Simulative Performance Evaluation of the sim$^{\text{TD}}$ Self Organizing Traffic Information System

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***Abstract*—The sim$^{\text{TD}}$ (Safe and Intelligent Mobility: Test Field Germany) research project is another step towards bringing Car-to-X technology to marketability. One of its envisioned applications is a Traffic Information System (TIS) based on self-generated maps for vehicles not equipped with digital maps. To assure reliable operation, the function itself, its performance and the effect of its input parameters was simulatively evaluated before it was validated on real vehicles.**

In this paper we demonstrate how to adequately parameterize and evaluate such a TIS. We find feasible values for the input parameters for the creation of self-generated maps to ensure solid operation of the function. We further contribute to the community and other projects using similar TIS deployments by introducing applicable metrics for TIS evaluation in general and show our findings for the sim$^{\text{TD}}$ research project.

I. INTRODUCTION

Inter-Vehicle Communication (IVC) based on modern wireless technology is expected to enable more comfortable, safer, and more efficient road traffic. While during the last years mainly simulation results and conceptual work has been published, this promising technology is now about to take the next step. All over the world, researchers and developers from academia and industry are working on Field Operational Tests (FOTs) to gather experience with new IVC systems.

One of them is the German sim$^{\text{TD}}$ research project, which started in September 2009 with a scheduled duration of 48 months. The project aims at verifying the positive effects of WAVE-based IVC [1], [2] on traffic safety and efficiency under real life conditions. Jointly funded by the German Federal Ministry of Economics and Technology (BMWi), the Federal Ministry of Education and Research (BMBF), the Federal Ministry of Transport, Building and Urban Development (BMVBS), eighteen partners are working together to implement and validate twenty one applications by a large fleet of vehicles and road side stations in the Frankfurt/Main region. A comprehensive overview can be found in [3].

According to [4], Intelligent Transportation Systems (ITS) applications can be classified into safety and efficiency applications. To give an example of the former, simple periodic beacon messages can be utilized to keep vehicles informed about their surroundings, that is the presence of other vehicles. These messages are called Cooperative Awareness Messages (CAMs) and form the basis for diverse safety applications such as intersection management or blind spot warning. Efficiency applications include the exchange of complex data, e.g., information on current traffic situations. This enables the construction of a decentralized Traffic Information System (TIS) which promises to overcome some of the limitations centralized TIS deployments have, such as high latencies, limited regional resolution, and high operational costs.

One particular kind of TIS, and one of the applications investigated in sim$^{\text{TD}}$, is a Self-Organizing Traffic Information System (SOTIS) operating both independent of infrastructure and of pre-installed digital maps [5]. Since a high market penetration rate is crucial for the performance of a decentralized TIS [6], it is desirable to create sensibly priced systems. Enabling the vehicles to create the maps themselves, is one aspect to achieve this. This approach was therefore followed in sim$^{\text{TD}}$. In such a system, the creation and aggregation of these maps among the vehicles play a vital role for the feasibility of the overall system.

Guided by an evaluation of this approach, we contribute to the state of the art in evaluating Traffic Information Systems based on self-generated map data, as follows.

- We propose metrics for evaluating the quality of self-generated map data as well as the performance of the TIS.
- We further investigate how these metrics are impacted by different parameterizations of the SOTIS, both qualitatively and quantitatively.
- We present findings for the sim$^{\text{TD}}$ project, which are also applicable for other FOTs using similar TIS deployments.

This paper is structured as follows: After reviewing other projects and related work (Section II), the decentralized TIS under study is explained in detail (Section III), along with metrics for the evaluation of distributed map generation. We introduce our simulation framework and the setups used (Section IV) to find a suitable parameterization for distributed map generation (Section V). Based on our findings, we conduct a performance evaluation of the TIS, for which we propose pertinent metrics (Section VI).

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Figure 1. Photograph of a prototype of the simTD TIS in the field. Visualized is the knowledge-base (white) and stored traffic information: travel time measurements are indicated by colors.

II. RELATED WORK

Accurate traffic information is a prerequisite for dynamic route planning and guidance. A number of research projects investigating this topic have been started in the last years.

An approach relying heavily on infrastructure is followed in Japan by the Smartway project [7]. This project tries to combine the existing Electronic Toll Collect (ETC) and Vehicle Information and Communication System (VICS) and to provide safety and efficiency services to drivers. In order to achieve this, sensors to detect hazardous road conditions and current traffic situation are placed alongside the road. Infrastructure is then in turn used for information dissemination via Dedicated Short Range Communications (DSRC).

