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# V2X-Based Traffic Congestion Recognition and Avoidance

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## Abstract

Finding a way to improve traffic efficiency is a high-frequented problem to be solved. One new promising approach is the use of decentralized wireless vehicle to vehicle communication based on the Vehicle-2-X (V2X) technology. The underlying idea is that vehicles share information about their current local traffic situation and use this information to optimize their routes. In this paper, we introduce a new algorithm that can be used by navigation systems to calculate routes circumnavigating congested roads. To evaluate the improvements that can be achieved by our algorithm, simulations have been carried out which show that navigation systems using the V2X technology for a more intelligent route calculation can improve the traffic efficiency of future transport systems. For the simulation of all aspects of V2X Communication scenarios, different simulators have to be combined and an interaction among them at runtime of the simulation has to be enabled. Hence, we have developed the V2X Simulation Runtime Infrastructure (VSimRTI) which couples discrete event-based simulators, e.g. for communication network, traffic, and V2X application simulation. The flexibility of VSimRTI allows us to vary the composition of integrated simulators depending on the specific requirements of a scenario.

***Key Words***: Vehicle-2-X Communication, V2X, Simulation, V2X Simulation Runtime Infrastructure, VSimRTI

## 1. Introduction

Today, the average time an individual spends in motion lies between 60 and 90 minutes per day. The average European travels an annual distance of 10,000 to 15,000 km by vehicle which is equivalent to 35 km per day [1]. Even if drivers attempt to avoid daily rush hour traffic, the circumnavigation of all suddenly arising traffic congestions is mostly impossible with current traffic management systems. To manage these challenges in the future, the U.S. Federal Highway Administration (FHWA) identified three general approaches to reduce traffic congestion [2]:

- Extension of the current base capacity, e.g. increase in the number and size of highways.
- Encouragement of alternative travel and land use concepts that require fewer resources, e.g. non-automotive travel modes.
- Using the existing capacities more efficiently

The approach proposed in this paper focuses on the third strategy. As stated in the FHWA final report [2], all of these three strategies reduce traffic congestion, but strategies for a more efficient use of existing capacities have the most effective impact, since they concentrate on the basic cause of the problems instead of only alleviating negative effects.

### 1.1 Outline

This paper is divided into seven sections. The following section gives a brief overview of the current state of similar systems and applications. We discuss different approaches for V2X simulation architectures in section

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3. In section 4, we describe our approach to be used by navigation systems to recalculate routes circumnavigating congested roads. Section 5 explains the simulation scenario we have used to evaluate our approach. The results of our analysis are shown in section 6. The last section offers our conclusion.

## 2. State of the Art

The implementation of GPS satellite route guidance systems in vehicles was the basis for the deployment of new technologies for the reduction of traffic congestion by increasing traffic efficiency. The GPS technology enabled the on-board vehicle equipment to determine its current geographical position. Accordingly, the possibility to deploy several subsequent technologies like the Traffic Message Channel (TMC) was established. TMC transmits geo-based information about the current traffic situation, e.g. information about accidents, road works, or traffic congestions via the Radio Data System (RDS). A disadvantage of TMC is the limited bandwidth of RDS. To overcome this drawback, a further approach uses GPRS-based services via GSM for information transmission. Here, the GPS system is equipped with a GSM module that connects to a server and requests more detailed traffic information than was possible with TMC.

In several cases, these technologies improve traffic efficiency. However, there are numerous situations where these systems fail. For example, when roads are blocked or crowded, the TMC transmits information about the location of the congestion and proposes an alternative route. Now, vehicles receiving this information try to use the suggested alternative route to circumnavigate the congested area. If too many vehicles use the TMC system, the capacity of the alternative route could not be sufficient either. As a result, congestion may occur on the alternative route, too. Furthermore, the congestion of the original road could be already resolved since there is a time delay till the TMC system gets the information about new traffic situations and transmits it to the drivers [1]. Even if GPRS-based systems can provide more individual alternative routes, their effectiveness is also limited since they use a limited number of sensors across major roads for their traffic suggestions. Smaller roads are not covered, and as a result, these systems might also guide vehicles into hitherto unknown traffic congestions.

