Agent-Based Mobility Simulation Model for Disaster Response Vehicles

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Abstract: This study aims at developing an agent-based mobility simulation model that can be used in determining road traffic routes for exclusive use of disaster response vehicles (DRV) during disaster events. Agent-based simulation offers a technique to model traffic flow of DRV as agents that adapt its environment according to its attributes and behaviors. The development of the simulation framework uses an open source multi-agent transport simulation, MATSim. Its routing algorithm parameter integrates into the controller module combining road closures parameter and mobility simulation choice that works inside the simulation iterative framework. Model scenarios experimentations and visualizations were performed on a simple road network demonstrating the outputs of modules integrated in the model, as well as the travel time computations taken from actual urban perspective. The study resulted with traffic routes generated and stored in the mobility simulation output files thereby establishing the shortest paths for exclusive use of DRV.

Key Words: Agent-Based Mobility Simulation, Traffic Routes, Shortest Paths, Travel Times

1. INTRODUCTION

In times of disasters, being stuck in traffic reduces the travel time quality of disaster response vehicles in reaching their desired destinations. In addition, traffic control system will be disrupted. Considering that disaster response vehicles contribute a lot in any stages of disaster event, being trapped in traffic jam or degraded road network capacity would highly affect their performance in the field. In addition, traffic simulation software was uncommon for transport planning and traffic management according to the survey conducted for 120 cities by Espada, Lidasan and De Leon (2008). Clearly, there is a deficiency of simulation models to support agencies in traffic management planning.

Road network control is crucial to cope with the increase of travel demand for disaster response operations, after the initial period of disaster. Depending on the level of road damages, possible road closures may occur in the road network. The degraded road traffic routes of disaster response vehicles will result in increase of travel time period from its source to destination. Agent-based mobility simulation offers a method to model the traffic flow of disaster response vehicles.

During the occurrence of Tropical Storm Washi (Sendong), the most affected areas were those near the strip of Cagayan de Oro river (Ramos, 2011). Landslides near the river banks, flash floods, overflowing rivers and tributaries, caused some barangays having swept away during the occurrence of Tropical Depression Shanshan (*Crising*) (Del Rosario, 2013).

A quick response to disaster situations can prevent or minimize unfavorable consequences such as deaths and damage to properties (Elalouf, 2012). Though disaster vehicles when in rescue activities are exempted from traffic laws, still it is not a guarantee that they will reach their destinations as quickly as possible. The likelihood of future potential disasters that may occur in the city contributed the motivation to study the area of traffic simulation.

The study aims to construct an agent-based traffic flow simulation model to assist the traffic management planners in assigning disaster response vehicles (e.g. fire trucks, ambulances and police cars) to traverse traffic routes possible under a degraded road network in times of disaster.

1.1 Conceptual Model

Figure 1 illustrates the conceptual framework of an agent-based mobility simulation model that can be implemented as part of the overall planning in the deployment of response vehicles in times of disaster. The road network coverage with identified locations of disaster response depots and the number of disaster response vehicles is translated as input to the simulation model. Once the location of the affected area is identified in the road network, a degraded road traffic route is translated as road closure input to the simulation model. The execution of the simulation model monitors the travel times of the disaster response vehicles from origin to its destination. Running the simulation model generates experimental results. By experiments and visualization, the operational requirements of the model are verified and validated. Finally, road traffic routes from origin-to-destination per vehicle can now be identified based on the travel times of each vehicle in the model. Output analysis followed using the experimental results. The output of the analysis can be used as an alternative solution for some areas in traffic management system. Thus, this simulation model helps in the decision making process in determining the traffic routes for exclusive routing implementation.

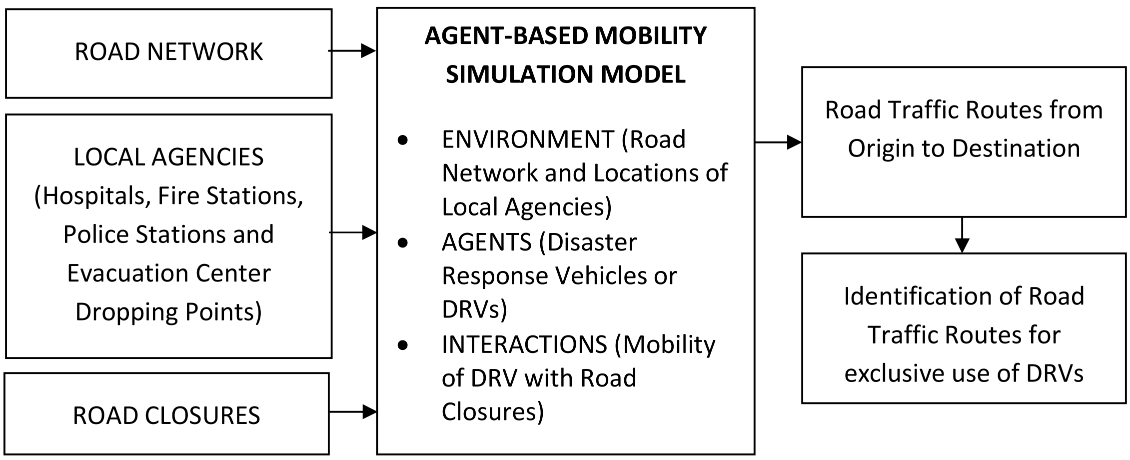


Figure 1: Agent-Based Mobility Simulation Model Conceptual Framework

2. LITERATURE REVIEW

2.1 Agent-Based Mobility Simulation

Studies involving mobility or traffic flow and traffic routing have generally use modelling simulation and shortest path algorithms. Lefebvre and Balmer (2007) used multi-agent transport simulation for large-scale agent-based transport simulation and investigated the variations of Dijkstra's algorithm and A*-algorithm as well. Sumalee and Kurauchi (2006) used Monte-Carlo simulation approach to approximate the capacity reliability of the network. The study was then used to evaluate the performances of traffic regulation policies with road network of Kobe city in Japan. Similar study was also conducted by D'Este and Taylor (2001) about network reliability and modelling, investigating consequences to road network when some links are cut. Modelling and simulation was also used for forecasting and travel demand as applied by Dantas et.al. (2001). Teknomo (2008) multi-agent simulation modelling approach considered route probability as direct output of the simulation rather than an input to the network.