In the U.S. one of the most important research projects is the California Partners for Advanced Transit and Highways (PATH) project, which was started in 1986. One of its many objectives is the deployment of an Advanced Traveler Information System (ATIS) using DSRC for V2V communication. The system has been analyzed using a model based in traffic simulation. Additionally drivers' compliance behavior was taken into account to further increase the degree of realism of the model [8].

In Germany, AKTIV VM aimed at interconnecting vehicles with smart road infrastructure to provide traffic information to drivers [9]. During its runtime from 2006 to 2010, it investigated components such as a centralized road network optimizer, a component to substitute variable traffic signs by communication, or an integrated adaptive navigation system which does not only take into account the current traffic situation when making routing decisions, but also supports advised detours. Multiple channels for communication have been tested, and besides FM-Radio and Digital Audio Broadcast (DAB) also DSRC was used. In a partner project called CoCar, traffic information was disseminated using cellular infrastructure, namely UMTS, to overcome the problems of low penetration rates in the roll-out phase of ITS deployments [10].

Based on results of its predecessor *PRE-DRIVE C2X*, the recently started European project *DRIVE C2X* is planning to develop a SOTIS-based TIS similar to simTD, carrying out a comprehensive assessment of cooperative systems through extensive European FOTs and establishing a Europe-wide testing environment for cooperative systems [11].

With respect to quality assessment, the authors in [12] presented desired metrics for evaluating traffic data quality as a result to a call from the Federal Highway Administration (FHWA) in 2003. In particular they identified six properties: accuracy, completeness, validity, timeliness, coverage, and accessibility.

These metrics have been implemented in [13] which proposes the derivation of events (such as congestions) from traffic data. Based on the completeness and validity of these events, they introduce two specific data quality metrics: the fraction of events successfully reported and the false positive rate. However, they acknowledge that fuzzy event classification would make the process of quality evaluation too complex to apply these metrics.

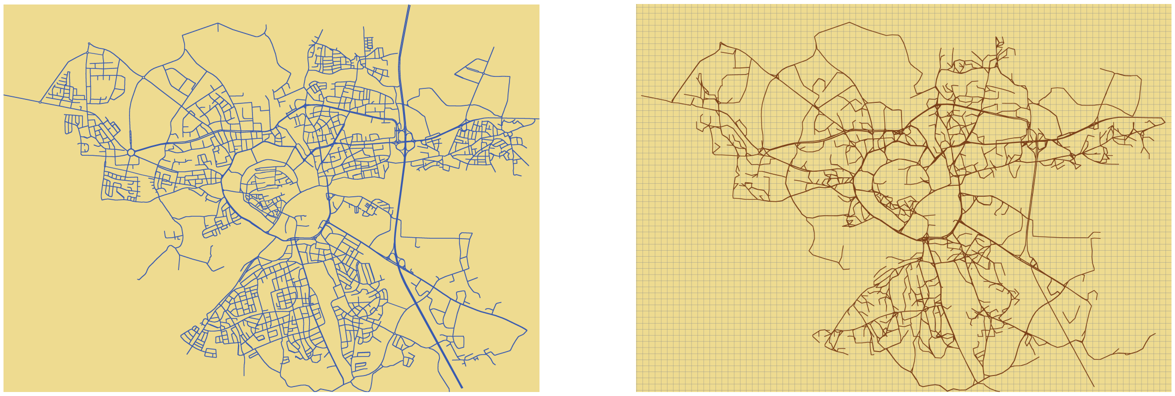
For the TIS under study in this work, these definitions were therefore inapplicable, as the derivation of unique events is infeasible for self-generated map data. Moreover, the focus of the SOTIS proposed in simTD is not to distribute specific events, but to rather provide a cooperative view on the traffic situation, including the dissemination of road topology information.

Therefore, we introduce new metrics for TIS evaluation, inspired by the six properties of [12], but tailored to self organizing systems.

III. THE SIMTD TIS

The objective of the TIS used in simTD is to provide drivers with information about road conditions ahead of them and to also allow for rerouting if a navigation system is installed. One of the design goals was to also support and include vehicles not equipped with (commercial) digital maps.

Therefore the choice was made to use a system based on the approach presented in [5] by Wischhof et al. Instead of using pre-installed maps, vehicles generate maps on their own by using a GPS receiver and a global reference grid known to all vehicles (obtained by a UTM map projection). In short, a vehicle creates a new Geo Reference Point (GRP) whenever it cuts a horizontal or vertical line of the grid. It then connects this and the last point. The resulting line is called a Geo Reference Edge (GRE). It is then possible to attach information to each GRE, such as travel-time or road conditions. Once a new edge is created, a vehicle will also save the time it needed to travel from the starting point to the ending point. A sample photograph of the system in action can be found in Figure 1. The self-generated map is drawn in the display, colored to indicate available traffic information. By drawing all known edges we obtain a visualization of the map as known to the vehicle. In Figure 2b the visualization of the knowledge-base of a specific vehicle can be seen. The red lines depict the current view of the map as known by this vehicle.



