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UMI
Accident Risk Assessment Using Microsimulation for Dynamic Route Guidance

BY

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A thesis submitted in conformity with the requirements for the degree of Master of Applied Science

Graduate Department of Civil Engineering

University of Toronto

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ABSTRACT

Dynamic route guidance systems (DRG) provide routing information to motorists based on current traffic conditions on a network. However, not enough attention has been given to the impact of such dynamic routing decisions on the overall safety of the network in terms of the predicted number of accidents. The objectives of this research are to investigate the variation of network-wide accidents caused by traffic redistribution subject to various levels of DRG market penetration, and to examine the potential of a new safety-enhanced route guidance system (SRG). A microsimulation model was developed and integrated with a set of accident prediction models (APM) for links and intersections. The accident estimates obtained from this APM-integrated microsimulation model were plotted against time to produce accident profiles that could explain the relationships between DRG or SRG market penetrations and the number of network-wide accidents.
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CHAPTER 1
INTRODUCTION

Route guidance systems are becoming one of the most popular in-vehicle devices, with potential significant contribution to real time network control. Rapid developments of intelligent transportation system tools expand the collection of real-time traffic information on networks so that dynamic route guidance systems (DRG) could take into account the prevailing traffic conditions and suggest routes to drivers with minimum travel time.

Pathfinder, TravTek, ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) and TANGO (Traffic Information and Navigation in Gothenburg) are examples of relatively large-scale projects conducted to evaluate network performance. These projects focused on whether route guidance systems could help drivers to avoid congestion and improve the quality of their trips. However, these studies required significant resources. For example, ADVANCE required more than 3,000 private and commercial vehicles. From a safety standpoint, Picado (1) suggested that the test vehicles in large-scale projects did not log enough miles to conduct a risk analysis.

An alternative to this problem is to use traffic microsimulation models, which are capable of realistically emulating the flow of individual vehicle units on a network. Models such as RGCONTRAM and Paramics have been used in pilot studies (2-3) to model and evaluate the network-wide effects of DRGs. However, not enough attention has been given to the impact
of such dynamic routing decisions on the overall safety of the network in terms of the predicted number of accidents.

The objectives of this research are to investigate the variation of network-wide accidents caused by traffic redistribution subject to various levels of DRG market penetration, and to examine the potential of a new safety-enhanced route guidance system (SRG).

A microsimulation model was developed using Paramics and integrated with a set of accident prediction models for links and intersections. This APM-integrated microsimulation model was utilized to collect pertinent flow information on a network every five minutes and quantified the accident potential for both links and intersections. These accident estimates were plotted against time to produce accident profiles that could describe the change of accident occurrence during a given period of peak traffic. Together with the average travel time calculated by the simulation model, these accident profiles could be used to explain the relationships between DRG market penetrations and the number of network-wide accidents.

The APM-integrated microsimulation model was also applied to create SRGs by suggesting routes with the fewest estimated accidents. The accident profiles for various SRG market penetrations were also produced to examine the SRG impact on network-wide accidents.
CHAPTER 2
LITERATURE REVIEW

Accident potential is primarily related to traffic volume, which is the most common independent variable for accident prediction models (APMs). Dzbik et al. (4) developed both macroscopic and microscopic APMs for freeways in Ontario using flow and length of road segments as variables. Macroscopic APMs calculate accident frequency using daily traffic flow whereas microscopic APMs use hourly volume. They concluded that the afternoon congested period has a higher accident rate than the morning rush period for expressways. Mucsi (5) developed microscopic APMs for 2-lane rural roads in Ontario. Again, the results indicated the difference of accident potential between day and night.

DRGs cause traffic redistribution on a network. As rerouting activities occur in real-time, the evaluation of network accidents for shorter time intervals becomes important. Therefore, comparing microscopic versus macroscopic APMs, microscopic prediction models seem to be a more appropriate model form to study DRGs as they can estimate accidents for shorter time intervals.

In Ontario, the overall within-intersection and intersection-related collisions constituted 45 and 44.7 percent of all collisions in 1995 and 1997 respectively (6-7). The number of per-trip turns at intersections could increase as drivers reroute more frequently to achieve travel time reduction following the provided guidance. As turning traffic at intersections is one of the major sources of accidents, as is the case in Toronto, it seems plausible for a route
guidance system to attempt to minimize the number of turns on recommended routes in order to avoid turning accidents. Intended for safety purposes or not, some route guidance devices are currently available in the market, such as the navigation unit NVA-N751AS by Alpine, that provide the option of minimizing the number of turns in recommended routes.

Several studies have investigated intersection-related implications of route guidance. Blue et al. (8) considered the trade-off between time and sum of turns, which they called complexity, at intersections on a network. Upadhyay et al. (9) demonstrated that the effectiveness of route guidance is related to the level of intersection delays. Regarding safety analysis using APMs and simulation, Chatterjee and McDonald (2) carried out a study on a network in the UK to examine the impact of modified routing patterns resulting from the provision of information by DRGs on accident risk. Network safety effects were also examined. Lord et al. (3) carried out a similar study using part of the Toronto network. However, all the above studies used macroscopic APMs and the calculation of accident frequency was static and external to the traffic simulations. Thus, the effects of the instantaneous change of accidents due to the applications of DRGs were in fact not fully captured.

Considering the significance of accidents at intersections and the need for dynamic accident prediction, this study combined microscopic accident prediction models for intersections and traffic microsimulation, thus the actual variations of short-term accidents on a dynamic traffic network can be precisely described.
The APM-integrated microsimulation model developed in this study simultaneously collects all the turn counts at every intersection and the traffic counts for each direction on a link every five minutes. APMs were then applied to quantify the accident potential for both links and intersections using the collected traffic counts at the same intervals. This real-time accident estimation process was also applied to possibly enhance the utility of DRGs via potential accident risk minimization. Although these safety-enhanced route guidance systems (SRG) suggests motorists to minimal accident risk routes in a user-optimal fashion, the study on overall impacts on the system is also important. Therefore, the evaluation model was again utilized to examine the overall effects of SRG on network safety.
CHAPTER 3

METHODOLOGY

3.1 Accident Prediction Models

Accident Prediction Models are developed to quantify the number of accidents for a specific reference population from which they were derived. This is because the accidents that occurred or reported may vary among jurisdictions due to a number of factors, such as the monetary threshold for reporting accidents or the local driver characteristics. Since all the three cases in this study were based on Toronto area, all APMs for links and intersections were developed for the City of Toronto and are described as follow.

3.1.1 Intersection APM

At the University of Toronto, Hauer et al. [10] developed 15 models to describe different types of collision patterns for 145 urban signalized intersections in Metropolitan Toronto. All intersections had fixed-time signals with two-way traffic flows on all approaches and no turn restrictions. These models estimate accidents per hour for different turning movements based on the corresponding turning flow per hour. Only 5 major models out of the 15 models were selected for this study since they have covered 87% of the total accidents for the reference population. The models for left and right turning accidents are:

\[
E\{m_{\text{Left}}\} = 0.0418 \times 10^{-6} \times F_C \times F_L^{0.4634} \tag{1}
\]

\[
E\{m_{\text{Right}}\} = 1.7741 \times 10^{-9} \times F_C^{1.1121} \times F_R^{0.5467} \tag{2}
\]
Where,

\[ E\{m_{\text{Left}}\} = \text{expected number of left-turning accidents for one hour}, \]
\[ E\{m_{\text{Right}}\} = \text{expected number of right-turning accidents for one hour}, \]
\[ F_C = \text{hourly flow of conflict traffic for the turning movement}, \]
\[ F_L = \text{hourly left-turning traffic flow}, \]
\[ F_R = \text{hourly right-turning traffic flow}. \]

Three major types of collisions constituted the majority of accidents that are caused by the through traffic at intersections. The three models are:

\[ E\{m_{\text{Thro}}^1\} = 0.2052 \times 10^{-6} \times F_T \]  \hspace{1cm} (3)

\[ E\{m_{\text{Thro}}^2\} = 0.1014 \times 10^{-6} \times F_T \]  \hspace{1cm} (4)

\[ E\{m_{\text{Thro}}^3\} = 8.1296 \times 10^{-6} \times F_C^{0.3662} \]  \hspace{1cm} (5)

Where,

\[ E\{m_{\text{Thro}}^1\} = \text{expected number of accidents before entering intersection}, \]
\[ E\{m_{\text{Thro}}^2\} = \text{expected number of accidents inside the intersection}, \]
\[ E\{m_{\text{Thro}}^3\} = \text{expected number of accidents with right-coming traffic}, \]
\[ F_T = \text{hourly flow of through traffic}, \]
\[ F_C = \text{hourly flow of right coming conflict traffic}. \]
The total number of accidents at an intersection for through traffic movements therefore can be estimated by:

\[ E\{m_{\text{tho}}\} = E\{m_{\text{tho}}^1\} + E\{m_{\text{tho}}^2\} + E\{m_{\text{tho}}^3\} \]  

(6)

The relationship between predicted left turning and right turning accidents and the conflicting traffic flows are shown in Figure 1. The figure shows that for the same levels of conflicting flows, there is a significant difference between the numbers of accidents caused by left and right turning movements. Since the difference of accident rates increases with the traffic demand, the use of a microscopic approach for the evaluation of accidents at intersections is clearly justified, especially at intersections with heavy traffic.

