detail take advantage of the characteristics of the viewing system, in our case, the human eye. As we look at any scene, we see much detail in the foreground but as our eye begins to travel to more distant point, less detail is evident. At some point, we simply cannot see objects even if they are on a flat-plane in front of us. Levels of detail programming takes advantage of this limit to human visual resolution.

In essence, we specify distances in which objects come in to view and distances in which details of objects come in to view. If objects exceed that distance from the present eye point, the computer is no longer required to perform the computation to present that in real-time. As can be seen, the ability to shed the computation of many objects in the world releases considerable computational capability that can be directed to the actual scene being viewed. Hence, levels of detail programming represents a considerable saving of resources and is a method that can be enacted on any graphics computational system. The two things of benefit from the present work are the following. First, the simulation of the particular I-35W corridor was enhanced by this method. This requires extensive work since each item has to be 'tagged' according to the 'level of detail' required. In this simulation we used four levels of detail as designated by the distance from the current eye point. Greater levels can be specified, but they represent a compromise between programming time and subsequent realism of the displayed scene. The second major benefit from this process was the assimilation by the programmers of how this method works, so that it may be enacted on other scenes and other graphics computational facilities as present at Human Factors Research Laboratory.

WORK TASK 3. SYNTHESIS OF C PROGRAMMING

The XTAR system is used to both create synthetic worlds and to manipulate through them at real-time frame rates (in excess of at least 15Hz, although the Human Factors Research Laboratory system runs up to 60Hz and normally at 30Hz during data collection phases). The actual simulation process takes input from a number of sources and enables the frame-by-frame rendering of the graphics engine as well as the creation of user-defined data collection and reduction routines. Several sources of input go into simulation. First, the graphics file that describes the graphics objects is converted from runtime-data format (.dlo) to a runtime format. Second, several initialization files describe the experiment that will be run. These initialization files include graphic object initialization (i.e., setting the initial object location), data collection and reduction specifications (i.e., collect x/y position, reaction time, response time, etc.). and experimental baseline conditions (i.e., independent variables such as subject number, trial number, condition number, etc.) are used to drive the graphics engine and the subsequent data collection and reduction modules.

A critical component of the synthesis is the linkage between the car model and the graphics generation facility. Input from the actual vehicle (i.e., steering position, gas pedal position, and brake pedal position) are used as input to a set of motion equations that represent the target vehicle. In the case of simulation, the vehicle used at Human Factors Research Laboratory is a 1990 Honda Accord. Hence, in the mathematical model of the equations of motion developed at Human Factors Research Laboratory, the transfer functions themselves describe how input into an actual Honda 1990 Accord would affect what the driver sees and feels. Output from the mathematical description is then used as one of the sources of input into the graphics engine as described above. The major task of the present component of the project was to link these various sources into a synthesized program which would permit full simulation. This task has been achieved and the full simulation has been used for multiple project supported by both the Center for Transportation Studies and the Minnesota Department of Transportation, see Figure 1.