2.2 Shortest Path Algorithms in Mobility Simulation

Sanders and Schultes (2007) outlined algorithms for route planning in transportation networks that run faster than Dijkstra's algorithm. Their study focused on successful speedup techniques in static road network with fixed edge cost. Elalouf (2012) model incorporated joint analysis of expected route time and its variance and used dynamic-programming shortest path algorithm. Chen and Chou (1999) compared the generalized Floyd algorithm with K-shortest path algorithms by which many real transportation issues like disaster rescue and evaluation are applicable.

However, previous studies did not address mobility simulation where traffic routes can be made exclusive for disaster response vehicles in times of disaster. Using agent-based mobility simulation, this study will identify road traffic routes that can be made exclusive for the use of disaster response vehicles in order to reach its desired destination at minimal possible time.

3. RESEARCH METHODOLOGY

3.1 Research Design

In data requirements and analysis step of the development, data were gathered in the identification of road network and establishing of area coverage. Data were requested from local agencies and verified at random the actual measurements of distances. The elements and assumptions were identified in design details and specifications of the traffic simulation model.

Selection of simulation software package as open-source followed after the validity of the conceptual model. Aside from being open-sourced software, MATSim (Chen et at, 2014) was selected because it offered a framework for agent-based mobility simulation as well as a controller that allowed iterative running of simulations and analysis of outputs applicable in this study. MATSim (Waraich et at, 2009) supported the traffic engineering application in developing the simulation model, same with scenario visualizer using Senozon VIA. After software was selected, simulation program was constructed. Remarks on the assumptions from the field experts were gathered prior to the start of development and implementation.

Initial run of the simulation model took place followed by its validation. When necessary, the newly constructed simulation program was adjusted according to the objectives of the model. A cycle of experimentation and visualization took place until the model executed the expected outputs.

Analysis of model results was done and drawn insights as to the relationship with the real-life data gathered. Documentation of processes and its results were undertaken from the start until the evaluation process of the simulation development life cycle.

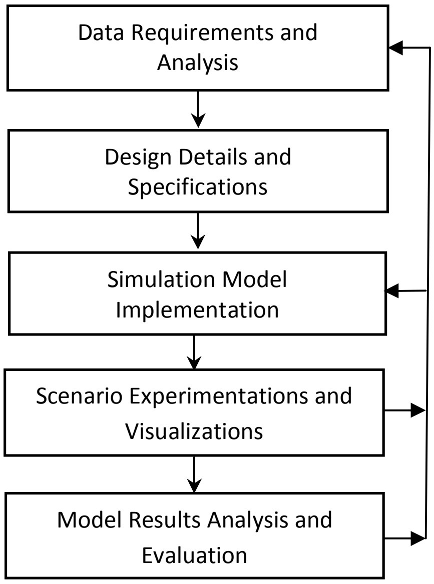


Figure 2: Agent-Based Transport Simulation Model Development Life Cycle

4. DISCUSSION OF RESULTS

4.1 Data Requirements and Analysis

Through interviews and letter of request for secondary data, a copy of the road network map of CDO in JPEG image format was accessed as seen in Appendix A. Also gathered were the lists of respective entities: (1) hospitals; (2) BFP stations; and (3) police stations (Appendix B).

4.1.1 Map of road network coverage

The city is located in Northern Mindanao bordered by the municipalities of Opol to the west; Tagoloan to the east, and by the province of Bukidnon to the south. In the northern part of the city is the port of Cagayan de Oro facing the Macabalan Bay. The designated road network coverage in the study has a total area of approximately 73.2 sq. km which includes along the flood-prone areas at the coastal and riverside. During the occurrence of Tropical Storm Sendong, the most affected areas were those near the strip of Cagayan river (Ramos, 2011). Landslides near the river banks, flash floods, overflowing rivers and tributaries, caused some barangays having swept away (Del Rosario, 2013). Due to this event, the five major bridges were decided to be included. These are the bridges that lie along Cagayan River connecting its two main lands, Carmen area to the west and poblacion city proper to the east. As seen in Figure 3, the selected road network coverage shows these five major bridges along Cagayan River.