**FIGURE 1** Estimated accident frequency per year for ranges of turning flows and conflicting traffic flows at intersections. ('50, right' means 50 right turning vehicles per hour)
3.1.2 Link APM

Since a microscopic APM for links was not available for the same reference population as for intersection models, a macroscopic model was used but it was modified in order to provide more accurate accident estimations. For example, consider the link model adopted for the hypothetical network in case 1, which was developed by Lord(11) using 220 4-lane road sections in Toronto, of which 59 were in the CBD and 161 in non-CBD areas. The accident data, from years 1985 to 1995, was provided by the Traffic Data Centre of Metro Transportation. The model form is:

\[
E\{m_{\text{Link}}\} = 1.02 \times 10^{-4} \times L^{0.498} \times F^{1.205} \tag{7}
\]

Where,

\[
E\{m_{\text{Link}}\} = \text{expected number of accidents for 1 year},
\]

\[
L = \text{length of section in kilometers},
\]

\[
F = \text{link flow in ADT for both directions}.
\]

For the above macroscopic model, the traffic flow term “F” is the sum of flows for the two directions on a link. Because of the exponential term of the flow variable in the model, the predicted accidents for a link using the total traffic flow cannot be distributed between the two directions using simple flow proportions. Therefore, in the current microscopic analysis, the proportion of the predicted total accidents for the south bound, for example, is

\[
\frac{S^b}{(S^b+N^b)}
\]

while for north bound is

\[
\frac{N^b}{(S^b+N^b)}
\]

where \( b \) is the exponential term of the flow variable in the link model.
3.2 Accident Risk Consideration in Route Assignment

Previous sections described the estimation of accident rates using APMs for all components of a network. These accident estimates can be applied to incorporate safety consideration in route choice in order to achieve safety-enhanced dynamic route guidance systems (SRG).

Maher et al. (12) examined the optimization of flows in a network with minimum delay and accident frequency and concluded that the incorporation of accidents in optimization has very little effect. Other researches (2-3) have also studied the applications of route choice by minimizing the risk of accident involvement as well as the evaluation of the resulting network safety performance. Both studies used travel time penalty multipliers or cost factors to increase the travel time/cost for high-risk routes, thereby rerouting drivers to less risky routes. Researchers in study (2) used 10% travel time multipliers for intermediate roads and 50% travel time multipliers for minor roads. They expected that the accident risk of traveling on a major road would always be lower than traveling on an intermediate or minor road.

In a dynamic traffic system, however, if we consider the quantified accident risk using APMs, there may be chances that traveling on a low-demand minor link has a lower quantified accident risk than traveling on a major link with relatively higher flow. Also, the argument that as distance traveled is reduced, the rate of accident drop is questionable since it is possible that a longer link with less number of intersections might be safer. In any of these cases, the prevailing traffic condition is in fact the key factor when safety of a route is considered. Thus, the need for a dynamic model for safety assessment is again evident.
3.3 Application of APM to Risk Assessment

3.3.1 At Intersections

Recall that for left turning movements, the model to describe the expected accidents in one hour is given by equation (1). Assuming that the overall risk is uniformly shared among all vehicles, the risk of an individual vehicle being involved in an accident while making a left turn would be:

\[ E\{r_{\text{Left}}\} = \frac{0.0418 \times 10^{-6} \times F_C \times F_L^{0.4634}}{F_L} \]  

(8)

Similarly, for right turning movement,

\[ E\{r_{\text{Right}}\} = \frac{1.7741 \times 10^{-9} \times F_C^{1.1121} \times F_R^{0.5467}}{F_R} \]  

(9)

For through traffic movement, the models for the three possible types of collision are given by equations (3,4,5). The risk of having an accident while passing through an intersection is therefore:

\[ E\{r_{\text{Thro}}\} = \frac{E\{m_{\text{Thro}}\}}{F_T} \]  

(10)

Where

\[ E\{m_{\text{Thro}}\} = E\{m_{\text{Thro}}^1\} + E\{m_{\text{Thro}}^2\} + E\{m_{\text{Thro}}^3\} \]  

(11)
Figure 2 shows the relationship between accident risk associated with different conflicting traffic and turning flows. Substantial difference in risk between left and right turns was observed which suggested that accident risk saving might be achieved by proper assembling of consecutive turning movements in route guidance.

![Figure 2](image)

**FIGURE 2** Estimated accident risk per year per vehicle for ranges of turning flows and conflicting traffic flows at intersections. (50, right : 50 right turning vehicles per hour)

### 3.3.2 On Links

The standard form of APM provides an exponential term to the traffic flow variable. Some studies (4, 13, 14) presented models with the exponential term less than 1 and some studies (4, 5, 15) with this term greater than 1. The predicted accidents on a link are calculated using equation (7). Assuming uniform risk distribution among all vehicles, the risk to an individual driver passes through a link is:
Figure 3 depicts an APM with an exponential term less than 1. For a certain number of vehicles, $dV$, on a link with a higher traffic flow being rerouted to another link with a lower flow, the marginal accident frequency will increase from $dA_b$ to $dA_a$. This would imply that, with exponential term less than 1, the total accidents on a network increase when traffic is being evenly distributed among all the links on a network. In other words, when a route guidance system attempts to reduce accident potential of a driver, it would divert traffic to more congested routes, where the per-vehicle risk is lower. It has been actually found that for route guidance based on minimum accident potential, traffic flow tends to concentrate on as few links as possible (3, 12).

\[ E\{r_{\text{Link}}\} = \frac{1.02 \times 10^{-4} \times L^{0.498} \times F^{1.205}}{365 \times F} \]  \hspace{1cm} (12)

**FIGURE 3** Accident prediction model for a link with an exponential term for flow variable less than 1.
Since the exponential term of the above link model is greater than 1, one might infer that the less the flow, the less would be the risk of getting into an accident. Therefore, when accident risk is considered in route choice, traffic will be evenly distributed on a network. However, this assumption has neglected the effect of intersections. In reality, the intersections on a traffic network with dynamically changing turning flows would cause network-wide accident risk to fluctuate depending on the cumulative effect of turning movements. Therefore, in the case of general networks, a dynamic accident assessment model applied to the specific network would enable explicit conclusions to be drawn.

3.4 Route Assignment Model for DRG

The driver population is divided into ‘familiar’/informed and ‘unfamiliar’/uninformed drivers. To emulate the effect of DRG market penetrations, information on the present state of traffic conditions is fed back to a certain percentage of familiar drivers such that they are able to select the route with the least travel time cost. This cost is in the form of remaining time in seconds to the destination for each alternative route at each junction.

3.5 Route Assignment Model for SRG

During simulation, the internal APMs could calculate the accident risk for all turns and links on every candidate route. The best routes suggested by SRGs therefore could be selected based on the minimum accident risk. The corresponding turning decisions were determined for all vehicles heading in different destinations. These turning decisions were fed back to SRG-equipped drivers every five minutes such that the target portion of equipped drivers under investigation could reroute accordingly without stochastic perturbation.
There is a limitation of using the current APM for accident risk calculation in SRG route assignments. Accident prediction models for links utilize daily flow as the main input variable, leading to an increase in the number of predicted accidents as daily flow increases and vice versa. Daily flow in this case is used as an indication of 'exposure'. When short-term flow measures such as hourly volume is used to calculate the accident risk for SRG, results could be potentially misleading. Elementary traffic flow theories show that traffic flow drops when congestion develops. This could lead to guiding travelers to heavily congested routes, deceived by the low flow variables. This is due to the fact that flow is not unique and there are two flow values associated with every speed or density value. This perhaps can explain the observation by Lord et al. (3) that there is significant increase in travel time when safety is considered in route choice. This highlights the importance of combining travel time consideration in SRG route assignments when APMs are used for accident risk estimations under congested traffic conditions.

To this end, several methods have been used in previous research to combine travel time and accident risk for route assignments in SRGs. Chatterjee and McDonald (2) used 50% travel time penalty for minor links. Lord et al. (3) used various cost factors for different links with different accident risk.

In fact, the decision to reroute depends on numerous factors such as the perceived accident cost or trip cost. Judycki (16) defined willingness-to-pay cost as the cost that motorists are willing to pay for safety improvements to avert a fatality or injury. But he revealed that these cost estimates show the amount motorists actually pay to reduce accident risks, not
necessarily what they are willing to pay. Not only may different drivers have different perceived costs, even for the same driver, the perceived cost may vary with trip purposes. In fact, drivers are more likely to reroute if they are on a long trip (I). The perceived safety cost becomes even more debatable for across-type safety comparisons such as a freeway route versus a surface street route. This is due to the substantial differences between travel time and safety for the two types of facilities. Picado(I) further suggested that, in order to save time by diverting from a freeway, the level of freeway congestion must be quite severe.

In light of the above complex issues, it is very difficult to include the development of a generic travel-time multiplication factor for SRG route assignments. More in-depth research is required. Perhaps this was also the reason why both studies (2-3) have not described the rationale behind the penalty or multiplication factors. To resolve this limitation, the layout for all networks in this study were orthogonal, which enabled the accident risk to be the only route choice criteria for SRGs as long as there is no significant variation on travel time caused by congestion.