(a) Road map of the city of Ingolstadt, Germany as used in our simulations

(b) Grid based approximation of the road map as contained in one vehicle's knowledge-base using the self-generation approach, 10 min into the simulation

Figure 2. Self-generated maps approximate real road maps accurate enough to be used as a basis for TIS deployments.

Obviously, the amount of edges in a vehicle's knowledge-base depends on the grid size G, as GRPs are only created when the vehicle crosses a grid line. The smaller G is, the closer the knowledge-base will approximate the real map, but at the same time, more points have to be saved.

To provide drivers with information about GREs they have not created themselves, vehicles need to exchange data from their knowledge-base over the wireless channel. To do so, vehicles in sim$^{\text{TD}}$ exchange traffic information in a SOTIS manner [14]. When two vehicles encounter each other, each vehicle will choose GRPs from its knowledge-base following a specific strategy and send it to the other vehicle. The selected points have to be ordered and connected, that is, they have to form a Geo Reference List (GRL). A GRL contains the GRPs and the traffic information that was saved along with them. The receiver can then recreate the GREs and merge them into his knowledge-base. Vehicles do not send edges directly because several operations have to be performed during the merge process:

- If one of the GRPs is already known, a new edge will be created, containing the already existing one and the other, unknown point. This is to avoid duplicate GRPs within a knowledge-base.
- If the edge consists of two already known GRPs, the traffic information is aggregated into the already known edge and the received edge can be discarded.
- If both GRPs are unknown, the edge can be added to the knowledge-base.

As can be seen, we need to be able to tell if two Geo Reference Points (GRPs) represent the same grid cut, that is, to answer whether point p_1 equals point p_2. Based on the euclidian distance between both points and a maximum radius I_{max}, called the identity radius, the system considers two points to refer to the same position if $\| p_2 - p_1 \| \leq I_{\text{max}}$.

The grid size G and identity radius I_{max} have to be chosen carefully as they heavily influence the performance of the TIS. In the following we show a way how to choose them and present results for a specific scenario.

A. Grid Size

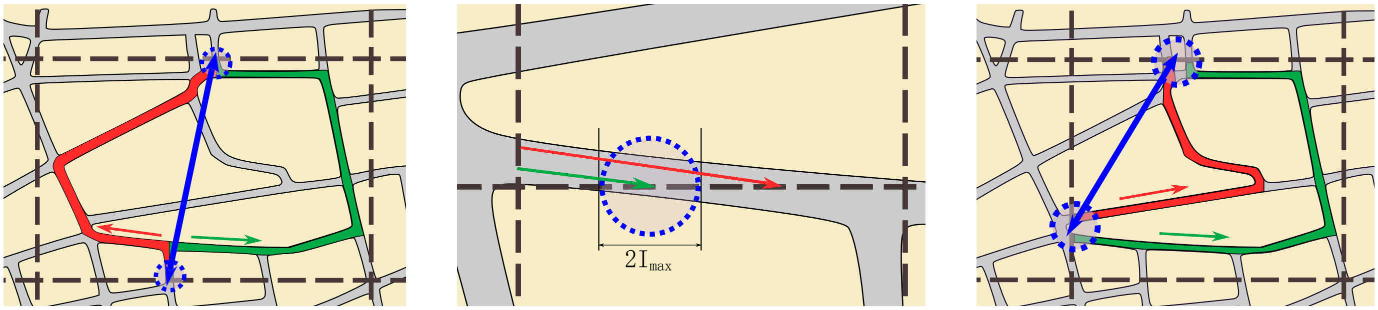
One important input parameter for the whole system is the grid size, that is, the distance between two grid lines and hence the size of the grid cells. As there are no special universal properties regarding horizontal (east/west) and vertical (north/south) streets, we assume quadratic grid cells.

Obviously, it is desirable to set G as high as possible to reduce knowledge-base size and transfer volume: the bigger the grid size, the less Geo Reference Points (GRPs) are created by vehicles as they will then intersect grid lines less often. Less GRPs then lead to smaller knowledge-bases, which in turn can lead to less data sent over wireless channel. Less cuts with grid lines can also cause less errors like redundant or collapsed edges (Figures 3c and 3b).