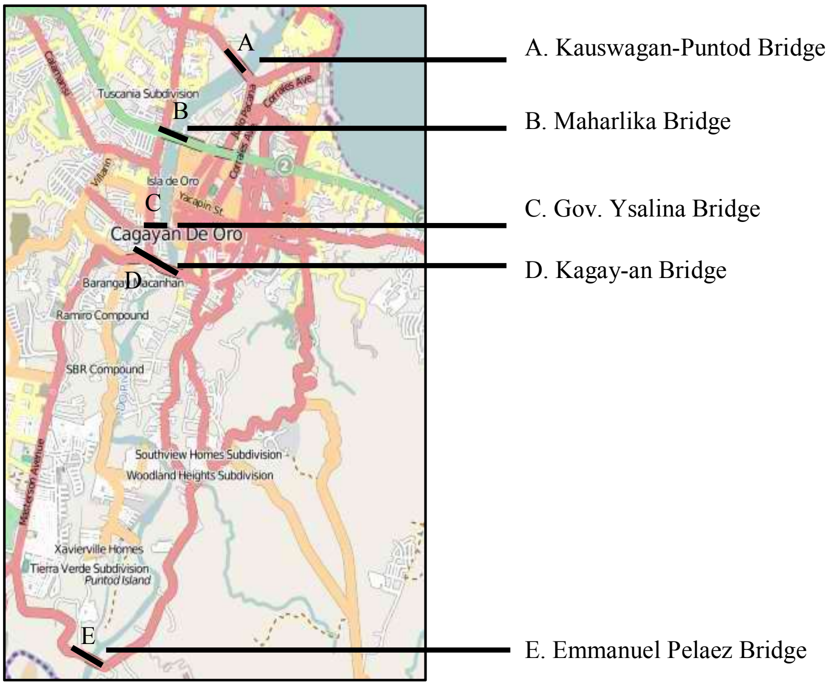


Figure 3. Road network coverage including five major bridges along Cagayan de Oro river (Source of Map: OpenStreetMap in OSM Format)

4.1.2 List of hospitals, fire stations, police stations and evacuation center dropping points

Ten medical institutions both private and public hospitals were selected as the general type of hospitals that have emergency departments (Appendix B). Hospitals were selected based on its availability of ambulance services.

Three fire stations (Station 1, Station 4 Sub-Station and Station 5) were included in the study (Appendix B). These were selected based on its proximity in the area. One was located from the northern part (Station 5), another from the southern part (Station 4 Sub-station) and last at the center of the city (Station 1). Four stations (Station 7, Station 8 and two Station 8 Sub-stations) in the list located beyond the borders of the road network coverage therefore excluded as input data**.**

Six police stations, PNP Headquarter and Cagayan de Oro Police Office (COCPO) City Public Safety Company (CPSC) were included in the study (Appendix B). These stations were selected based on its location within the area coverage. Other stations (PPS-6; PPS-7; PPS-8; and PPS-10) were located beyond the road network defined therefore excluded as input data. Barangay halls, covered courts, parking spaces or public schools were the usual shelters for evacuees. In this study, two evacuation center dropping points (Appendix B) were selected based on its proximity along the river; one representing the west side- Balulang Elementary School and one representing the east side-Burgos Barangay Hall.

4.2 Design Details and Specifications

4.2.1 Element 1: study area

The study area included the five major bridges that lie along the primary roads of the city across the Cagayan de Oro River connecting its two main lands, District 1 to the West and

District 2 to the East, located in the province of Misamis Oriental, Philippines (Figure 3). The designated road network coverage has a total area of approximately 73.2 sq. km which includes the riverside.

4.2.2 Element 2: road network and facilities

The model involves three main entities: *road network, facilities* and *population. Road network* is described by two variables: nodes and links. It is represented using graphical representation and has 3847 nodes and 9630 directed links (Figure 4). A stretch of a particular street may consist of nodes and links representing intersections and street sections, respectively. MATSim handles only one-way links. In this model, *oneway* attribute has a default value of 1 and *modes* attribute assigned only as car. *Facilities* are represented by its geographical coordinate locations in the network. It involves twenty one entities from the following agencies: 10 hospitals with ambulance services, 3 fire stations, 8 police stations and two evacuation centers. Facilities are mapped on its nearest links located in the road network.

4.2.3 Element 3: population and demand generation

The *population* is composed of different types of DRV representing the major agents in the traffic simulation model. These are ambulances, fire trucks and police cars. The hospitals, fire stations and police stations are assigned as origins of agents, where vehicles start and end their activities, whereas evacuation centers are assigned as destinations of agents. Population is characterized by four variables: person, plan, act and leg. The *leg variable* is characterized by *mode* that defines the type of vehicle, assigned as car. The model advances by performing traffic routing activities. Each traffic routing activity, seven events are processed in the following sequence: *end activity event, agent departure event, wait to link event, enter link event, leave link event, agent arrival event* and *start activity event*. The *end activity event* initiates the agent to depart from the facility of origin and back again in the same flow of events.