The exit table shown in Table 1 consists of all the turning decisions for the target number of SRG-equipped vehicles being simulated. These turning decisions computed by the SRG route assignment models after accident risk calculations. These turning decisions were represented by the indices from 0 to 3. The index 0 represents the default turning decision computed by the internal route assignment model. For all the orthogonal networks in this study, the indices for right and left turns at the end of a link were 1 and 3 respectively. The through traffic across intersections was denoted by the index 2.
### Table 1 Exit Turn Table

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#### The Overall Dynamic Accident Estimation Model

The dynamic accident estimation model was developed via integrating the APMs with traffic simulation using the Application Programming Interface (API) of Paramics, which is a microscopic simulation software developed by Quadstone (17). The coding of the API developed is presented in Appendix B. During simulation, the API extracted real-time network and vehicle information using the call-back functions provided by the simulation software. This information was then passed to the APMs as data input for accident calculations. The logical flow diagrams of the integrated model for DRG and SRG are presented in Figure 4 and 5 respectively. The API program, which included the link and intersection tables as shown in Table 2 and 3, was loaded together with the simulation network before simulation started. The link and intersection tables contain all the information required for the estimation of accidents using the internal APMs. These accident estimates were also used to determine the appropriate turning decisions that computed by the SRG route assignments. These turning decisions were stored in the exit turn table. The order of
the entries in all tables followed the internal computation sequence of the simulation model.

This computation sequence was the order of which the simulation software updated all vehicle movements and network information during traffic simulation. The sequence is presented in Appendix C. The simulation software employed this computation sequence to update the link and turn counts on all tables without searching and matching for data records, thus significantly reduced the computation overhead.

**Intersection Table**

<table>
<thead>
<tr>
<th>Index</th>
<th>Turn Count</th>
<th>Turn Direction</th>
<th>Conflicted Turn Index</th>
<th>Conflicted Turn Count</th>
<th>Accident Risk</th>
<th>Accident Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12</td>
<td>R</td>
<td>75</td>
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<td>0.003578</td>
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<td>8</td>
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<td>0.022829</td>
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</tbody>
</table>

**TABLE 2** Intersection table structure.

**Link Table**

<table>
<thead>
<tr>
<th>Index</th>
<th>Traffic Count</th>
<th>Link Length</th>
<th>Opposing Link Index</th>
<th>Opposing Link Traffic Count</th>
<th>Accident Risk</th>
<th>Accident Frequency</th>
</tr>
</thead>
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<tr>
<td>0</td>
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<td>0.484</td>
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<td>73</td>
<td>27</td>
<td>0.024923</td>
<td>0.69783</td>
</tr>
</tbody>
</table>

**TABLE 3** Link table structure
The warm-up period for the simulation was 15 minutes, which exceeded the longest average travel time on this network. During simulation, the model simultaneously collected all 12 turning counts at each intersection and traffic counts for each direction of every link every 5 minutes. The turn counts were extracted from the network and stored on the link and intersection tables for accident calculations. These calculations were performed every five minutes. The calculated accident frequencies and rates were then stored on the tables and also displayed on the report interface. At the end of simulation, the total accidents for links and intersections were also reported. No pedestrian accidents were considered.

The average saving on accident risk is the percentage difference between the lowest and highest computed accident risk for all routes leading to the same destination. Since this value was crucial for the evaluation of SRG benefits, it was also reported at the end of the simulation.
Start

Load API program on simulator and create tables for links and intersections.

Warm up the simulation

Time-step start

Update traffic counts for links and intersections

Time-step end

Yes

Calculate total accidents and risk for links and intersections

Output accidents for links and intersections for this time-step

No

Simulation end

Yes

Output total accidents for intersections and links for the entire simulation period

End

FIGURE 4 Program flow of the dynamic accident estimation model for DRG.
Load API program on simulator and create tables for links, intersections and exit decisions

Warm up the

Time-step start

Vehicles reroute following exit decision table

Update traffic counts in tables

Link table Intersection table Exit decision

No

Time-step end

Yes

Calculate total accidents and risk for links and intersections for this time step

Output accidents for links and

Update exit decisions

Simulation end

No

Yes

Output total accidents for intersections and links for the entire simulation period

End

FIGURE 5 Program flow of the dynamic accident estimation model for SRG.
CHAPTER 4
MODEL APPLICATIONS

4.1 Case 1 - Hypothetical Network

The integrated simulation model was applied to a hypothetical urban network as shown in Figure 6. Hypothetical networks in fact have been used in many studies (8, 18) in which explicit conclusions have been drawn regarding the evaluation of dynamic route assignments. The hypothetical urban network in this case study consists of 24 arterial links and 9 signalized intersections. The configurations of both links and intersections of the network were chosen to be compliant with the reference population from which the APMs were developed. This is to ensure an accurate and consistent estimation of accidents. The length of each link is 1 km, considering the minimum length requirement for reliable results (19). None of the links has internal minor intersections and therefore all links have the same accident potential for a given level of traffic flow.

FIGURE 6 Layout of the hypothetical urban network for case 1.
4.1.1 Traffic demand

The pattern and quantity of traffic demand affect the performance of DRGs in terms of travel time and variations of predicted accidents. The adopted traffic demand pattern simulated a peak in the middle of a two-hour simulation period as depicted in Figure 7. This demand pattern allowed the dissipation of congestion at the end of simulation. Thus enabled the measure of travel time reduction, which is the key benefit of DRGs or SRGs. In Figure 8, it can be seen that as the percentages of DRG or SRG-equipped drivers increased, the average travel time decreased to an asymptotic level. This trend indicates that DRGs and SRGs were effectively simulated at this demand level on this network.

![Traffic demand profile for hypothetical network in case 1.](image)

FIGURE 7 Traffic demand profile for hypothetical network in case 1.
4.1.2 Simulation Results and Discussions

4.1.2.1 Accident Profile

The accident estimates provided by the APM-integrated microsimulation model were plotted against time to generate accident profiles as shown in Figure 9. Summation of the accident estimates across the time axis is the total number of accidents (per year rate), which is also the area under the accident profile.

A closer look at the accident profile reveals quite interesting findings. When accident profiles of different DRG market penetrations were plotted on the same graph, a transition point T was observed. Before this transition point, there were more accidents when DRGs were used. But after this transition point, more accidents occurred when fewer drivers were equipped with DRGs. This finding can be further explained as follows:

FIGURE 8 Change of average travel time due to different market penetrations of DRG and SRG. (Case 1 - Hypothetical network)
FIGURE 9 Accident profiles for different market penetrations of (a) DRG and (b) SRG. (Case 1 - Hypothetical network)
When DRG-equipped drivers rerouted frequently to save travel time under congested conditions, traffic was more distributed and the network was more efficiently utilized. Due to the travel-time savings and the improved distribution of traffic, the overall network throughput has increased as more motorists reached destinations in shorter time. Since more traffic was handled on the network with more maneuvers and turns during this period, more accidents therefore occurred. This was more evident for higher DRG market penetrations.

When none of the drivers were using DRG, the travel time increased due to network inefficiency, and hence the network throughput dropped. After the transition point, although the traffic demand dropped below the congested level, a large percentage of drivers were still on the network, thus creating additional accidents. Therefore, even though the actual demand dropped below the congestion level beyond the transition point T, there were more accidents when fewer drivers were using DRGs.

In the early stage of our study, the safety impacts of DRGs and SRGs on a network were investigated by using the total number of accidents during one-hour simulation before the transition point. The overall deterioration of the safety of the network under route guidance was somewhat puzzling, as the lower level of accidents after the transition point was not yet observed. Therefore, it gave a false impression that guidance systems always increase the total number of accidents. In fact, for precise results, the comprehensive evaluation of DRG and SRG benefits should compare the difference between the total areas under the accident profiles as well as the average travel time for different market penetrations. As evident from the profiles, DRGs tend to compress the profile in time, resulting in higher accident rates.
early on, and lower accident rates later on in time. The early deterioration and the later improvement potentially outweigh each other to a large extent.

4.1.2.2 DRG

Figure 10(a) shows the percentage increase of link and intersection accidents subject to different market penetrations of DRG. Link accidents increased continuously to a maximum of 6% when all drivers were equipped with DRGs. Regarding intersection accidents, the maximum number of accidents occurred at 60% DRG market penetration. In Figure 7, the shortest average travel time was also obtained at this 60% DRG optimum. It therefore suggests that as long as DRGs are effective in reducing travel time, accidents would increase proportionally with market penetrations of DRG. Beyond the 60% optimum, due to the diminishing return of DRG performance, the number of accidents at intersections slightly decreased.

Figure 9(a) shows the accident profiles when 0, 10, 60 and 100% drivers were equipped with DRGs. Clearly, the levels of DRG market penetration affected the occurrence of accidents across time. The penetration levels also affected the number of total accidents, which is the area under the accident profiles. From the same figure, before the transition point, it is obvious that more accidents would occur for 60% than both 10% and 100% DRG-equipped network. This finding supports the 60% point of inflection we have discussed earlier in Figure 10(a).
FIGURE 10 Change of accidents due to different market penetrations of (a) DRG and (b) SRG. (Case 1 - Hypothetical network)
In summary, the number of accidents increased with the DRG market penetrations. However, the extent of increase is significantly dampened when the entire temporal profile is considered. A sixty-percent DRG-equipped network yielded the highest amount of intersection accidents during the peak demand period when congestion occurred. As traffic demand dropped below the congestion level after the transition point, the 60% optimal DRG market penetration led to the lowest number of accidents.