However, G cannot be chosen arbitrarily high. As can be seen in Figure 3a, too large grid cells may allow for multiple routes through the cell – all with the same entry and exit points. These routes will be represented by the same Geo Reference Edge (GRE) (blue line in Figure). Traffic information attached to this edge can therefore not be mapped to a real street and might not be valid. A driver considering to take the red route would then interpret a congestion warning for the blue route as relevant to him, although he will not be affected by the congestion.

B. Identity Radius

The identity radius I_{max} will decide whether two points are considered to refer to the same position. If I_{max} is chosen too big, it is possible that vehicles traveling on two different roads are creating GRPs which are erroneously considered equal (Figure 3c). These roads, however, cut the grid cell at two different exit positions. As the cuts will be aggregated into one GRP, this results in only one edge being created instead of two. This edge will therefore be referred to as *collapsed*.



(a) A too big grid size G can lead to merging two routes (red, green) with the same start and end GRPs to one *Collapsed Edge* (blue)

(b) A too small $I_{\max}$ can cause two GRPs (intersection of red and green arrows with dashed grid-line) representing the same road to not be merged. There will then be two *Redundant Edges* where only one edge should be

(c) A too big $I_{\max}$ can lead to merging two possible routes through a grid cell (red, green) to one *Collapsed Edge* (blue)

Figure 3. Collapsed and redundant edges negatively influence the performance of the TIS and are thus referred to as faulty edges

If $I_{\max}$ is chosen too small, two GRPs that belong to the same street will not be merged into one, leading to two *Redundant Edges* to be created for one route (Figure 3b). Redundant edges pose a problem when it comes to aggregating traffic information for this particular road. When the same route through a grid cell is represented by two different GREs, vehicles will not be able to determine which edge holds the correct traffic information. In addition, more disk space and transfer volume will be used for these redundant edges as they will be saved and exported just like any other edge.

Redundant edges are usually created when streets are overly wide in relation to $I_{\max}$ (e.g., due to many lanes), or when a street cuts the grid in an acute angle. The authors in [5] proposed that only cuts with an angle bigger than a predefined α shall create GRPs. This, however, leads to the problem that certain parts or even whole streets are not represented by any GRE. In sim$^{\mathrm{TD}}$ the angle constraint is not accounted for.

As can be seen, $I_{\max}$ cannot be chosen in a straightforward fashion. Rather, its value has to be chosen after its influence was studied carefully. We have therefore identified both G and $I_{\max}$ as input parameters that have to be investigated by extensive simulations.

C. Knowledge-base exchange strategies

In order to efficiently and effectively distribute traffic information among participating vehicles, a selection strategy has to be applied for exporting GREs from a vehicle's knowledge-base. We increase the flexibility of this approach by combining the results of multiple exporter algorithms, each following a different basic selection strategy and contributing GREs to the generated data packet according to a predefined weight. Earlier studies within the sim$^{\mathrm{TD}}$ project identified the following three basic strategies:

- Newest: All known edges are sorted according to the most recent age of the attached information. Starting from the newest information, edge lists are generated. Once an edge with expired data is reached, the current list is considered finished and will be added to the data packet.
- Nearby: Edges are selected dependent on their distance to the exporting vehicle. Edges are randomly selected from all GREs within a predefined radius until no more edges can be found or the assigned size is exceeded.
- Random: Random points are selected from the knowledge-base and for each point construction of a GRL is attempted by iterating over all preceding points. If the GRL branches, one branch is selected as the start of a new list while the other one is used to extend the current list.

In order to allow for efficient data encoding, exporters will try to maximize the length of the exported GRLs. If an edge was already marked for export in one exporter, it is not be included in any other GRL.

We will examine the effects of different weights for the exporters and how well the TIS performs using different settings in Section VI.

IV. SIMULATION SETUP

As described above and as shown in the original publications [5], [14] the choice of input parameters has a strong influence on the overall performance of the Traffic Information System (TIS). We therefore carried out extensive simulations in order to find suitable values for the grid size G, the identity radius $I_{\max}$ and the exporter's forwarding strategy.

For this we incorporated the original OSGi-based source code (which is running on the actual vehicles) into a single-threaded discrete-event simulation environment. It is well-established in the ITS-community that in order to produce meaningful results, a suitable mobility model has to be used [15]. To account for this, we coupled our simulator with the SUMO [16] traffic simulator using TraCI [17] and used a step length of 200 ms. The simulation ended after 1000 simulated seconds.