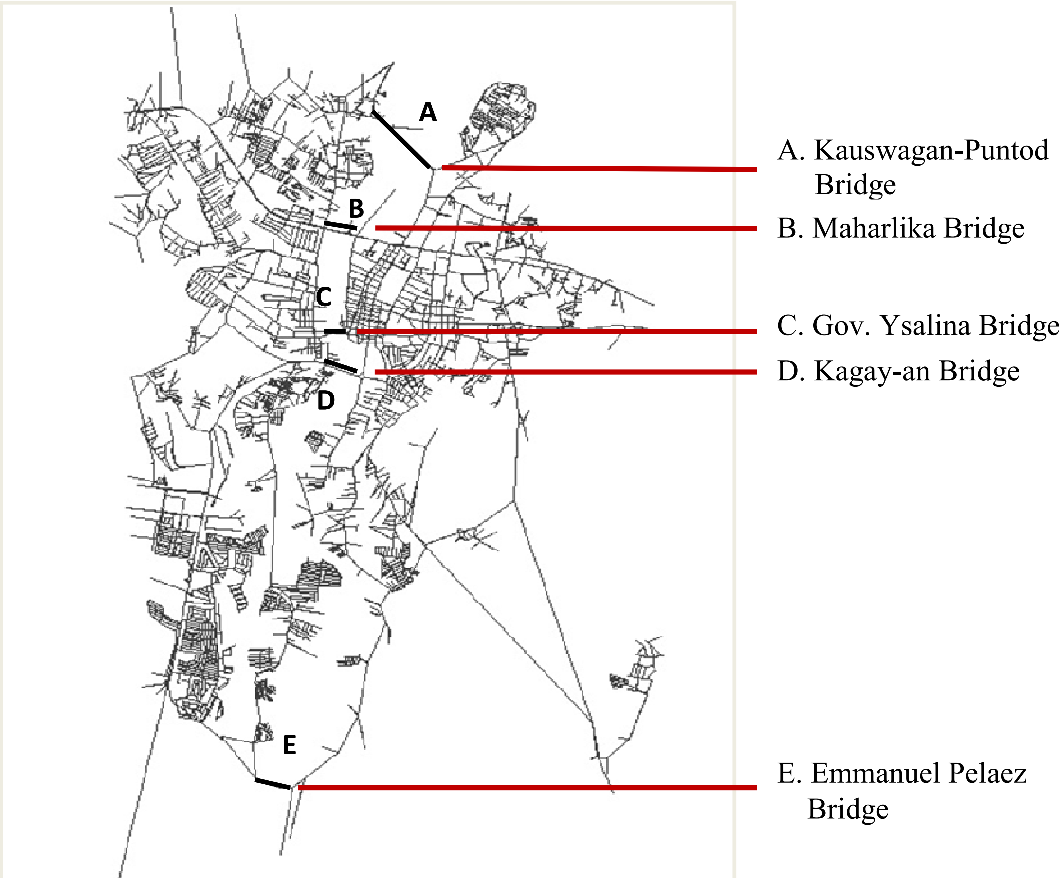


Figure 4: Nodes and Links representation of Road Network (in XML Format) with 3837 Nodes and 9630 Links that Includes five Major Bridges along Cagayan River

4.3 Simulation Model Implementation

Model programming of the conceptual model was ensured using MATSim, an open-source specialized software for agent-based transport simulations (Lefebvre and Balmer, 2007). MATSim java classes with its libraries were identified necessary for the implementation of the conceptual model. With some customization and java codes development, the main java code was created. The mainMenu.java held the java codes that generated the necessary XML files needed for the scenario generation.

4.3.1 Source to destination conversion

The source files as input to the mainMenu.java are (1) map_cdo.osm, (2) facilities.txt and (3) population.txt**.** In order to get the touch of real world, additional vehicles other than the DRV were added in the population. Using a random generator a java code was created to generate additional population or vehicles. Road obstructions during disaster were considered where link IDs of the roads with obstructions were identified as input to the road closures generator. Each link in the network.xml file was assigned with a unique link ID. Figure 5 showed the flow diagram of the conversion from source to destination files.

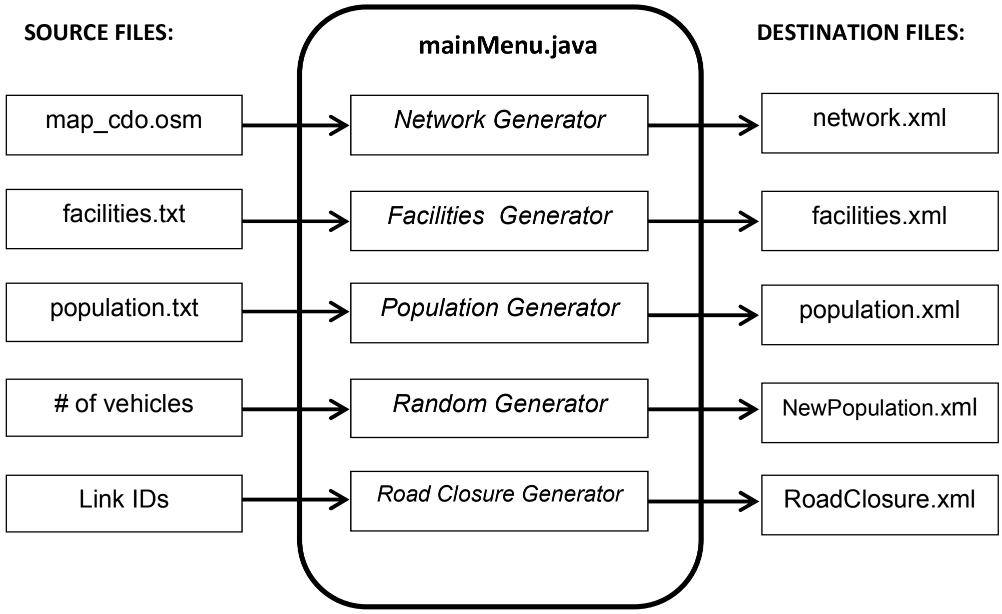


Figure 5. Source to Destination Conversion Flow Diagram

4.3.2 Scenario generation

Once the XML (eXtensible Markup Language) files were generated by the mainMenu.java code, these XML files were placed in an input directory, (*./input*) and brought to the scenario generator under the config.xml. In order to produce the output of the scenario, an output generator was used to run the config.xml file. This was handled by *generateOutput(),* a part of the mainMenu.java code which was run only after generating the required input XML files. Finally, a separate output directory (*./output*) was created storing the simulation model results.

The config.xml file was created as a separate file from the java file. No source file was needed to create the config.xml. The output of the model was stored in files under each iteration sub-folders, *./ITERS* and visualized using SENOZON VIA visualizer.