4.1.2.3 SRG

The route-choice criteria for SRG and DRG are different. The former is based on the quantified accident risk whereas the latter is based on the travel delay. Since SRGs were also dynamically rerouting traffic on the network, the average trip time was reduced when the percentage of SRG-equipped drivers increased. This trend is shown in Figure 7.

Figure 10(b) shows a slight increase in total intersection accidents at low SRG market penetration. As the market penetration increased, the number of intersection accidents decreased, which led to a reduction of total accidents. The reason for this trend is explained as follow:

The accident risk for SRGs was calculated using equation (8) to (12). In these equations, the calculated accident risk increased with the amount of conflict traffic flow ($F_C$). This implies that SRG-equipped drivers chose the routes with the least amount of conflicting traffic, thus the number of accidents at intersections would also be reduced.
Figure 9(b) shows the accident profiles for different SRG market penetrations. A transition point T was also observed. Before the transition point, when SRGs were used by drivers, the total accidents increased the most for 60-80% SRG market penetration. From the same figure, after transition point, the accident profiles overlap for various SRG market penetrations, indicating the insignificant impact of SRG market penetration on accident variation when the traffic demand was low.

From driver perspective, results show that there was an average saving on accident risk of approximately 10%. If a larger network is used, it is possible that the risk saving would increase because of the more significant variation of accident risk among candidate routes. In addition, assuming all drivers were sharing the total accidents on a network, as total accidents decreased when SRGs were used, the accident risk for SRG-equipped drivers was also reduced.

4.1.2.4 Comparison between DRG and SRG

It has been shown that the relationships between average travel time and DRG or SRG market penetrations were similar for this network. The accident profiles for 80% DRG-equipped and 80% SRG-equipped network are shown in Figure 11. It shows that the number of total accidents for SRG was lower than DRG throughout the high demand period before the transition point. But for the low demand period after the transition point, the predicted accidents were similar for the two types of guidance systems.
FIGURE 11 Accident profiles for 80% DRG-equipped and 80% SRG-equipped network. (a) link and intersection accidents, and (b) total accidents. (Case 1 - Hypothetical network)
4.2 Case 2 - DownTown Toronto Network

In addition to applying the APM-integrated microsimulation model to a hypothetical network in case 1, the model was further applied to the downtown Toronto area. Accident profiles were also produced to outline the accident trends when different percentages of drivers were equipped with DRGs or SRGs. With a real traffic network being modelled in this case 2 study, more explicit conclusions about the impact of DRGs or SRGs on network-wide accidents can be drawn.

The layout of the downtown network is shown in Figure 12. It covers the area from College Street southbound to King Street and from Bathurst Street eastbound to Jarvis Street. Since the APMs for minor roads and within-block intersections for the study area were not available, this study aimed on the predicted number of accidents for the 24 major signalized intersections and 38 major arterials within the study area. Similar to the hypothetical network in case 1, the pedestrian accidents were also outside the scope of this study.

The signal information, lane configurations and turning restrictions required for modelling the network were obtained on-site. It was found that stringent peak-hour route controls were implemented in the study area. Therefore, it was necessary to exclude the peak-hour turning restrictions at intersections in order to provide alternative routes for DRG or SRG-equipped drivers such that the effects of DRGs or SRGs could be preserved.
The APM-integrated microsimulation model in this case study employed the DRG and SRG route assignment models and the overall dynamic accident estimation model that have been used in case 1 for the hypothetical network. However, the integrated models were modified to accommodate the changes in accident calculation due to three factors, which were the consideration of link lengths in accident calculations, the difference of link models being used and the difference in simulation duration. In case 1 study, all links were non-CBD links, which were 1 km long and the simulation time was two hours. But in this case study using the real downtown Toronto network, all links were different in lengths and the simulation time was the three-hour morning peak period.

FIGURE 12 Layout of downtown Toronto network for case 2 and 3.
4.2.1 Traffic Demand

The traffic demand for the downtown network was obtained via traffic assignment using the EMME/2 network provided by the Joint Program at the University of Toronto. This traversal matrix was a flat demand covering the entire three-hour morning peak from 7:00 to 10:00 am. Origin and destination zones were created to feed traffic into the target area from all major arterials. Six internal zones were also created. All created zones were located at the virtual gate locations in the EMME2 network, at which the origin and destination traffic demands were collected during the three-hour simulation period using the EMME2 network. Afterward, the output O-D matrix designated by the virtual gates was converted to the appropriate traversal matrix format for the microsimulation model in this study. The converted traversal matrix is shown in Table 4.

Aggregation of the traversal matrix from the EMME2 network was necessary due to the difference in complexity between the EMME2 network and the microsimulation model in this study. The aggregation process included the distribution of traffic flow among major links for the uncoded minor links, and the combinations of origin and destination traffic flow for small zones into larger zones.

4.2.2 Network Calibration

The network was calibrated to reasonably represent the actual downtown traffic conditions. The parameters for network calibration included signposting, familiarity, staking stoplines and demand adjustments. The flow patterns, queue lengths and congestion spots were also examined and compared with the actual network traffic conditions during calibration.
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**TABLE 4 Demand matrix for downtown network**
The recurrent congestion for downtown area occurs on highways and major roads leading to the CBD area. This traffic condition reduced the amount of incoming traffic to the study area, thus serious congestion was not observed. The traffic was quite evenly distributed across the network during the morning peak since commuters are often very familiar with the traffic condition on a network.

4.2.3 Accident Prediction Models

The Accident Prediction Models for intersections in the downtown Toronto network were the same as those for the hypothetical network in case 1. However, the APM for links was different although it was also developed by Lord(11). The model is of the following form:

\[ E\{m_{\text{Link}}\} = 0.2592 \times L^{0.864} \times F^{0.491} \]  

(13)

Where,

\[ E\{m_{\text{Link}}\} = \text{expected number of accidents for 1 year}, \]
\[ L = \text{length of section in kilometers}, \]
\[ F = \text{link flow in ADT for both directions}. \]

This model is a mid-block model that predicts the number of accidents on a link without minor intersections. This model was applicable for this case study in which minor intersections for each link were also not considered. The distribution of predicted accident frequency and accident risk for each traffic direction on a link were also adjusted using the same method as described in Section 3.1.2 in case 1.
4.2.4 Simulation Results and Discussions

4.2.4.1 DRG

Figure 13 shows the accident profiles when 30, 40, 60 and 80% drivers were equipped with DRGs. No systematic trend was found between DRG market penetrations and link or intersection accidents. The maximum variation of link and intersection accidents subject to different DRG market penetrations was only less than 2%. The transition point $T$ found on the hypothetical network in case 1 was not observed on these profiles. These observations were discussed as follow:

With uncognested traffic condition on this downtown network, travel time saving by DRGs was insignificant, which also limited the extent of traffic redistribution. Figure 14 depicts the effect of travel time subject to various DRG or SRG market penetrations. It is evident that no travel time saving was achieved for all DRG market penetrations. Without intense traffic redistribution, the effect on total accidents due to different DRG market penetrations was also limited. Thus the systematic variations of accidents and the transition points were not observed. In fact, this trend was also reflected by the only 2% change of average accident savings across the whole network as shown in the simulation results. This narrow accident saving indicates the insignificant variations of traffic flow among different routes on the network in regardless of the percentage of drivers using DRGs.
FIGURE 13 Accident profiles for different DRG market penetrations for (a) links, and (b) intersections. (Case 2 - Downtown network with the original traffic demand)
4.2.4.2 SRG

The link APM for SRG route assignments for this network was different from the one used in the hypothetical network in case 1. The link APM for this downtown network was developed specifically for CBD links whereas the link APM for case 1 was for non-CBD links. Since SRG route assignment models were affected by APMs, different patterns of traffic distribution were observed. Figure 14 shows that the average travel time increased with the percentages of SRG market penetration. This trend indicates that SRG route assignments for this network created congestion by concentrating traffic on certain links, which also increased the average travel time for SRG-equipped drivers. This observation was also consistent with the visual inspections on the traffic condition during simulation.
Signal timing was also another reason for congestion to occur when SRGs were simulated using this downtown network. The initial signal timing for all the intersections on the network was designed for the current traffic patterns. When SRGs were equipped by drivers and traffic was redistributed, the initial signal timing might not be able to handle the redistributed traffic patterns, thus creating congestion.

Figure 15(a) shows a slight decrease in intersection accidents with SRG market penetrations. However, since the average travel time was also increased, this reduction of intersection accidents might be contributed by the concentration of traffic on certain intersections instead of the traffic distribution as found in case 1. This interpretation was also supported by the increase of average accident saving from 23% at low SRG market penetration to 34% at high SRG market penetration, indicating the increase of traffic variations among links on the network when more drivers were equipped with SRGs.

Comparing the traffic concentration on this downtown network with the traffic distribution in the hypothetical network in case 1, it is evident that APMs affect SRG route assignments. Since SRGs would possibly lead to traffic congestion as observed in this case study, it is therefore not a feasible route assignment algorithm.
FIGURE 15 Accident profiles for different SRG market penetrations for (a) links, and (b) intersections. (Case 2 - Downtown network with the original traffic demand)
4.3 Case 3 - DownTown Toronto Network with an adjusted peak traffic demand

In the previous case 2, the traffic demand obtained from traffic simulation using the EMME2 network reflected the uncongested condition of the study area. Since the effects of DRGs were insignificant under this traffic condition, the simulation results show no systematic relationship between accident trends and DRG or SRG market penetrations.