We chose to perform simulations in a realistic suburban scenario based on real geodata for the city of Ingolstadt, Germany [18]. We imported this geodata (i.e., road and building geometry, speed limits, one way streets, etc.) from OpenStreetMap, and adapted it to reflect realistic intersection management (correct turning lanes, coherent traffic light phases). The used map is depicted in Figure 2a.

Table I
SIMULATION PARAMETERS AND TERMINOLOGY

Simulation time	1000 s
Step length	200 ms
Density of moving vehicles	16 cars/km^2
Area size	~50 km^2
Data exchange interval	4 s
Maximum transmission range	300 m
Maximum packet size	1000 B
GRP	Geo Reference Point
GRE	Geo Reference Edge
GRL	Geo Reference List
Grid size G	distance between two grid lines
Identity Radius $I_{\max}$	Maximum distance between to GRPs to be considered equal
Faulty Edges F	Sum of Redundant and Collapsed Edges

Vehicles in SUMO use the Krauss microscopic driver model [19] and follow all traffic regulations, such as traffic lights, right of way, turning restrictions and so on. We chose a rather small transmission range of 300 m for radio communications as in these high level evaluations we did not account for network collisions or obstacles. Modeling such effects, in particular with respect to shadowing [20], [21], requires the use of a complete IVC simulation framework integrating a full-fledged network simulator, e.g., the *Veins* simulation framework [22]. In order to keep the simulation model as close to the FOT code base as possible, however, we decided against approximating the complex OSGI bundle code in such a simulation framework.

We further improve the degree of realism in our simulation by (a) configuring vehicles to not exchange TIS-data at arbitrary points in time, but restricting them to communicate with partners in their vicinity only every four seconds and (b) setting the vehicle density to a comparatively low value of 16 cars/km^2. This is because, in the real sim$^{\text{TD}}$ system, the TIS function will be only one of many, and access to resources like CPU or radio will be limited. Moreover, if the function would be able to export all of its knowledge-base by simply transmitting every few milliseconds, a simulated area of approximately 50 km^2 would not be enough as, of course, the maximum size of the knowledge-base is limited in our simulation due to the fixed area size.

For easy reference all simulation parameters can be looked up in Table I.

V. PARAMETERIZING THE GRID

The intention of the first simulation runs was to give valuable information about the effects of the grid size G and the identity radius $I_{\max}$. In Section III-A and III-B we identified the occurrence of *Redundant* and *Collapsed Edges* as the major negative effect of disadvantageously chosen values for G and $I_{\max}$. We therefore selected the number of *Redundant* and *Collapsed Edges* as the main metric to assess the performance of our system depending on the identity radius and the grid size. We refer to both collapsed and redundant edges as *Faulty Edges* (F).

It is very difficult to determine which kind of faulty edge has a more negative impact on the system, as in the end it is the driver who is confronted with inaccurate traffic information. The impact is also heavily dependent on the particular edge and cannot be generalized. We therefore decided that collapsed and redundant edges should be equally weighted and that the goal be to minimize the overall count of faulty edges F. Formally, we find the minimum of the function $f\colon (G, I_{\max}) \to F$. Please note that, in order to identify edges as redundant or collapsed, knowledge about the road map has to be utilized. As this knowledge is, of course, not available to vehicles in the real system, their drivers cannot identify an edge as faulty. We therefore have to parameterize the system a priori to keep the amount of faulty edges as low as possible.

In a first step we investigate the sensitivity of selected metrics to grid size G and identity radius $I_{\max}$. The results of simulating the sim$^{\text{TD}}$ TIS for a broad range of these input parameters are presented in Figure 4.