To overcome all the drawbacks mentioned above, one new promising approach is the usage of decentralized wireless vehicle to vehicle communication based on the Vehicle-2-X (V2X) technology. Here, vehicles are equipped with a wireless local area network adapter (ITS vehicle station) which enables them to communicate with other vehicles and with fixed access points close to the roads (ITS roadside station). This future technology is to improve both traffic safety and efficiency [3]. V2X enabled vehicles transmit information such as their current speed, position, and direction to their neighbourhood. This information can be used by the individual vehicle to make more detailed estimations about the current traffic situation in its vicinity. As a result, vehicle routes to circumnavigate traffic congestions can be calculated in a more intelligent and dynamic way than is currently possible with existing GPS-based navigation systems. Compared to conventional systems, a further advantage of the V2X technology is the decentralized organisation by a dynamically changing network of vehicles that does not necessarily need a fixed infrastructure. Thus, V2X-based solutions for the reduction of traffic congestion are applicable in all places where V2X equipped vehicles occur. According to Maurer [1, p. 151], decentralized and adaptive systems are superior to centralized ones. Boyoms [4] presents a V2X-based algorithm to circumnavigate congested areas and reduce travel time. His simulations show a benefit of an approx. 6.5% reduction of the travel time at a penetration rate of 25% V2X-based vehicles.

To give a brief illustration, a simple V2X-based traffic efficiency use case is visualized in Figure 1. It shows
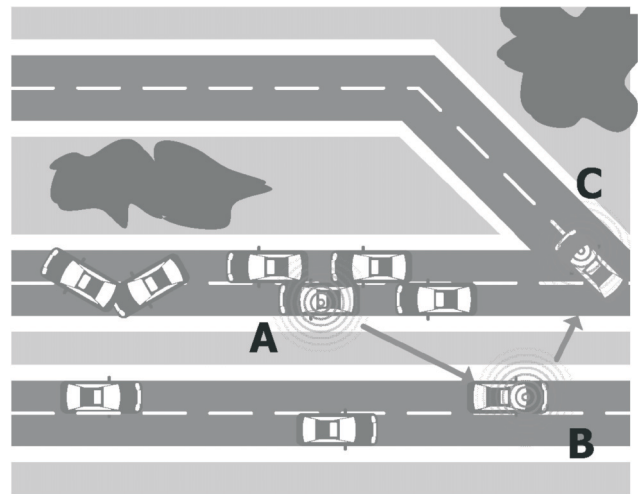


**Figure 1.** A simple example V2X use case.

a situation where vehicle A cannot cross the road because it is blocked by an accident. Vehicle A is equipped with a V2X communication system, and as a result, it sends an information about the accident to other vehicles in its vicinity. Vehicle B, which moves in the opposite direction, carries the information to vehicle C. Thus, vehicle C can circumnavigate the congestion and make a right turn into another road. Forwarding a message via multiple vehicles, as shown in this example, is done by a geographic routing algorithm explained in [3].

Using the V2X technology, new strategies can be developed to process statical road map data as well as highly dynamic information to reduce travel time and to avoid traffic congestion. Our approach achieves these ideas and uses a more detailed algorithm to yield a further improvement of traffic efficiency.

## 3. V2X Simulation Architectures

Before introducing a V2X application in a real system, its functionality, efficiency, and further effects have to be tested carefully. To evaluate the improvements that can be achieved, several simulations have to be carried out. According to [5,6], a realistic simulation of V2X communication scenarios needs to consider various aspects of simulation, i.e. the vehicular traffic, the V2X communication network, the application, and the environment. Vehicular traffic includes the physical movements of vehicles on an arbitrary road network. The simulation of the V2X communication network handles the wireless message transmission among vehicles, and between a vehicle and the fixed infrastructure. Application simulation means the simulation of applications that are to be integrated into real world vehicles. For this purpose, inner vehicle interfaces have to be emulated to allow the application to interact with other modules of the vehicle, e.g. GPS sensors. The last aspect is the environment simulation which includes the road network itself as well as temporary events, such as weather conditions and road works.

### 3.1 Architecture Approaches

In general, existing V2X simulation architectures can be divided into three different areas:
● An integrated simulator covering all V2X domains,
● A fixed coupling of different simulators,
● A flexible simulator coupling realised by a simulation runtime infrastructure.

### 3.1.1 Integrated Simulator Covering Traffic, Communication, and Applications Domains

An integrated simulator covers the three domains important for V2X simulations, i.e. vehicular traffic, communication, and application simulations. Only one clock for the time management exists and no further synchronization is necessary. Here, the integration of different simulation domains is a major challenge for the simulator developers. In the history of computer simulations, vehicular traffic and wireless communication have been divergent domains without intersections. In general, an expert in developing traffic simulators does not necessarily have detailed knowledge about the simulation of wireless communication and vice versa. Thus, the development of such a tool with a high accuracy in traffic, communication, and application simulation has proven to be difficult. As a result, existing integrated simulators are rather suited for high-level simulations.