There
Will Be
Buildings
Along The
Road That
You Will
Pass

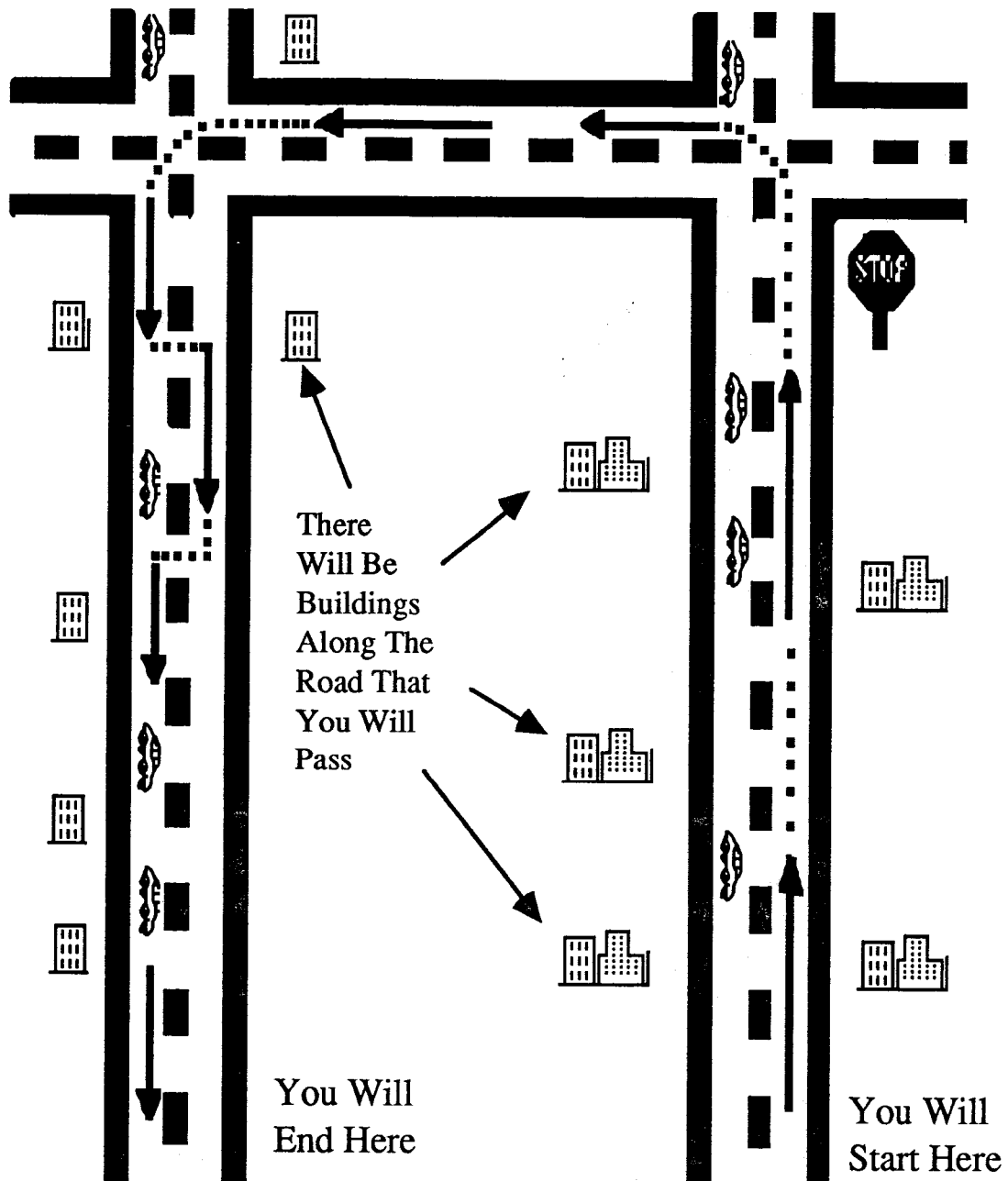You Will
End Here

You Will
Start Here

Figure 1. *Example of an I-35W Based World taken from the MINDER Software and used in the Testing of Multiple Capabilities such as Sign Recognition and In-Vehicle Radio Data Systems Display Technologies.*

WORK TASK 4. DATA REDUCTION AND ANALYSIS PROGRAMMING

The simulation facility presents real-time displays to the driver who can make decisions about speed and direction as he or she does in the real-world. This closed-loop form of simulation is very different from the open-loop systems which compose much of the driver training environment. A critical problem that arises in real-time, high-fidelity simulation is the question of data management. The simulation facility at Human Factors Research Laboratory is capable of recording vehicle position and status over 60 times per second, which, in an experimental procedure lasting any appreciable length, generates a large amount of raw data. The purpose of the present task was to capture and manage that data stream so that meaningful results could be quickly obtained in experimental procedures. The major forms of data taken are the position of the vehicle (essentially the eye point) in relation to roadways and objects in the environment, the velocity of the vehicle, as represented by the data from the potentiometer attached to the gas pedal of the Honda 1990, and braking data obtained in a similar manner from the brake. These analog signals are reduced by analog-to-digital conversion into a stream of number recorded on the hard disk associated with the XTAR system. The primary program created under this work task was a capability to calculate Root Mean Square Error around the center line of the roadway presented to the driver. This information, when translated into engineering units, gives the researcher information as to the lane drift of the driver. This is exceptionally valuable information, since the experimenter can then observe whether some manipulation, e.g., the introduction of a new Radio Data Set system, affects the driver's capability to safely control the vehicle during subsidiary operation of such Advanced Vehicle Information Systems.

Root Mean Error Square can be integrated over differing time units, depending upon the time bin size selected in the data reduction program. Thus the experimenter can determine whether they wish to examine moment-by-moment performance in some particular vehicle or roadway configuration, e.g., a left-turn, or whether they wish to examine long-term performance over an extended time such as would occur in fatigue-type studies. This represents a characteristic of the data reduction program that is at the discretion of the experimenter in response to the type of question they are posing. Further, the data reduction programs facilitate transfer of collected data from the original analog-to-digital data stream to a form that can be entered into one of several commercial statistical software packages the Human Factors Research Laboratory uses, e.g., SPSS.