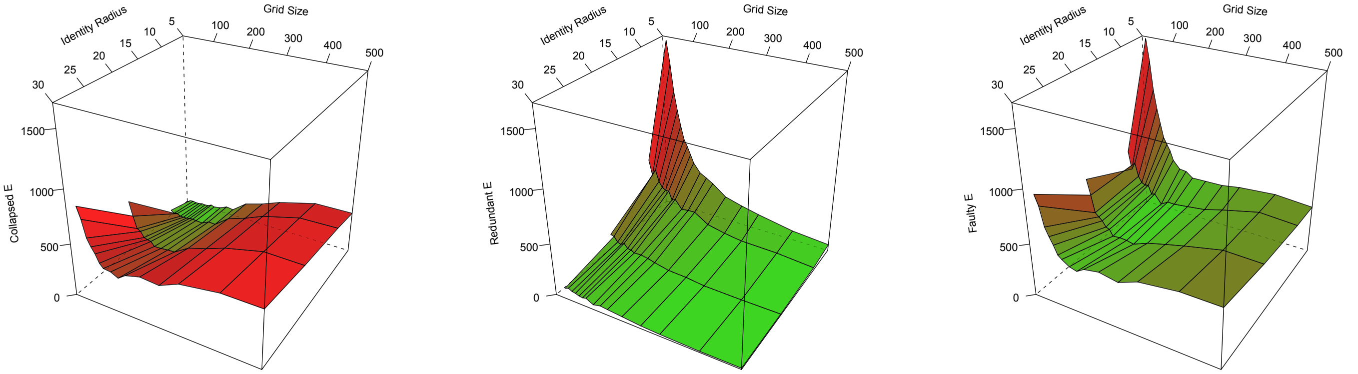
As expected, the amount of collapsed edges is considerably smaller when G and $I_{\max}$ are given small values (Figure 4a). This is because with a small $I_{\max}$ two GRPs of streets exiting a grid cell close to each other are less likely to be in each other's identity radius and therefore less likely to be merged into one GRP. With smaller grid cells (that is, smaller values for G) it becomes also more improbable that two or more different routes through one grid cell exist. Increasing one of the parameters will therefore lead to more collapsed edges.

The behavior for redundant edges, however, is almost contrary. Smaller values for G and $I_{\max}$ will generate a large amount of redundant edges as can be seen in Figure 4b. This is explainable by the angles in which streets with more than one lane cut the grid. With more acute angles the distance on the grid line between GRPs created by vehicles on different lanes will increase. A redundant edge is generated if these points do not lie in each other's identity radius. This occurs more often with smaller values for $I_{\max}$. The influence of G is not that obvious, but can be explained succinctly: Smaller grid cells lead to more cut points of streets with the grid lines. The more often a vehicle intersects a grid line, the more likely a redundant edge is created, as a) GRPs from different grid cells are not merged and b) a straight street cutting grid lines in an acute angle will cut the now denser grid more often.

To get a rough estimation of good values for G and $I_{\max}$ in order to minimize the number of faulty edges we combined both results.

As illustrated in Figure 4c, inputs of $I_{\max}$ in an interval of $[15 \,..\, 23]$ and G in an interval of $[110 \,..\, 130]$ minimize the value of $f\colon (G, I_{\max}) \to F$. We therefore investigate values of f in this range in more detail, performing further simulations with a more fine-grained resolution for G and $I_{\max}$ in the identified region.

The results are plotted in Figure 5. As can be seen at this level of detail, even though $G = 124$ leads to minimal values of f, no tighter bound for a global optimum of G can be established; for the considered range of parameters the specific geometry of the road map outweighs the influence of G: for



(a) Collapsed Edges occur less often when grid size and identity radius are given smaller values

(b) Yet, small values for identity radius and grid size lead to a large amount of redundant edges

(c) Combining both figures gives an idea of where to find the global minimum

Figure 4. Simulative study of faulty edges when changing parameters G and I_{max}

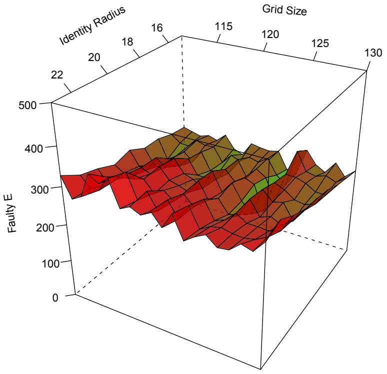


Figure 5. Rerunning the simulations with a higher resolution and a limited range for the input parameters led to a global minimum specific for our scenario.

example, changing the grid size by only one meter can cause a street to now lie directly on a grid line or move a street away from a grid line, reducing or increasing the number of redundant grid cuts. We can, however, still see a tight correspondence between I_{max} and f: increasing this parameter increases the amount of faulty edges, indicated by red coloring. Our findings showed that these extra faulty edges were mainly collapsed edges, that is, an identity radius of 20 m was still big enough to merge GRPs of disjunct streets. The function leveled at approx. 17 m, i.e., there were only a few disjunct streets that were erroneously merged.

We believe that these values ($G = 124$ and $I_{\text{max}} = 17$) obtained in our simulations, while certainly specific for the city of Ingolstadt, can be extrapolated from our road map to other European cities, because of its typical mixture of high- and low-capacity roads, traffic lights, and unregulated intersections, as well as high- and low-density areas.

VI. PERFORMANCE EVALUATION

With grid size and identity radius being defined, we were now able to evaluate the performance of the sim$^{\text{TD}}$ TIS with respect to the chosen selection strategy of knowledge-base entries for transmission (that is, the way how GREs are selected from a vehicle's knowledge-base and exchanged with other nearby vehicles).