However, the MATSim log files were opened either as text files or excel files. The flow diagram of the scenario generation was seen in Figure 6. It showed the flow of input components into MATSim output results using the output generator function from the main Java program. Output results were then viewed using the VIA visualizer and text editor.

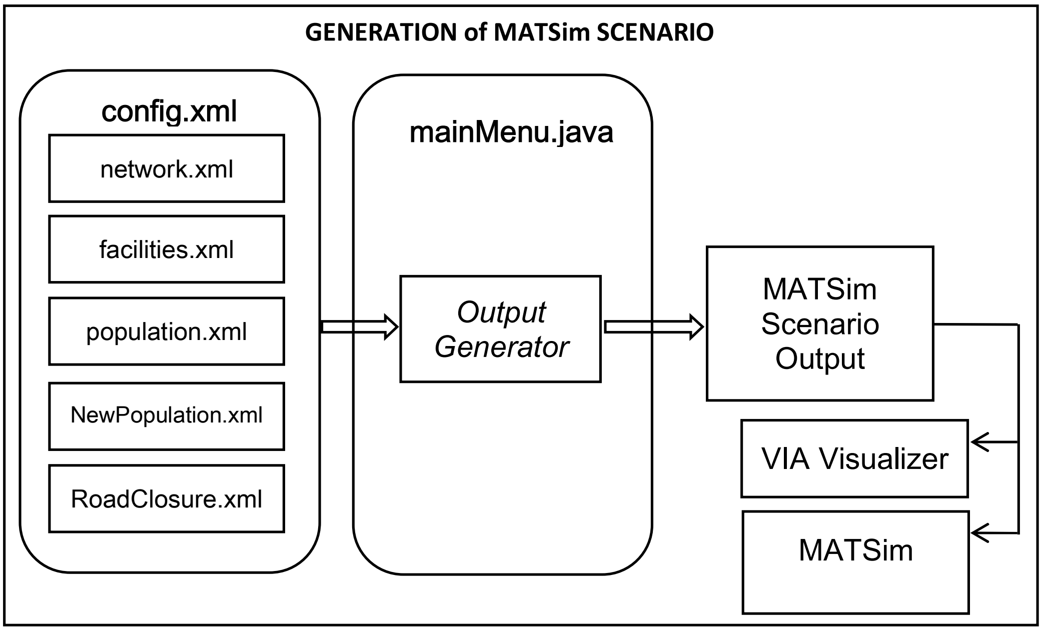


Figure 6: Scenario Generation Flow Diagram

4.3.3 Calculation of shortest Paths

The java code in MATSim package *org.matsim.core.router.util* under class *LeastCostPathCalculator.class* computes the shortest paths of Dijkstra algorithm.

```
==============================================================================
/**
* Calculates the cheapest route from Node 'fromNode' to Node 'toNode' at
* starting time 'startTime'.
*
* @param fromNode
*             The Node at which the route should start.
* @param toNode
*             The Node at which the route should end.
* @param startTime
*             The time at which the route should start. <i>Note:</i> Using
*             {@link Time#UNDEFINED_TIME} does not imply "time is not
*          relevant",
*             rather, {@link Path#travelTime} will return {@link Double#NaN}.
*/
@Override
public Path calcLeastCostPath(final Node fromNode, final Node toNode, final double
startTime, final Person person, final Vehicle vehicle) {

          double arrivalTime = 0;
          boolean stillSearching = true;

          augmentIterationId(); // this call makes the class not threadsafe
          this.person = person;
          this.vehicle = vehicle;

          if (this.pruneDeadEnds == true) {
```

```
            this.deadEndEntryNode =
    getPreProcessData(toNode).getDeadEndEntryNode();
        }

        PseudoRemovePriorityQueue<Node> pendingNodes = new
    PseudoRemovePriorityQueue<Node>(500);
        initFromNode(fromNode, toNode, startTime, pendingNodes);

        while (stillSearching) {
            Node outNode = pendingNodes.poll();

            if (outNode == null) {
                Log.warn("No route was found from node " +
        fromNode.getId() + " to node " + toNode.getId());
                return null;
            }
            if (outNode == toNode) {
                stillSearching = false;
                DijkstraNodeData outData = getData(outNode);
                arrivalTime = outData.getTime();
            } else {
                relaxNode(outNode, toNode, pendingNodes);
            }
        }
        // now construct and return the path
        return constructPath(fromNode, toNode, startTime, arrivalTime);
    }
==============================================================================
```

4.3.4 Calculation of travel time

The java code in MATSim package *org.matsim.core.util* under *TravelTime.class* calculates the total travel time of the shortest paths generated from Dijkstra's algorithm.

4.4 Scenario Experimentations and Visualizations

The simulation model was applied to the network of Cagayan de Oro City in the Philippines. A scenario representing disaster event with no bridge closures occurred and another with bridge closures, therefore, two scenarios were assumed. The facilities were mapped based on its actual geographical x and y coordinates in the road network. There are 23 facilities located in its nearest link in the network. These are 10 hospitals, 3 fire stations, 8 police stations and 2 evacuation centers (Appendix C).