### 3.1.2 Fixed Coupling of Different Simulators for the Different Domains

Fixed simulator couplings are couplings of independent simulators where each simulator is specified for one of the domains, i.e. vehicular traffic, communication, or application simulation. Each simulator has an own clock for its time management. Thus, additional synchronization mechanisms have to be implemented in the coupling mechanism to ensure that all events of the coupled simulators are processed in the correct order. The coupling component is adapted to the used simulators and integrated simulation tools cannot be exchanged. A disadvantage of the fixed coupling is that a re-implementation is not only necessary if a simulator is to be exchanged, but also the integration of new versions of one of the coupled simulators mostly requires to make adjustments. So, a fixed simulator coupling only works well as long as all simulation scenarios have similar requirements that are fulfilled by the existing coupling.

### 3.1.3 Simulation Runtime Infrastructure (RTI) with Common Interfaces for Flexible Simulator Coupling

If requirements vary depending on the simulated

scenarios, it is not satisfying to use simulator couplings that are adapted to specific simulators and cannot be exchanged. To master this challenge, a simulation runtime infrastructure (RTI) with common interfaces allows the integration of arbitrary discrete event-based simulators. The coupling via common interfaces provides the flexibility to exchange simulators according to the specific requirements of a simulation scenario. A central management is provided by the simulation runtime infrastructure and offers services to handle synchronization, communication among the coupled simulators as well as lifecycle management of each component. A solution can be inspired by the IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) [7]. Thus, attaching a simulator only requires to implement the interfaces of the simulation runtime infrastructure and to realize the commands specified within. The internals of the underlying implementation are hidden.

### 3.2 Our Simulation Architecture VSimRTI

For sophisticated V2X simulations, we developed the V2X Simulation Runtime Infrastructure (VSimRTI) [8,9] that follows the third approach. We can couple arbitrary simulators and enjoy the flexibility to exchange them depending on the specific requirements of a simulation scenario. The VSimRTI system architecture supports a subset of the HLA standard and some of its fundamental concepts are used. However, the complexity of the whole HLA standard and its implementation would have exceeded the scope of a V2X simulation framework. So, a lightweight framework was created which facilitates the simulation of V2X communication scenarios.

In order to increase performance and scalability of complex V2X simulations, we implemented a time management service that enables optimistic synchronization in VSimRTI. Our analysis of several series of scenarios showed the benefits of optimistic synchronization in V2X simulation environments [10].

## 4. Algorithm for Circumnavigating Congested Roads and Improving Traffic Efficiency

### 4.1 Overview

For the prediction of traffic congestion, traffic density is essential. Advanced GPS navigation systems receive information about possible obstacles, like blocked roads, via TMC. But, as discussed in the section above, these centralized traffic management systems show weaknesses if too many vehicles follow their suggestions. As a result, it becomes difficult for a driver to decide if it is useful to accept the circumnavigation proposed by the navigation system [1, p. 13]. The V2X technology allows to create a more effective local image of the current traffic situation. The additional information enables a driver to find an improved route to minimize travel time.

An approach to the prediction of traffic congestion is the detection of the vehicles' speed. In our solution, all V2X-based vehicles transmit certain information about their current traffic situation to other vehicles in their vicinity. As a result, vehicles can use received information to recalculate a new optimized route based on the current traffic situation. One advantage of our algorithm is that vehicles also know of the traffic situations of the bypass roads. Thus, in contrast to classical traffic management systems, it is avoided that vehicles try to use roads to circumnavigate the congestion which have been also congested in the meantime. To achieve this aim, the fundamental indicator of our algorithm to recalculate the routes is the vehicles' speed in the vicinity.

### 4.2 Our Approach in Detail

Routing algorithms in GPS navigation systems, like Dijkstra, use road segment weighting for calculating the vehicle routes where the fixed defined travel time of a road segment is used as the weighting factor. Our approach is aimed at replacing the weighting factor by a more effective value. Therefore, we use the average of the vehicles' current road segment time for the weighting. This road segment time is the amount of time that a vehicle needs to pass trough a road segment.