In this case 3 study, it was assumed that a peak traffic demand occurred and caused congestion in the downtown area. This hypothetical peak was similar to the peak traffic condition on the hypothetical network in case 1 but it was a more realistic approach because of the actual downtown network being modelled. The APM-integrated microsimulation model was again utilized to generate accident profiles, aiming at whether these profiles could effectively describe the DRG or SRG impact on network-wide accidents.

4.3.1 Traffic Demand Adjustment

The duration of the simulation was the same as for case 2, which covered the three hours morning peak period from 7:00 to 10:00 am. Using the demand matrix obtained from the simulation using EMME/2 network, a hypothetical peak traffic demand was created by adjusting the release of vehicles during traffic simulation, forcing more vehicles to enter the network in the early phase of simulation. The comparison between the original and the adjusted traffic demand profiles is shown in Figure 16. For the entire traffic simulation, the number of trips remained the same as in the unadjusted case. This was to ensure that the simulation results only described the effects of the temporal change of traffic flow subject to the uses of DRGs or SRGs, but without affecting the actual total traffic demand.
4.3.2 Simulation Results and Discussions

Simulation results indicate that congestion occurred as a result of the traffic demand adjustment, which created a hypothetical peak. In Figure 17, a reduction of travel time was obtained when DRGs were equipped by drivers. The shortest average travel time was obtained at approximately 60% DRG market penetration. On the contrary, travel time increased with SRG market penetrations, indicating that the SRG algorithm did not help to mitigate traffic congestion on this network.
FIGURE 17 Change of average travel time due to different market penetrations of DRG and SRG. (Case 3 - Downtown network with an adjusted peak traffic demand)

4.3.2.1 DRG

Figure 18 shows the accident profiles when 20, 40, 60 and 100% drivers were equipped with DRGs. Similar to case 1, the levels of DRG market penetration affected the occurrence of accidents across time and created a transition point T. As mentioned earlier in case 1, this transition point represents the reverse trend of accidents due to the reduction of travel time as drivers were equipped with DRGs. Considering the whole simulation period subject to different market penetrations of DRG, the maximum percentage change of link and intersection accidents is only less than 1%. It indicates that the area between accident profiles before and after the transition point is roughly equal, suggesting that DRG market penetrations had no significant effect on the total number of accidents when a hypothetical peak traffic demand occurred on this downtown network.
FIGURE 18 Accident Profiles for different DRG market penetrations for (a) links, and (b) intersections. (Case 3 - Downtown network with an adjusted peak traffic demand)
From the same figure, before the transition point, it is obvious that more accidents would occur for 60% than both 20%, 40% and 100% DRG-equipped networks. In Figure 17, the maximum travel time saving of 23% is also found at 60% DRG market penetration. Therefore, it is clear that a DRG optimum point existed, which was similar to the 60% optimum found in the hypothetical network in case 1.

To further investigate the accident trends before the transition point $T$, the change of total accidents before the transition point were plotted against different percentages of DRG-equipped networks. The result is shown in Figure 19. From this figure, both link and intersection accidents increase with the DRG market penetrations before the 60% optimum. As the market penetration increased further, both types of accidents reduced. This finding parallels the 60% point of inflection as discussed earlier in previous paragraph as well as in Figure 9 for case 1. It further reinforced the argument that as long as DRGs are effective in reducing travel time, accidents would increase proportionally with DRG market penetrations. However, in both case 1 and 3, when DRG market penetrations increased beyond the 60% optimum, due to the diminishing return of DRG performance, the number of accidents tend to decrease.
FIGURE 19 Change of accidents before transition point due to different DRG market penetrations. (Case 3 - Downtown network with an adjusted peak traffic demand)

4.3.2.2 SRG

Simulation results show a less than 1% change of total accidents subject to various level of SRG market penetrations. However, this observation alone does not prove that SRGs are superior route guidance algorithms since the travel time increased to a maximum of 45% when all drivers on the network were equipped with SRGs, which is shown in Figure 17. The figure also indicates that as SRG market penetration increases, the extent of traffic concentration and the average travel time also increase. This flow concentration was also reflected by the increase of average accident saving from 30% to 46% as shown in the simulation results. This wide range of accident saving indicates the significant traffic variation among different links on the network when drivers were using SRGs.
These observations show that when the exponent of the flow term in the link APM was less than 1 and travel time was not considered in route selection, the SRG route assignment model became problematic as it concentrated traffic by suggesting vehicles to more congested links with lower traffic flow. It therefore points to the fact that a better methodology to combine travel time and safety considerations in SRG route assignments is necessary.

Figure 20 shows the accident profiles for 20%, 40%, 70% and 90% SRG market penetrations. A transition point is also observed but it is not the same as the transition point for DRGs. Before this transition point, when SRGs were used by drivers on a congested network, the total accidents decreased due to the concentration of traffic as mentioned earlier in previous paragraph. However, after the transition point when traffic demand reduced below the congestion level, the accident profiles reflect more accidents when more drivers were equipped with SRGs, indicating that SRGs became effective as congestion released. As traffic demand dropped further, the accident profiles show no systematic relationship between accident trends and SRG market penetrations. This is similar to the observations in case 2, which indicates the insignificant impact of SRG market penetrations on network accidents when the traffic demand was low.
FIGURE 20 Accident Profiles for different SRG market penetrations for (a) links, and (b) intersections. (Case 3 - Downtown network with an adjusted peak traffic demand)
CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

This research has demonstrated the feasibility of using an APM-integrated microsimulation model to investigate the impact of dynamic route guidance systems on network-wide accidents. The accident profiles generated from the output of the microsimulation model can effectively describe the accident trends subject to different levels of DRG or SRG market penetrations. In fact, these accident profiles can also be used to explain the accident trends resulting from other ITS deployments or traffic management measures. For example, in the case when highway traffic is rerouted to surface streets using variable message signs. Since the travel time, the predicted total accidents and the extent of congestion are affected, two separate accident profiles will be generated using the microsimulation model. As these profiles can effectively describe the relationship between accident trends and travel time benefits, quantitative impact analysis can be conducted for better decision making.

This study also highlights the capability of using microsimulation to capture the congestion effects for safety analysis. This microscopic approach can also cover the entire network, introducing a more advanced dynamic network-wide approach that outweighs the traditional type-specific static accident analysis.

When congestion levels are low, DRG market penetrations do not significantly affect the occurrence of accidents. However, as in cases 1 and 3 when DRGs increased the efficiency of a congested network by suggesting routes to drivers with shorter travel time, DRGs also
tend to increase the total accidents on the network. As DRGs increase the overall network throughput by reducing the average travel time during congestion, there are fewer residual vehicles on the network after the peak demand period. Therefore, fewer accidents would occur. Because of this reversed effect, the evaluation of DRGs should consider the increase in the number of accidents during peak traffic periods, and the counterbalancing post-peak reduction of accidents as DRG-equipped drivers finish their trips earlier.

Simulation results show an approximate 10% increase in network-wide accidents on the hypothetical network in case 1 and but an insignificant accident change on the downtown network in case 3. Considering the reduction of travel time and anxiety might offset the impact of the possible extra accidents, there is clear evidence that DRGs are beneficial from both driver and system perspectives.

When accident risk is considered in SRG route assignments, even though intersection accidents are considered, the exponents of the flow terms in the link APMs affect the traffic redistribution patterns. With an exponent greater than 1 as for the hypothetical network in case 1, the traffic was evenly distributed, providing similar traffic distribution effects as drivers were equipped with DRGs. On the contrary, for the downtown network where the exponent was less than 1, the traffic was concentrated on certain links, which created congestion and extended the travel time for drivers. Therefore, there is no clear evidence in favor of or against the proposed SRG as a route guidance strategy. This is because when only quantified accident risk is considered in route choice, the resulting traffic pattern is sensitive to the exponential terms of the parameters in the APMs. This suggests further
research on methods to combine accident risk with travel time considerations in SRG route assignment models in order to address the limitations that we have discussed in this study. Moreover, accident risk is one of the many route choice strategies that can affect the accident profiles. Other route choice strategies, which can also possibly improve guidance systems, should also be explored and evaluated using the APM-integrated microsimulation model developed in this study.

The development of advanced APMs is also required in order to improve the accident prediction in the simulation model. The accident prediction models, which use traffic flow as the only variable for accident prediction, assume that the accident potential stays the same for different traffic densities with the same flow. However, in these two cases, the accident potentials are different. This limitation highlights the importance of developing more sophisticated APMs for traffic microsimulation, which can accurately predict accidents under dynamic traffic situations using additional traffic parameters such as density or occupancy.
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APPENDIX A

Simulation Results
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APPENDIX B

Application Programming Interface (API) Codes
API name: Plugin-nov27.c
Network name: Downtown-nov27
Date: November 27, 2000
Description: This plugin gathers traffic information every 5 minutes and calculate the corresponding accidents predicted using the coded Accident Prediction Models.