WORK TASK 5. FIELD VALIDATION OF THE CREATED SIMULATION ROADWAY

The purpose of this work task was to provide a brief validation of the programming work done in the creation of the simulation. When a simulation is developed to re-create a specific environment, there are numerous aspects of that environment that need to be considered. In particular, the eye point of the driver is critical in providing a valid simulation. This criticality can easily be envisaged as an individual changes between a small vehicle and a large truck. The visual scene, as it appears to each respective driver, is very different. We constructed our scene to appear as it would to a driver of a 1990 Honda Accord, which is both the simulation vehicle and on-road vehicle. The on-road vehicle was then driven extensively on that route to test the driver's response to the simulation environment. Adjustments were made as to eye height line until the appropriate viewing angle was established. The ability to manipulate this angle is a purpose-constructed part of the simulation software so that, if manipulated, the eye height of differing vehicle could be simulated for Minnesota Department of Transportation purposes.

Having established the vehicle location with respect to the environment and the appropriate viewing angle to simulate the designated corridor, the next purpose of validation was to match backgrounds. For that purpose, we developed a 2-dimensional representation of the Minneapolis downtown skyline. This appeared in simulation and was positioned with respect to the roadway as it appeared to the on-road driver. This necessitated some compromise since the XTAR system does not deal with curvilinear roadway configurations with particular efficiency. To preserve computational efficiency, the simulated I-35W corridor was re-created as a straight roadway. In reality I-35W, from the Cross-town commons to the downtown area, has a number of small curves and vertical elevation changes. These were not presented in simulation due to hardware restrictions. Therefore, the positioning of the downtown skyline represented the best compromise taken from on-road observations.

In completing the software development, the programmers developed an urban landscape in which multiple buildings were presented. These were matched with the best representation of the I-35W corridor. Again, due to hardware restrictions, this simulation was more generic in nature than the full corridor software. In the latter environment, walls were positioned adjacent to the roadway to simulate the noise baffling walls that accompany the initial portions of I-35W after exiting the Cross-town commons. These were initially restricted according to the dictates of the on-road observations. However, they proved helpful to establish relative velocity and were extended in the final version of the software used by different programs. In addition to fixed characteristics of the scene, moving vehicles were introduced. In the developed database, we have a number of vehicles including large and small

cars, vans, and motorcycles. These were used to look at obstruction lines. Since the roadway was modeled with adjacent running lanes, as would occur in a diversion situation, obstruction lines for vehicle were not co-incident with normal on-road conditions and were not evaluated extensively. Since the present simulation facility was used as a basis for multiple environments, and the complexity of the scene was restricted by the capability of the XTAR system used, complete artificial representation of the corridor was not the goal. In essence, a local freeway section was recreated which provided a basis for further work. Therefore, the principal characteristics of the roadway, e.g., viewpoint angle, were the major subject of on-road validation. This was accomplished by observation runs in the on-road vehicle as noted.

The results of the present comparison have been used as the basis for understanding the limitations of the XTAR, PC-Based type technology. For example, realism of simulation is vastly enhanced by the use of texture maps or 'texturing' in which pre-developed textures are 'added' to existing polygons or polygon-based objects. It is clear from the results of the present validation, that the XTAR technology cannot bear anything more than a rudimentary similarity to the actual sophisticated scene. Also, as more work is required in simulation representing crowded roadways, it is clear that more moving vehicles are required. On-road validation observed that even at low-usage times, the simulated I-35W corridor chosen supports a much larger number of vehicles than could be simulated using the system noted. It was on the basis of these findings that increased hardware capability was proposed and subsequently supported. Hence, the present validation results are most valuable in deciding the level of simulation validity required for specific projects and this is an important outcome of the present work. Such findings promise to inform the decision on the apportionment of simulation resources and indicate which level of simulation is needed for which level of research question.

RELEVANCE TO THE MINNESOTA DEPARTMENT OF TRANSPORTATION

- The finished MINDER facility presents a common simulation environment for testing comparison technologies in the same real-world surrogate upon which they are expected to operate.

- MINDER provides a valid traffic environment in which 'levels of detail' programming are incorporated.

- MINDER provides a template for future simulation which can be elaborated to include the whole Twin City Metro area freeway system.

- MINDER can be used by traffic engineers to examine the effects on drivers of changing the roadway configuration.

- MINDER has been used in conjunction with several GUIDESTAR programs and the Trilogy project. We expect MINDER to be used for testing the Genesis devices in simulation also.