4.4.1 Scenario 1: no bridge closures

The scenario was based on disaster response operations right after the occurrence of disaster. The operations took place in Cagayan de Oro City. The scenario has two evacuation centers identified, 1. Balulang Elementary School Evacuation Area located at the west side of Cagayan de Oro and 2. Burgos Barangay Hall Area located at the east side of the city. The road network has 21 facilities as origins of agents having 3 to 4 DRVs in each, traversing the network into 2 different evacuation centers. A total of 67 DRVs joined the operations over the time and 50 additional vehicles coming from private institutions traveling on their own rescue operations with different origins and destinations. No road obstructions were considered so traffic movements can access all five bridges defined in the network. During the simulation run, DRVs were expected to pass the nearest bridge on its trip to the destinations or evacuation areas. Thus, passing only the routes that gave shortest time traveled. One snapshot for model scenario 1 used Agent ID#58, experimenting a DRV trip starting from the Aluba Fire Station (Origin) passing Kagay-an Bridge going to Balulang Evacuation Center dropping point (Destination) then back to its origin (Appendix D).

4.4.2 Scenario 2: with bridge closures

In this scenario, road obstructions were represented as bridge closures in the network. The link ids of the identified bridges for closure were required as the data needed to run the java class for road closure generation. In the experiment performed, the link ids of the following three bridges were entered; *Gov. Ysalina Bridge*, *Kagay-an Bridge* and *Maharlika Bridge*. The same two evacuation areas and fifty additional vehicles were considered in the experiment. This time considering road obstructions of three bridges only. The DRVs and other vehicles were expected to pass only to the two remaining bridges not included in the road closure generation; *Emmanuel Pelaez Bridge* and *Kauswagan-Puntod Bridge*. The expectation of vehicle movements was met as seen during the visualization of the output. One snapshot of model scenario 2 used Agent#58, experimenting a DRV trip starting from the Aluba Fire Station (Origin) passing Emmanuel Pelaez Bridge going to Balulang Evacuation Center dropping point (Destination) then back to its origin (Appendix E).

4.5 Model Results Analysis and Evaluation

4.5.1 Scenario 1: no bridge closures

Based on the generated events file, there were 667 directed links used by agents representing the DRVs. It was about 6.9 percent of the total 9630 directed links in the network. The events file stored all activities of 117 agents, 67 agents represented the DRVs and 50 agents represented the additional other vehicles. Finally, when no bridge obstruction occurred, the DRVs coming from 86% of the entities passed by the Carmen Bridge. For faster road traffic access, it was identified that Carmen Bridge can be established exclusive for DRVs during disaster response together with the 667 directed links.

4.5.2 Scenario 2: with bridge closures

Results showed that there were 841 directed links used by agents representing the DRVs, about 8.7 percent of the total 9630 directed links in the network. Note that three bridges (*i.e. Marcos Bridge, Carmen Bridge and Rotunda Bridge*) were considered for road closures. DRVs originated from 90% of the entities passed by Kauswagan-Puntod Bridge. Therefore, it was identified that this bridge and the 841 directed links were potential candidates in declaring routes for exclusive use of DRVs.

4.5.3 Evaluation using face validation from field experts

The goal was to verify and validate if the simulation model had a reasonable representation of the real-world system and its conformance in the design specifications (Table 1) and operational behavior (Table 2). Four domain experts were invited from the field of traffic engineering, computing, planning and management for the face validation. Two evaluators were invited from the academe, one was a Transportation Engineering and Built Environment

Specialist and the other was a Computing Scientist. The other two evaluators were from the local government units, one was handling management and administration as Technical Supervisor from Road and Traffic Administration Office and the second was involved in planning as Coordinator of Cagayan de Oro City Planning Office.

Table 1: Model Design Specifications VERIFICATION Sheet

Criterion	**Reasonable Results** (Accepted/Rejected)
(1) Road Network Graphical Representation	Accepted
(2) Entities Location Map Coordinates	Accepted
(3) Disaster Response Vehicles as Agents	Accepted
(4) Dropping Points Location Map Coordinates	Accepted
(5) Bridge Closures Using Link IDs and Directions	Accepted
(6) Other Vehicles as Agents	Accepted

Table 2: Model Operational Behavior VALIDATION Sheet

Criterion	**Reasonable Results** (Accepted/Rejected)
(1) Road Network Shows Five Bridges	Accepted
(2) Acceptable Locations of Entities	Accepted
(3) Agent Travel From Source to Destination	Accepted
(4) Agent Travel From Destination Back to Source	Accepted
(5) Acceptable Location of Dropping Point	Accepted
(6) Bridge Closure Takes Effect	Accepted
(7) Agent Avoid Bridge Closure	Accepted
(8) Agent Find Other Route From Source to Destination if Bridge Closure is Encountered	Accepted
(9) Other Agents Present	Accepted

Either accepting or rejecting, the field experts evaluated the simulation model in terms of reasonableness based on their field of expertise. On the final output results, the experts from the academe accepted the design specifications and operational behavior of the simulation model. Directions of streets or network links were verified as non-prone disaster links by the administrative experts based on actual records of the local government unit and commented for consideration on relocating the assigned evacuation center to nearby higher grounds farther from the assumed location of evacuation center.

Generally, the four evaluators verified, validated and accepted the design specifications of the simulation model as well as validated and accepted the operational behavior of the simulation model.

4.5.4 Travel time validation using test car technique and simulation model results

Looking at the plans file, from both scenarios, it was found out that the calculated travel time resulted from the simulation was actually equal to the amount of running time that the vehicle was in actual motion. The running time was computed as equal to the difference between the travel time and stopped time delay. Validation of actual measurement of travel time and delay using test car technique (Mappala and Javier, 2013) and simulation model were compared as shown in Table 3 with actual routes from Madonna and Child Hospital to Balulang Elementary School.