#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <math.h>
#include "plugin.h"
#include "api_user.h"
#include "truefalse.h"

void update_conflict_turn_count(int intTableRowIndex, int p_count);
void update_opposing_link_count(int p_LinkTableRowIndex, double link_count);
double minimum_accident_risk(double p_1, double p_2, double p_3, double p_4,
                               double p_5, double p_6, double p_7, double p_8);
double risk_saving_calculation(double *p_route);

/*,-----------------------------*/
Parameters for accident models */
/*,-----------------------------*/
/* Right turning model */
/* adjustment for acc/yr for 3 hour simulation */
static double Rb0 = 0.000000431698;
static double Rb1 = 1.1121;
static double Rb2 = 0.5467;

/* Left turning model */
static double Lb0 = 0.000010171; /* (parameter * 243) for acc/yr for 3 hour simulation */
static double Lb1 = 1.1121;
static double Lb2 = 0.5467;

/* Through model */
static double T_m1_b0 = 0.000049932; /* (parameter * 243) for acc/yr for 3 hour simulation */
static double T_m1_b1 = 1.0;
static double T_m2_b0 = 0.000024674; /* (parameter * 243) for acc/yr for 3 hour simulation */
static double T_m2_b1 = 1.0;
static double T_m3_b0 = 0.0019782; /* (parameter * 243) for acc/yr for 3 hour simulation */
static double T_m3_b2 = 0.3662;

/* Link model parameters */
static double Link_b0 = 0.2592;
static double Link_b1 = 0.491;
static double Link_b2 = 0.864;

/* Update accident risk every 5 minutes (300 seconds) */
#define duration 300

/* Cumulated total accident for intersections and links */
double total_itn_accident_risk = 0.0;
double total_itn_accident_freq = 0.0;

double total_link_accident_risk = 0.0;
double total_link_accident_freq = 0.0;

int simulation_run = 0; /* count the number of simulation runs */
static char *rd_linkname; /* the name of links on which vehicle units make turn decisions */
int rd_nextturn = 0; /* the turn decisions for vehicles */
int rd_destination = 0;

/* Variables for the calculation of average accident risk savings */
double risk_saving;
int risk_saving_counter = 0;
double stored_link_count = 0; /* to convert cumulative counts to count per time step */

int linkTableIndex = 0;
int intTableIndex = 0;

//------------------------------------------------------------------------------
/* Intersection table definition */
/*
 /Remarks: 288 records in this table were hard-coded in this */
 /program. However, the record index follow */
 /the sequence when these records are called by */
 /the callback function during simulation */
//------------------------------------------------------------------------------
struct itn_record {
 double turn_count;
 char turn_direction;
 int conflict_turn;
 double conflict_turn_count;
 double risk;
 double turn_accident_freq;
} it[288];

//------------------------------------------------------------------------------
/* Link table definition */
/*
 /Remarks: 96 records in this table were hard-coded in this */
 /program. However, the record index follow */
 /the sequence when these records are called by */
 /the callback function during simulation */
//------------------------------------------------------------------------------
struct link_record {
 double onLink_count;
 double onLink_length;
 int opLink; /*opposing link*/
 double opLink_count;
 double risk;
 double onLink_accident_freq;
} lk[96];

//------------------------------------------------------------------------------
/* Decision table (1D - array) */
/*
 /Remarks: Contains the physical names of all links */
 /on which turn decisions were computed by APM */
//------------------------------------------------------------------------------
char* decision_link[96];

//------------------------------------------------------------------------------
/* Exit turn table (2D - array) */
/*
 /Remarks: X-index represent the destination zone */
 /Y-index represent the link on which vehicles travel */
 /array values refer to the calculated turn decisions */
//------------------------------------------------------------------------------
int exit_turn[96][23];

//------------------------------------------------------------------------------
/* API started */
/* Set up tables */
//------------------------------------------------------------------------------
void api_setup (void)
{
   int m=0;
int n=0;
total_itn_accident_risk = 0;
total_itn_accident_freq = 0;
total_link_accident_risk = 0;
total_link_accident_freq = 0;

api_printf("\n********* API loaded **********\n");
api_printf("Loading tables .................\n");

/* ------------------------------------------------------------------------*/
/* Load intersection tables records */
/* 280 records follow simulation sequence for next lane as described */
/* in Appendix C and not shown completely here for clarity */
/* ------------------------------------------------------------------------*/

it[0].turn_count = 0;
it[0].turn_direction = 'R';
it[0].conflict_turn = 999;
it[0].conflict_turn_count = 0;
it[0].risk = 0;
it[0].turn_accident_freq = 0;

it[1].turn_count = 0;
it[1].turn_direction = 'T';
it[1].conflict_turn = 61;
it[1].conflict_turn_count = 0;
it[1].risk = 0;
it[1].turn_accident_freq = 0;

it[2].turn_count = 0;
it[2].turn_direction = 'L';
it[2].conflict_turn = 115;
it[2].conflict_turn_count = 0;
it[2].risk = 0;
it[2].turn_accident_freq = 0;

it[3].turn_count = 0;
it[3].turn_direction = 'R';
it[3].conflict_turn = 232;
it[3].conflict_turn_count = 0;
it[3].risk = 0;
it[3].turn_accident_freq = 0;

it[4].turn_count = 0;
it[4].turn_direction = 'T';
it[4].conflict_turn = 232;
it[4].conflict_turn_count = 0;
it[4].risk = 0;
it[4].turn_accident_freq = 0;

. . .

it[284].turn_count = 0;
it[284].turn_direction = 'L';
it[284].conflict_turn = 999; /* Accidents not calculated on dummy link */
it[284].conflict_turn_count = 0;
it[284].risk = 0;
it[284].turn_accident_freq = 0;

it[285].turn_count = 0;
it[285].turn_direction = 'R';
it[285].conflict_turn = 999; /* Accidents not calculated on dummy link */
it[285].conflict_turn_count = 0;
it[285].risk = 0;
it[285].turn_accident_freq = 0;
it[286].turn_count = 0;
it[286].turn_direction = 'T';
it[286].conflict_turn = 0;
it[286].conflict_turn_count = 0;
it[286].risk = 0;
it[286].turn_accident_freq = 0;

it[287].turn_count = 0;
it[287].turn_direction = 'L';
it[287].conflict_turn = 999; /* Accidents not calculated on dummy link */
it[287].conflict_turn_count = 0;
it[287].risk = 0;
it[287].turn_accident_freq = 0;

// Load link tables records /*
// 96 records follow simulation sequence for next lane as described */
// in Appendix C and not shown completely here for clarity */

lk[0].onLink_count = 0;
lk[0].onLink_length = 0.484;
lk[0].opLink = 16;
lk[0].opLink_count = 0;
lk[0].risk = 0;
lk[0].onLink_accident_freq = 0;

lk[1].onLink_count = 0;
lk[1].onLink_length = 0.64;
lk[1].opLink = 2;
lk[1].opLink_count = 0;
lk[1].risk = 0;
lk[1].onLink_accident_freq = 0;

lk[2].onLink_count = 0;
lk[2].onLink_length = 0.64;
lk[2].opLink = 1;
lk[2].opLink_count = 0;
lk[2].risk = 0;
lk[2].onLink_accident_freq = 0;

lk[3].onLink_count = 0;
lk[3].onLink_length = 0.578;
lk[3].opLink = 19;
lk[3].opLink_count = 0;
lk[3].risk = 0;
lk[3].onLink_accident_freq = 0;

lk[4].onLink_count = 0;
lk[4].onLink_length = 0.799;
lk[4].opLink = 5;
lk[4].opLink_count = 0;
lk[4].risk = 0;
lk[4].onLink_accident_freq = 0;

lk[93].onLink_count = 0;
lk[93].onLink_length = 0;
lk[93].opLink = 999; /* Accidents not calculated on dummy link */
lk[93].opLink_count = 0;
lk[93].risk = 0;
lk[93].onLink_accident_freq = 0;
lk[94].onLink_count = 0;
lk[94].onLink_length = 0;
lk[94].opLink = 999; /* Accidents not calculated on dummy link */
lk[94].opLink_count = 0;
lk[94].risk = 0;
lk[94].onLink_accident_freq = 0;

lk[95].onLink_count = 0;
lk[95].onLink_length = 0;
lk[95].opLink = 999; /* Accidents not calculated on dummy link */
lk[95].opLink_count = 0;
lk[95].risk = 0;
lk[95].onLink_accident_freq = 0;

/* -------------------------------*/
/* Load decision tables */
/* 96 records follow simulation sequence for link as in Link file */
/* -----------------------------------*/
decision_link[0] = "11:21";
decision_link[1] = "11:12";
decision_link[2] = "12:11";
decision_link[3] = "12:22";
decision_link[4] = "12:13";

decision_link[91] = "81:41";
decision_link[92] = "84:41";
decision_link[93] = "86:31";
decision_link[94] = "88:21";
decision_link[95] = "90:11";

/* -------------------------------*/
/* Load exit turn table */
/* Initialize all exit turns to 0 by default */
/* -----------------------------------*/
for (m=0; m < 96; m++)
{
    for (n=0; n<24; n++)
    {
        exit_turn[m][n] = 0;
    }
}
api_printf("\nLoading tables completed. \n");

/* -------------------------------*/

bool routing_enable(void)
{
    return TRUE;
}

/* -------------------------------*/
int routing_decision(void *linkp, void *vp)
{
    int r = 0;
    rd_nextturn = 0;