We have been asked to identify how each of our supported programs can help with three aspects of user service to the drivers of Minnesota and by extension to all drivers. These aspects are: 1) accident reduction, 2) congestion reduction, and 3) user acceptance. The MINDER program has indirect effects on each of these through fostering simulation research.

1) Accident Reduction

The main problem about present accident reduction procedures is that we use large epidemiological databases to attempt to assess individual accident circumstances. In ways in which accidents are the same, i.e., they involve vehicles and humans, we can make some general statements about patterns of accident events. That is, we can provide some information about trends like over-representation. What we cannot do is to understand those precursors to accident events in the milliseconds immediately preceding collision or, more importantly, near misses! These conditions cannot be investigated in real-world work since it exposes the individual to life-threatening conditions. Therefore, simulation is the ONLY way in which we can study the accident sequence and driver response to understand how to reduce accident frequency. The advantage in MINDER is that the reproduction of an actual roadway allows for the re-enactment of incidents on that roadway. This is, however, a research tool and is not in the form for accident investigation per se. In short, MINDER is expected to help significantly with accident reduction by providing an arena in which collision investigation can proceed.

11

2) Congestion Reduction

One of the major ways that has been proposed to reduce congestion is through advanced technologies bound to Intelligent Vehicle Highway Systems architecture. In particular, the notion of providing information to the traveler, en route, so that alternative congestion avoiding strategies can be engaged is expected to be a major influence in controlling congestion in the future. Such information channels are expected to provide real-time reports of traffic incidents and accidents so that temporary obstructions can be avoided as well as the more chronic traffic 'pinch points.' This information must be provided to the driver so that they can assimilate clearly the understood and presented messages. In particular, presenting messages should not decrease safety by distracting attention away from the driving task. In previous support work, we have noted that many in-vehicle information displays do this and may rightly be judged as a source of potential danger. An alternative to presenting in-vehicle information is to present the same information in a Heads-Up Display format. This gives the driver information on the windscreen in front of them, putatively allowing sight of the information and the forward view at the same time. There are some commercial systems in contemporary vehicles, but these present puerile information such as speed which is of little or no help to the driver. However, future Heads-Up Displays are expected to present real-time traffic information. Using the base of simulation established in MINDER, we have already tested a number of Heads-Up Display configurations and have presented papers and data from these investigations. These would not have been available without the MINDER base of support. Therefore, as a comprehensive simulation base, MINDER has and continues to permit research into methods of congestion reduction for the road user.

3) Driver Acceptance

We propose that driver acceptance of systems is directly related to the utility and perceived benefit and safety of new systems under consideration. In this respect the MINDER simulation facility can help in the testing of prototype systems so that drivers can evaluate new technologies without the associated problems of on-road driving. Consequently, MINDER is a critical facility in examining driver acceptance of any new technologies.

SUMMARY

The preceding report indicates how the specific work tasks have been accomplished. However, the old adage that 'a picture is worth a thousand words' certainly holds. For real-time simulation, where the task is to create a simulation world, the world itself is certainly worth more that tens of thousands of words. The essence of the final product of the MINDER program is in that simulation. Its value lies in the support that it has provided to conduct extensive Intelligent Vehicle Highway Systems and driver safety related research in simulation. It provides an arena of investigation that permits engineers and researchers to evaluate behavior that can be achieved in no other way. The simulation facility at the Human Factors Research Laboratory of the University of Minnesota is open for visitation to inspect these capabilities. In our reports, we have been asked to comment on the benefit for Minnesota Department of Transportation of the final product, and the use to the traveling public in the form of accident reduction, congestion reduction and driver acceptance of innovations and new technologies.

Publications and Presentations

(The following represents a list of publications and presentations directly sponsored under the MINDER contract. As the fundamental nature of the MINDER work was to provide a support platform for extended simulation research, most of the recent reports that have come from Human Factors Research Laboratory have benefited directly from the MINDER work. The extensive listing of these publications can be supplied upon request).

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Hancock, P.A., & Stackhouse, S. (1992). Human factors and safety issues in IVHS. *Proceedings of the 25th ISATA Conference on Road Transport Informatics/Intelligent Vehicle Highway Systems, 25*, 489-496.

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Shekhar, S., Yang, A., & Hancock, P.A. Evaluation of relational databases for advanced driver information systems. Paper presented at the Third Annual University of Minnesota Transportation Research Conference, St. Paul, MN, May, 1992.

Hancock, P.A., Chrysler, S., & Stackhouse, S. A simulation study to measure driving performance decrement due to the interaction of driving and non-driving tasks. Paper presented at the 3rd Annual Meeting of IVHS America, Washington, D.C., April, 1993.