A specific strategy is defined by the fraction of data each exporter may contribute to a network packet of maximum 1000 B. In the remainder of this paper we will refer to one strategy with the following notation:

$$\begin{array}{rcl} x.y.z & & \\ x & = & \text{Bytes for the } \textit{Newest} \text{ Exporter} \\ y & = & \text{Bytes for the } \textit{Nearby} \text{ Exporter} \\ z & = & \text{Bytes for the } \textit{Random} \text{ Random} \end{array}$$

Strategy 750.250.0 thus represents a configuration where up to 750 B will be used by the *Newest* exporter, 250 B by the *Nearby* exporter and 0 B by the *Random* exporter.

To avoid simulation of the bootstrapping process, evaluations were done in two steps: First, we only simulated the system without applying any metrics to evaluate it. Knowledge-bases built up by vehicles were then saved to disk. In a second simulation run 50 % of vehicles loaded their previously learned knowledge-base, while performance evaluation only involved the other 50 %.

We will not primarily focus on the actual performance of specific configurations because this is heavily dependent on implementation and system characteristics, but rather focus on identifying appropriate metrics to evaluate a TIS such as the one used in sim$^{\text{TD}}$, as those can then be used to evaluate similar TIS deployments.

A. Level of Information

Estimating the performance of such a system (i.e., one where vehicles are not equipped with a digital road map) in terms of traffic metrics is infeasible: All re-routing decisions are made by drivers based solely on local knowledge and without support by a Personal Navigation Assistant (PNA). We consequently

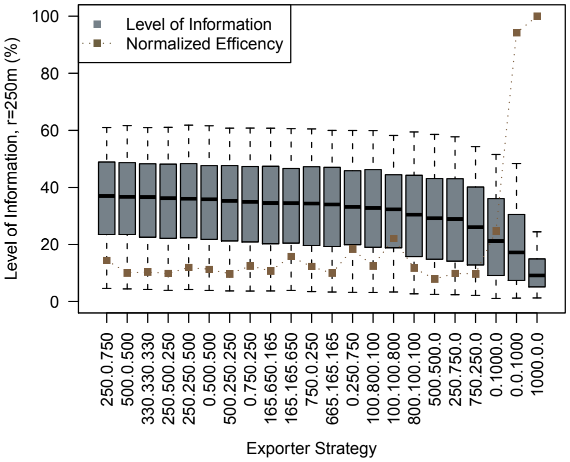


Figure 6. Measurements for the *level of information* in a 250 m radius w.r.t. different forwarding strategies (a mix of *Newest*, *Nearby*, and *Random*).

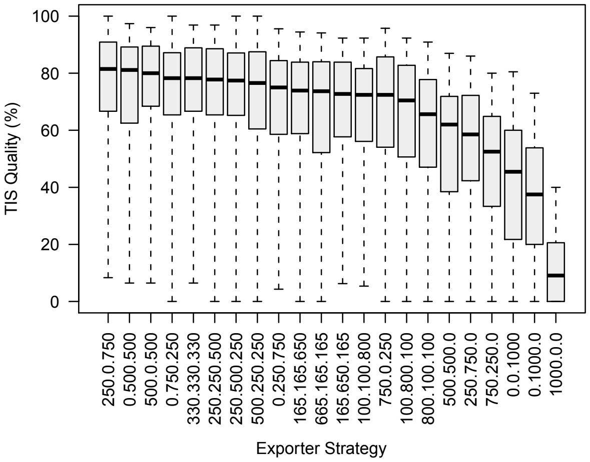


Figure 7. Measurements for the *quality* of the TIS.

opted to instead evaluate the amount of data available to support drivers in such a decision. It is evident that, the more drivers know about their environment, the better they can judge and evaluate a traffic situation. We therefore identified the *level of information* L as a metric to assess the overall performance of the TIS.