    /* Control SRG percentage by using random number generator */
    /* 32767 -> 100% */
    /* 29250 -> 90% */
    /* 26000 -> 80% */
    /* 22750 -> 70% */
    /* 19500 -> 60% */
    /* 16250 -> 50% */
    /* 13000 -> 40% */
    /* 9750 -> 30% */
    /* 6500 -> 20% */
}
/* 3250 -> 10% */

if (rand() < 1) /* no driver is using SRG */
{
    rd_linkname = link_name(linkp);
    rd_destination = vehicle_destination(vp);

    /* check if current link is a decision link */
    /* if yes, use the turn decision from exit_turn table */
    for (r=0; r < 96; r++)
    {
        if (strcmp(rd_linkname, decision_link[r]) == 0)
        {
            rd_nextturn = exit_turn[r][rd_destination];
        }
    }
}

/* decision remain 0 by default when link is not in decision link table */
return rd_nextturn;

/*------------------------------------------------------------------------------*/
void net_post_action(void)
{
    void* thisLink = NULL;
    void* exitLink = NULL;

    int j = 0;
    int k = 0;
    int t = 0;
    int u = 0;
    int v = 0;

    /* ------------------------------- */
    /* variables for turning movements at intersections */
    /* ------------------------------- */
    int nLinks = 0;
    int nExits = 0;
    int thisExit = 0;
    int nextExit = 0;
    int count = 0;

    /* store total turning risk for this simulation */
    double sim_ltn_accident_risk = 0.0;
    double sim_ltn_accident_freq = 0.0;
    double both_direction_accident_freq = 0.0;

    /* ------------------------------- */
    /* variables for link */
    /* ------------------------------- */
    double link_count;

    /* store total link risk for this simulation */
    double sim_link_accident_risk = 0.0;
    double sim_link_accident_freq = 0.0;

    /* for calculation of difference in risk for each simulation */
    double min_risk = 0.0;
    double max_risk = 0.0;
    double diff_risk = 0.0;
    double percent_saving = 0.0;

    /* array for route risk calculation */
    double route[17]; /* maximum 16 possible routes, route[0] not used */

    /* check if at a whole second first */
    if (simulation_time() - (float)floor((double)simulation_time()) > 0.0)
        return;

    /* Update tables every 5 minutes (300 seconds) */
    if (((int)simulation_time() % (duration - 1)) == 0)
After going through all links in the network:

```c

// update opposing link counter
update_opposing_link_counter(link_counter)

// if all records are in correct order
update_link_table()

// update link counter in link table

// update counter in the link table
link_counter = ++link_counter;

// if there are no update counter in the link table
update_counter = ++counter;

// add up to 2 extra counters to form a link counter

// update counter in the link table

// counter = link_counter (counter)

for (extract = 0; extract < nextextract; extract++)

    if (link_counter == 0)
        counter = 0;
    else
        counter = ++counter;

    for this link +

    nextextract = NULL;
    thisextract = 0;

    if (nextextract == {})
        return;

    if this has many extra

    nextextract = link-extract-link (chastest);

    thisextract = link (extract[+])

    for this link +

    nextextract = NULL;
    thisextract = 0;

    if (nextextract == {})
        return;
```

After finishing updating counter for the whole network, return.
/* Calculate turn accidents risk / freq. in turn table */
*/---------------------------------------------------------------*/

api_printf("Start computing turning accidents for intersections. \n");

sim_ltn_accident_risk = 0;
sim_ltn_accident_freq = 0;

for (t=0; t < 288; t++)
{
    /* Right turn accident calculation */
    if (it[t].turn_direction == 'R')
    {
        /* accident freq = acc / yr / 36 count = 5 min count for 3 hours simulation*/
        it[t].turn_accident_freq =
            R_b0 * pow((it[t].conflict_turn_count*12),R_b1)*
            pow((it[t].turn_count+12),R_b2);
        /* 100000 times for ease of calculation */
        if (!(!it[t].turn_count == 0))
            it[t].risk = 100000*(it[t].turn_accident_freq * 36 /
                                (it[t].turn_count+12*365*24));
        if (it[t].turn_count == 0)
            it[t].risk = 0;
        api_printf("turn %d = %f conflict %d = %f [%c] >> freq=%f risk=%f\n", t,
            it[t].turn_count, it[t].conflict_turn,
            it[t].turn_accident_freq, it[t].risk);
        if (simulation_run > 3) /* not warming up */
            sim_ltn_accident_freq += it[t].turn_accident_freq;
    }

    /* Left turn accident calculation */
    if (it[t].turn_direction == 'L')
    {
        it[t].turn_accident_freq =
            L_b0 * pow((it[t].conflict_turn_count*12),L_b1)*
            pow((it[t].turn_count+12),L_b2);
        if (!(!it[t].turn_count == 0))
            it[t].risk = 100000*(it[t].turn_accident_freq * 36 /
                                (it[t].turn_count+12*365*24));
        if (it[t].turn_count == 0)
            it[t].risk = 0;
        api_printf("turn %d = %f conflict %d = %f [%c] >> freq=%f risk=%f\n", t,
            it[t].turn_count, it[t].conflict_turn,
            it[t].turn_accident_freq, it[t].risk);
        if (simulation_run > 3)
            sim_ltn_accident_freq += it[t].risk; /* summary of risk not required */
        if (simulation_run > 3)
            sim_ltn_accident_freq += it[t].turn_accident_freq;
    }

    /* Through accident calculation */
    if (it[t].turn_direction == 'T')
    {
        it[t].turn_accident_freq =
            (T_m1_b0 + (12 * it[t].turn_count))+(T_m2_b0 *
            (12*it[t].turn_count)
            + (T_m3_b0 * pow((12 * it[t].conflict_turn_count), T_m3_b2));
        if (!(!it[t].turn_count == 0))
            it[t].risk = 100000*(it[t].turn_accident_freq*36/
{it[t].turn_count*12+365*24});

if (it[t].turn_count == 0)
    it[t].risk = 0;

api_printf("turn %d = %f conflict %d = %f [m] >> freq=%f risk=%f\n", t,
    it[t].turn_count, it[t].conflict_turn,
    it[t].turn_direction, it[t].turn_accident_freq, it[t].risk);

if (simulation_run > 3)
    sim_itn_accident_freq += it[t].turn_accident_freq;

}

total_itn_accident_risk += sim_itn_accident_risk;
total_itn_accident_freq += sim_itn_accident_freq;

api_printf("%f
", sim_itn_accident_freq); /* print intersection accidents */
/* output total intersection accident after this simulation */
api_printf("Cumulated intersection accidents freq = %f\n", total_itn_accident_freq);

api_printf("Start computing link accidents. \n");

sim_link_accident_risk = 0;
sim_link_accident_freq = 0;
for (u=0; u < 96; u++)
{
    if (!(lk[u].onLink_count==0 && lk[u].opLink_count==0))
    {
        both_direction_accident_freq =
            (Link_b0/(36))*pow((24*12*(lk[u].onLink_count +
            lk[u].opLink_count)), Link_bl) * pow(lk[u].onLink_length,
            link_b2);

        /* separate the total freq for the target direction */
        lk[u].onLink_accident_freq =
            (both_direction_accident_freq + pow(lk[u].onLink_count,
            Link_bl) /
            (pow(lk[u].onLink_count,Link_bl)+pow(lk[u].opLink_count,
            Link_bl)));
    }

    if (!(lk[u].onLink_count==0 && lk[u].opLink_count==0))
    lk[u].onLink_accident_freq = 0;

    if (!(lk[u].onLink_count == 0))
    lk[u].risk = 100000*(lk[u].onLink_accident_freq*36 /
        (365*24*12*lk[u].onLink_count));

    api_printf("link %d = %f op=> %d = %f freq=%f risk=%f\n", u,
        lk[u].onLink_count, lk[u].opLink, lk[u].opLink_count,
        both_direction_accident_freq, lk[u].onLink_accident_freq,
        lk[u].risk);

    if (simulation_run > 3) /* not warming up */
        sim_link_accident_freq += lk[u].onLink_accident_freq;

}

total_link_accident_risk += sim_link_accident_risk;
total_link_accident_freq += sim_link_accident_freq;
/* output total link accident after this simulation */
api_printf("%f\n", sim_link_accident_freq);
api_printf("cumulated link accidents freq = %fn", total_link_accident_freq);

/* Update exit turn table for all decision links by combining */
/* accident risk for all possible routes */
/*----------------------------------------------------------------------------*/

api_printf("Start updating Exit-turn array. \n");

/*/ link [ 1 ] to zone [ 7 ] => on link 1 travelling to destination zone 7 */
/*----------------------------------------------------------------------------*/

/* initialize all route risk to 999999 */
for (v=1; v<18; v++)
{
    route[v] = 999999;
}

    lk[37].risk +
    lk[9].risk + lk[30].risk + lk[34].risk + lk[37].risk
    +
    it[46].risk;
    lk[37].risk +
    it[102].risk;
    it[56].risk +
    it[157].risk;
    lk[37].risk +
    it[102].risk;
    lk[56].risk +
    it[157].risk;

risk_saving +/- risk_saving_calculation(route);
risk_saving_counter ++;