Table 3: Validation using Test Car Technique and Simulation Model

Route: From Madonna & Child Hospital To Balulang Elementary School (Total distance = 4.4km)	
A. Actual Measurement Using Test Car Technique	
Total travel time	00:22:04
Total delay	00:14:04
Total Running Time	00:07:59
Speed Ranges	11.95km/hr to 35.75 km/hr *(Source: MyTracks)*
B. Travel Time Using Simulation Model	
Total travel time	00:05:08
Total delay	none
Total Running Time	00:05:08
Speed Ranges	14.4 km/hr to 79.2 km/hr *(Source: MyTracks)*

Delay time was the time lost by traffic due to traffic friction, traffic control devices and geometric designs. The actual running time computed was only 36 percent from the actual total travel time measured due to the amount of travel time delay. The difference between the actual running time computed and running time resulted from the simulation model was mainly caused by the vehicle speed ranges.

5. CONCLUSIONS

In conclusion, the transport simulation model developed was reasonably accepted by the field experts coming from four different areas of traffic engineering and simulation expertise. Its design specifications and operational behavior was clearly demonstrated in the scenario experimentations and visualizations. Therefore, the paths generated by Dijkstra's algorithm in the simulation model can be utilized by traffic management decision-makers in determining traffic routes for exclusive use of disaster response vehicles in times of disaster. Based on results presented, the shortest paths traversed by the agents from origin to destination were not the same shortest paths traversed in returning to its origin, a one-way direction of links limitation in MATSim. Future studies can look into this limitation of having a one-way direction of links and extreme cases when all bridges connecting CDO-District 1 and CDO-District 2 are non-passable.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the guidance and information received from the developers of Multi-Agent Transport Simulation (MATSim), Prof. Dr. Nagel Kai of Transport Systems Planning and Transport Telematics at the Institute for Land and Sea Transport Systems, in Berlin, Germany and Dr. Marcel Rieser of Senozon AG in Switzerland.

APPENDIX A: CDO City Urban Road Network from GIS City Planning Office of Cagayan de Oro City

Source: GIS City Planning Office, 2012

APPENDIX B: List of CDO Hospitals, Fire Stations and Police Stations

Table 1: List of Selected Cagayan de Oro City Hospitals

Name of Hospital	Address	Quantity of Ambulance Vehicles
(1) Cagayan de Oro Medical Center	Tiano Street	1
(2) Capitol University Medical City	Gusa Highway	2
(3) City Hospital	Carmen	2
(4) Madonna and Child Hospital	Serina Street, Carmen	2
(5) Maria Reyna Hospital	Hayes Street	4
(6) Maternity Hospital	Gaerlan Street	1
(7) Polymedic General Hospital	Don Apolinar Velez Street	1
(8) Polymedic Medical Plaza	NHA	1
(9) Provincial Hospital	Corrales Avenue	4
(10) Sabal Hospital	Don Apolinar Velez Street	1

Source of Data: Department of Health (DOH), 2014

Table 2: List of Cagayan de Oro Bureau of Fire Protection Stations

Name of BFP Station	Address	Quantity of Fire Trucks
(1) Station 1-CV Roa (**Central Area)**	Capt. Vicente Roa	1
(2) Station 4-Nazareth		
a. Sub-station-Aluba (**South**)	Macasandig	1
(3) Station 5-Macabalan (**North**)	Macabalan	1

Source of Data: Facts and figures from interview with FO3 Henry A. Afdal, 2014

Table 3: List of Cagayan de Oro City Police Precinct Stations (PPS)

Police Precinct No.	Address	Quantity of Police Vehicles
PNP Headquarter	Gumamela Extension, Carmen	11
COCPO CPSC	Gumamela Extension, Carmen	14
1 (Divisoria)	Pabayo, Abejuela Streets	2
2 (Cogon)	Osmena, JR Borja Streets	2
3 (Agora)	Gaabucayan St	2
4 (Carmen)	Ipil Street., Carmen Market	2
5 (Macabalan)	Julio Pacana, Puntod	2
9 (Macasandig)	Jupiter Street.	2

Source of Data: COCPO, 2014

Table 4: List of Synthetic Evacuation Centers

Name of Evacuation Center	Address
(1) Balulang Elementary School	Balulang
(2) Burgos Barangay Hall	Burgos

APPENDIX C. Spatial Coverage of the Road Network in XML Formal and Locations of Facilities in the Network.

An estimated spatial coverage of 73.2 square kilometers includes the land, its surrounding river and coastal areas. The facilities are mapped based on its actual geographical x and y coordinates in the road network consisting of 23 facilities located in its nearest link in the network, 10 hospitals, 3 fire stations, 8 police stations and 2 evacuation centers.