We define L as the fractional length of streets intersecting a circular area of radius m for which traffic information is available. We denote the set of streets within m meters as S_m. We further denote the set of all GREs within m meters as K_m and the set of streets represented by each GRE as L_k. Thus, the level of information L can be expressed as

$$L(m) = \frac{\sum_{i=0}^{|K_m|} \sum_{j=0}^{|L_{k_i}|} \text{length}(l_j)}{\sum_{i=0}^{|S_m|} \text{length}(s_i)}.$$

In Figure 6 we present our findings for $m = 250\,\text{m}$. The boxes reach from the 25 % to the 75 % quantile with the median being indicated by a horizontal line within the box. In addition to values of L, we illustrate the efficiency of a certain strategy, that is the ratio between the volume of data sent and the attained *level of information*, plotted as brown squares. The efficiency was normalized in reference to the most efficient one. As can be seen, strategies with only one active exporter perform substantially worse than others, while all configurations with at least a small fraction of the *Random* exporter perform quite similarly. Increasing m showed that the amount of bytes given to the *Nearby* exporter plays an important role when it comes to spreading topology information among vehicles. Exporting edges in a LIFO manner as done by the *Newest* exporter proved effective for areas up to $500\,\text{m}$ away from the vehicle.

Simulations showed that all three operating modes of exporters have positive impacts in different scenarios, that is, different values for m, and should therefore all be included in the forwarding strategy.

B. Quality

To further specify which strategy performs best we introduce the quality Q of the TIS as a metric. Q is defined by the fraction of a vehicle's route about which it already had traffic information before passing it. It is evident that, with a higher quality Q, a driver could have avoided potential traffic situations more easily. We define K as the set of all GREs representing streets on a vehicle's route before passing them and R as the set of all streets on a vehicle's route. Thus, we obtain Q as

$$Q = \frac{\sum_{i=0}^{|K|} \text{length}(k_i)}{\sum_{i=0}^{|R|} \text{length}(r_i)}.$$

We present our results in Figure 7 and find that exporting random edges from the knowledge-base brings about a notable benefit for the quality of the system.

C. Efficiency

In a last step we analyze how efficiently data is spread throughout the network. For this we took into account how many edges received by a vehicle were not known prior to receiving them and at the same time how many edges were already known. While it is very important to receive traffic information about the same street more than once in order to perform plausibility checks or simply to learn about changing traffic situations, it is not beneficial to receive the same information about a certain street from one vehicle twice.

Figure 8 shows our measurements and highlights that exporting edges w.r.t. their distance to the sending vehicle is, as was expected, a valid approach to distribute topology information.

It could furthermore be discovered that a large part of data sent over the wireless channel is redundant. We therefore propose that scheduling algorithms should be applied when selecting data for information exchange in TIS deployments. Another valid approach to reduce data redundancy is incorporating neighborship relations to avoid sending data to the same vehicle twice.

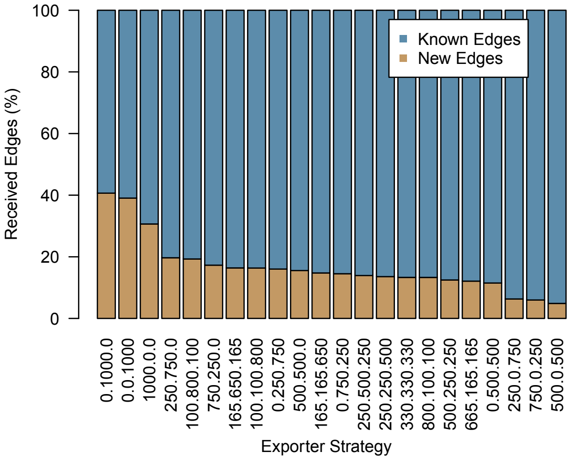


Figure 8. A large portion of information was already known by vehicles before receiving it.

VII. Conclusion and Future Work

The sim$^{\text{TD}}$ project dedicates itself to researching and testing Car-to-X communication and its applications. One of these applications is a Traffic Information System (TIS) for vehicles not equipped with digital maps. These vehicles generate maps by using a GPS receiver and a global reference grid. Whenever vehicles cross a grid line, a new point is created. Additionally a radius is introduced to determine if two points belong to the same street.

In extensive simulative studies we showed that both the grid size and this radius have a substantial influence on the operability of the TIS. We found practical settings for both and – backed by real life experiments – we believe that our findings are also applicable for other projects using similiar TIS deployments.

In a second simulation run, we evaluated the general performance of the TIS. We contribute to the Car-2-X community by introducing metrics, namely the level of information, the overall quality of a TIS, and its efficiency. We showed how they can be used to determine a well-working and transferable parameterization for the exchange of information between vehicles.

Future work within the sim$^{\text{TD}}$ project includes further, extensive real life experiments to analyze both long-term and short-term behavior of the deployed TIS as well as side effects that could not be accounted for in the simulation.

VIII. Acknowledgments

This work was funded within the project sim$^{\text{TD}}$ by the German Federal Ministries of Economics and Technology as well as Education and Research, and supported by the German Federal Ministry of Transport, Building and Urban Development.

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