/*----------------------------------------------------------------------------*/

/* initialize all route risk to 999999 */
for (v=1; v<18; v++)
{
    route[v] = 999999;
}

    lk[37].risk +
    it[46].risk;
    lk[37].risk +
    it[102].risk;
    it[56].risk +
    it[157].risk;
    lk[37].risk +
    it[102].risk;
    lk[56].risk +
    it[157].risk;
/* initialized to go straight */
exit_turn[1][8] = 2;
/* if turn is better */
if ((minimum Accident_risk(route[1], route[2], route[3], route[4],
    route[5], route[6], route[7], route[8])) >
    (minimum Accident_risk(route[9], route[10], route[11], route[12],
    route[13], route[14], route[15], route[16])))
exit_turn[1][8] = 1; /* l = turn right , 3 = turn left */
risk_saving += risk_saving_calculation(route);
risk_saving_counter ++;

/**************************************************************************
/* initialize all route risk to 999999 */
for (v=1; v<18; v++)
{
    route[v] = 999999;
}
    lk[37].risk +
    it[39].risk +
    it[46].risk + it[112].risk;
    lk[37].risk +
    it[91].risk +
    it[102].risk + it[112].risk;
    lk[7].risk +
    lk[9].risk +
    it[4].risk +
    it[13].risk +
    it[21].risk +
    it[28].risk +
    it[89].risk +
    it[157].risk +
    it[168].risk;
    lk[7].risk +
    lk[10].risk +
    lk[12].risk +
    lk[33].risk +
    lk[37].risk +
    lk[59].risk +
    lk[73].risk +
    it[4].risk +
    it[13].risk +
    it[22].risk +
    it[30].risk +
    it[37].risk +
    it[100].risk +
    it[167].risk;
    lk[6].risk +
    lk[25].risk +
    lk[47].risk +
    it[76].risk +
    lk[13].risk +
    lk[70].risk +
    it[4].risk +
    it[12].risk +
    it[19].risk +
    it[76].risk +
    it[143].risk +
    it[202].risk +
    it[211].risk;
    lk[22].risk +
    lk[26].risk +
    it[11].risk +
    it[3].risk +
    lk[37].risk +
    it[3].risk +
    it[11].risk +
    it[67].risk +
    it[79].risk +
    it[91].risk +
    it[102].risk +
    it[112].risk;
    lk[22].risk +
    lk[26].risk +
    lk[29].risk +
    it[3].risk +
    lk[56].risk +
    it[3].risk +
    it[11].risk +
    it[67].risk +
    it[78].risk +
    it[89].risk +
    it[157].risk +
    it[168].risk;
    it[22].risk +
    it[25].risk +
    lk[47].risk +
    it[76].risk +
    it[13].risk +
    it[143].risk +
    it[4].risk +
    it[211].risk;
route[12] = lk[3].risk +
    lk[21].risk +
    it[44].risk +
    lk[47].risk +
    it[65].risk +
    it[132].risk +
    it[143].risk

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/* initialized to go straight */
exit_turn[1][9] = 2;

/* if turn is better */
if ((minimum_accident_risk(route[1], route[2], route[3], route[4],
   route[5], route[6], route[7], route[8])) >
   (minimum_accident_risk(route[9], route[10], route[11], route[12], route[13],
   route[14], route[15], route[16])))
exit_turn[1][9] = 1;  /* 1 = turn right, 3 = turn left */

risk_saving += risk_saving_calculation(route);
risk_saving_counter ++;

/*-----------------------------------------------*/
/* link [ 1 ] to zone [ 10 ] */
/*-----------------------------------------------*/

/* initialize all route risk to 999999 */
for (v=1; v<18; v++)
{
   route[v] = 999999;
}

   lk[55].risk
   it[100].risk;

   lk[70].risk
   + it[4].risk + it[12].risk + it[19].risk + it[76].risk + it[143].risk +
   it[202].risk;

   lk[70].risk
   it[202].risk ;

   lk[70].risk
   it[202].risk;

/* initialized to go straight */
exit_turn[1][10] = 2;

/* if turn is better */
if ((minimum_accident_risk(route[1], route[2], route[3], route[4],
   route[5], route[6], route[7], route[8])) >
   (minimum_accident_risk(route[9], route[10], route[11], route[12], route[13],
   route[14], route[15], route[16])))
exit_turn[1][10] = 1;  /* 1 = turn right, 3 = turn left */

risk_saving += risk_saving_calculation(route);
risk_saving_counter ++;

/*-----------------------------------------------*/
/* link [ 37 ] to zone [ 12 ] */
/*-----------------------------------------------*/

/* initialize all route risk to 999999 */

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for (v=1; v<18; v++)
{
    route[v] = 999999;
}


/* initialized to go straight */
exit_turn[37][12] = 2;

/* if turn is better */
if ((minimum_accident_risk(route[1], route[2], route[3], route[4], route[5], route[6], route[7], route[8]) >
    (minimum_accident_risk(route[9], route[10], route[11], route[12], route[13], route[14], route[15], route[16])))
    exit_turn[37][12] = 1;  /* 1 = turn right, 3 = turn left */

risk_saving += risk_saving_calculation(route);
risk_saving_counter++;   

/*--------------------------------------------------------------------------*/
/* link [ 37 ] to zone [ 13 ] */
/*--------------------------------------------------------------------------*/

/* initialize all route risk to 999999 */
for (v=1; v<18; v++)
{
    route[v] = 999999;
}


/* initialized to go straight */
exit_turn[37][13] = 2;

/* if turn is better */
if ((minimum_accident_risk(route[1], route[2], route[3], route[4], route[5], route[6], route[7], route[8]) >
    (minimum_accident_risk(route[9], route[10], route[11], route[12], route[13], route[14], route[15], route[16])))
    exit_turn[37][13] = 1;  /* 1 = turn right, 3 = turn left */

risk_saving += risk_saving_calculation(route);
risk_saving_counter++;   

/*--------------------------------------------------------------------------*/
/* link [ 37 ] to zone [ 14 ] */
/*--------------------------------------------------------------------------*/

/* initialize all route risk to 999999 */
for (v=1; v<18; v++)
route[v] = 999999;

it[128].risk;
lk[63].risk + it[111].risk + it[175].risk + it[163].risk + it[151].risk + it[140].risk +
it[129].risk;
lk[63].risk + it[111].risk + it[175].risk + it[163].risk + it[151].risk + it[140].risk +
it[199].risk;
it[199].risk;

/* initialized to go straight */
exit_turn[37][14] = 2;

/* if turn is better */
if (minimum_accident_risk(route[1], route[2], route[3], route[4],
route[5], route[6], route[7], route[8]) >
minimum_accident_risk(route[9], route[10], route[11], route[12], route[13],
route[14], route[15], route[16]))
exit_turn[37][14] = 1; /* 1 = turn right, 3 = turn left */

risk_saving += risk_saving_calculation(route);
risk_saving_counter++;

} /*-----------------------------------------------*/

void update_conflict_turn_count(int p_intTableIndex, int p_count)
{
int z;
for (z=0; z < 288; z++)
{
if (it[z].conflict_turn == p_intTableIndex)
it[z].conflict_turn_count = (double)p_count;
}
}

} /*-----------------------------------------------*/

void update_opposing_link_count(int p_linkTableIndex, double link_count)
{
int m = 0;
for (m=0; m<96; m++)
{
if (lk[m].opLink == p_linkTableIndex)
lk[m].opLink_count = link_count;
}
}

} /*-----------------------------------------------*/

double risk_saving_calculation(double *p_route)
/*double p_route[]*/
{
int n;
double r_saving = 0; /*temporary storage for the percentage risk saving*/
double r_max = 0; /*temporary storage for the largest possible risk*/
double r_min = 999999; /*temporary storage for the smallest possible risk*/

for (n=1; n<18; n++)
{
    if (!p_route[n]==999999)
    {
        if (p_route[n] > r_max)
            r_max = p_route[n];
        if (p_route[n] < r_min)
            r_min = p_route[n];
    }
}

if (!r_max == r_min)
    /* calculate the largest possible accident risk saving*/
r_saving = (r_max - r_min)*100/r_max;

return r_saving;

double minimum_accident_risk(double p_1, double p_2, double p_3, double p_4, double p_5, double p_6, double p_7, double p_8)
{
    double r_min = 999999; /*temporary storage for the smallest possible risk*/

    if (p_1 < r_min)
        r_min = p_1;
    if (p_2 < r_min)
        r_min = p_2;
    if (p_3 < r_min)
        r_min = p_3;
    if (p_4 < r_min)
        r_min = p_4;
    if (p_5 < r_min)
        r_min = p_5;
    if (p_6 < r_min)
        r_min = p_6;
    if (p_7 < r_min)
        r_min = p_7;
    if (p_8 < r_min)
        r_min = p_8;
    return r_min;
}

/*end_action---------------------------------------------------------------------*/
void end_action(void)
{
    double average_risk_saving = 0;
    api_printf("Simulation ended \n");

    api_printf("Total intersection accidents = %f\n", total_itn_accident_freq);
    api_printf("Total link accidents = %f\n", total_link_accident_freq);

    average_risk_saving = risk_saving / risk_saving_counter;
    api_printf("Average risk saving = %f\n", average_risk_saving);
}
APPENDIX C

Simulation Sequence for Next Links on Downtown Network
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