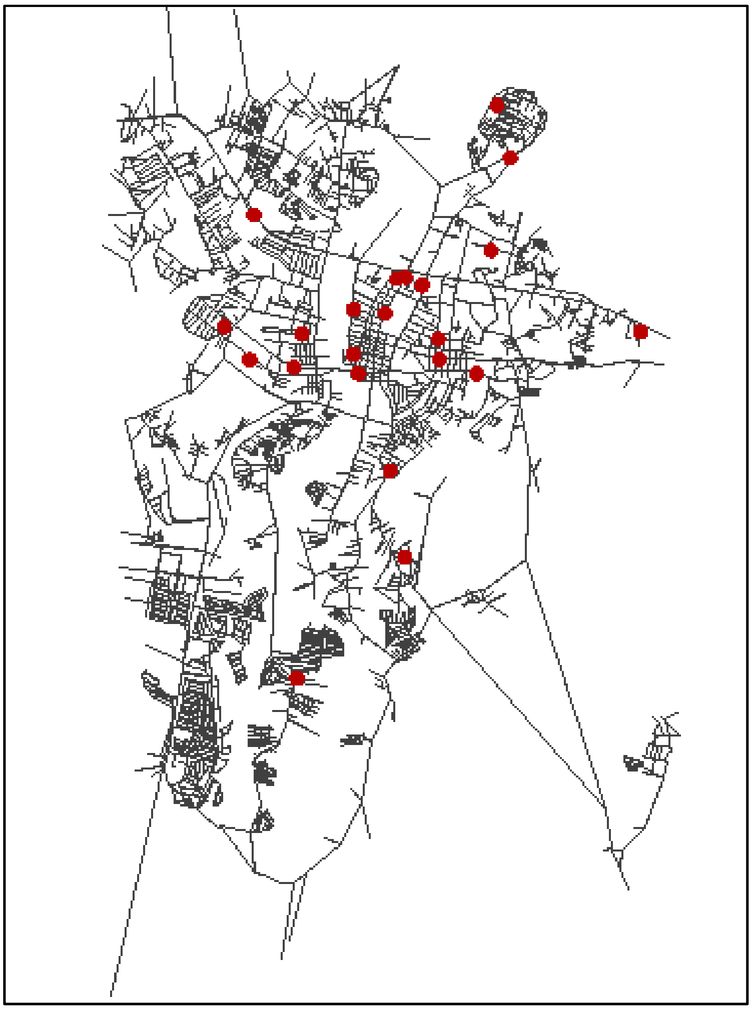


Figure 7: Road network in XML format (Note: Dots representing locations of DRV depots)

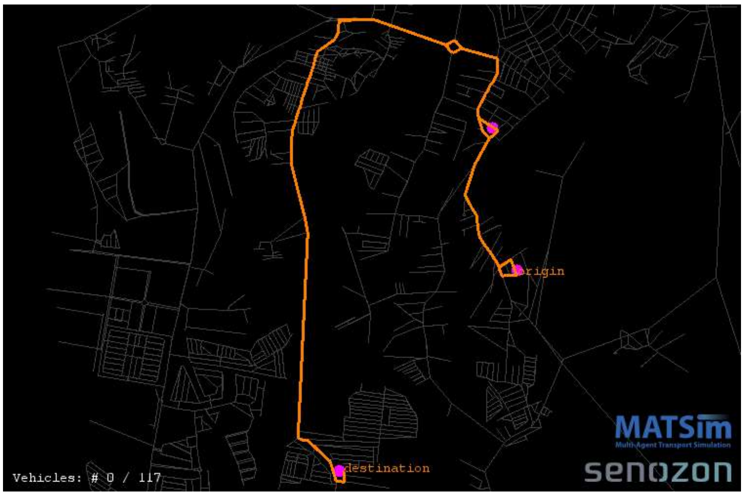
APPENDIX D. Screenshot of Model Scenario 1-No Bridge Closures

Model Scenario 1 using Agent ID#58:

Agent ID# : 58
Origin : Aluba Fire Station
Destination : Lower Balulang Evacuation Center
Routes (O-D) : **530** 362 360 3663 3661 3659 3657 3655 3653 3651 3649 3647 3645 3643 3641 3639 3637 3309 3311 5559 5561 5772 5773 6358 9739 9741 9743 9745 9747 9749 9751 9753 9755 9757 5304 8592 5066 5067 5068 8695 4707 4762 3937 5088 3368 3370 3372 3374 3376 3378 3380 3382 3384 3386 3388 3390 3392 3394 3396 3398 3400 3402 3404 3406 3408 3410 3412 3414 3416 3418 4657 5117 5119 5121 5123 7010 6190 **6192**
Travel Time **: 00:06:55**
Routes (D-O) : **6192** 6193 6191 7009 5124 5122 5120 5118 4658 3419 3417 3415

3413 3411 3409 3407 3405 3403 3401 3399 3397 3395 3393 3391 3389 3387 3385 3383 3381 3379 3377 3375 3373 3371 3265 3938 4763 4708 4723 5062 5063 5064 9537 5305 9758 9756 9754 9752 9750 9748 9746 9744 9742 9740 6359 4796 4797 3312 3310 3636 3638 3640 3642 3644 3646 3648 3650 3652 3654 3656 3658 83 85 **530**

Travel Time **: 00:06:47**



APPENDIX E. Screenshot of Model Scenario 2-With Bridge Closures

Model scenario 2 using Agent#58:

Agent ID# **: 58**

Origin : Aluba Fire Station

Destination : Lower Balulang Evacuation Center

Routes (O-D) **: 530** 362 360 3664 3666 3668 3670 3672 3674 3676 3678 463 465 467 469 471 473 475 477 479 481 483 277 279 281 5342 5340 5338 5336 5334 5332 5229 7548 7546 7544 7633 5214 18 16 7723 7725 7727 7729 7731 4537 4539 4541 4543 4545 4547 4549 8011 8009 5146 5144 5142 5140 5138 5136 5134 5132 5130 5128 5126 7010 6190 **6192**

Travel Time **: 00:08:31**

Routes (Return) **: 6192** 6193 6191 7009 5125 5127 5129 5131 5133 5135 5137 5139 5141 5143 5145 8008 8010 4550 4548 4546 4544 4542 4540 4538 7732 7730 7728 7726 7724 15 17 5213 7632 7543 7545 7547 5228 5331 5333 5335 5337 5339 5341 282 280 278 484 482 480 478 476 474 472 470 468 466 464 3679 3677 3675 3673 3671 3669 3667 3665 3663 3661 83 85 **530**

Travel Time **: 00:08:38**

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