Figure 2 shows a simple road network (left side) and illustrates how this network is transformed to a representation of edges and nodes (right side). Here, road segments are represented by edges and intersections are represented by nodes. Nodes ($N_j$, $j = 0, ..., 5$) have geographic coordinates, edges ($E_i$, $i = 0, ..., 4$) are lines that connect two nodes. Following this approach, the parameters of the edges can be used for the Dijkstra algorithm since every edge, $E_i$, has a maximum speed, $u_{i_{max}}$ (frequently equal to the speed limit of this edge) and a length, $s_i$, that can be calculated by the distance of its nodes' coordinates. The edge trip time, $T_{i_R}$, can be calcu-
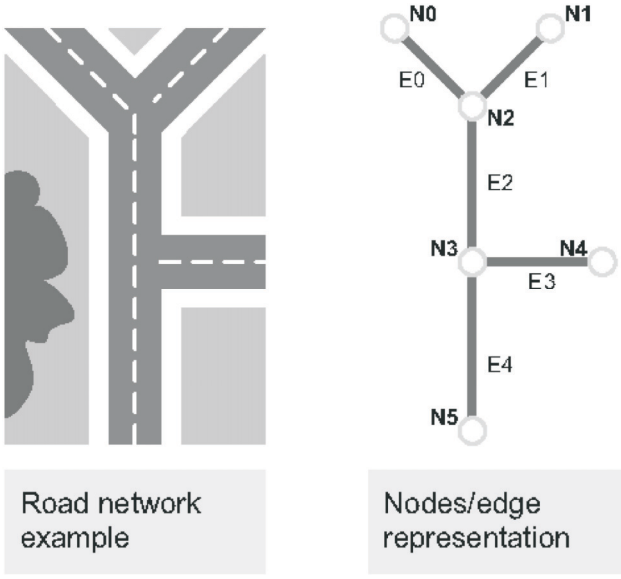
**Figure 2.** Edge and node representation of a road network.

lated using speed and length

$$T_{i_R} = \frac{s_i}{u_{i_{max}}} \tag{1}$$

$$[T_{i_R}] = \frac{m}{s} \tag{2}$$

with the help of these algorithms, either travel distance optimization can be performed by $s_i$ or travel time optimization by $T_{i_R}$. Using the average speed, $\overline{u_{i_t}}$, and the length of the edge, it is possible to calculate the travel time using equation 1.

Since a vehicle can only detect its current speed, the average speed for a road segment has to be calculated. Hence, a vehicle performs an averaging of all speed values recorded during passing an edge. However, this average speed is a good approximation even if some short edges might be skipped before a speed value could be recorded. At least one recorded speed value of an edge is necessary for vehicles to recognize a congested road segment. The more recorded speed values exist, the more accurate will the calculation of the average road segment time be. For example, if a vehicle has to stop at a red traffic light, this decreases the average road segment time and could cause the assumption that there is a congestion.

Furthermore, to detect congested roads as soon as possible, vehicles send intermediate messages when there speed is equal to zero. These values are used in the the same

manner like a calculated average speed of a road segment. Accordingly, the most important steps of our algorithm are:

- Every V2X-equipped vehicle sends its average speed for every passed edge to other vehicles in its vicinity.
- In case of a very low speed, a V2X-equipped vehicle sends an intermediate message when a time limit is exceeded.
- All V2X-equipped vehicles use the received speed values to calculate the edge weights for the corresponding road segments.
- The updated weights are used by a vehicle to recalculate its travel route. If the resulting travel time of a new route is shorter than the travel time of a previously selected route, the vehicle chooses the new one.

Vehicles use the route calculation algorithm, described above, to convert the received speed values into travel time. But, if each received value was converted independently, high frequent route changes could result. Since congestion is time dependent and dynamic, the newest speed values should have the highest weight. As a result, the weights are calculated with the help of time stamps. When a vehicle sends a message, a time stamp is attached. This approach results in $N$ travel time entries, $T_{i_R}$, and $N$ time stamps, $T_{i_s}(n)$, for an edge, $i$. After receiving a message, the corresponding time stamp is compared with the maximum time until an entry is deprecated, $T_{S_{MAX}}$, and the current time, $T_{S_{CUR}}$. The weight, $\alpha_i(n)$, for an entry as well as the weighted speed, $\overline{u_{i_t}}^*$, are calculated as follows:

$$\alpha_i(n) = \frac{\Delta T_{MAX} - (T_{S_{CUR}} - T_{i_s}(n))}{\sum_{n=0}^{N-1}(\Delta T_{MAX} - (T_{S_{CUR}} - T_{i_s}(n)))} \tag{3}$$

$$\overline{u_{i_t}}^* = \sum_{n=0}^{N-1} \alpha_i(n) \cdot \overline{u_{i_t}}(n) \tag{4}$$

This strategy, described above, is aimed at a dynamic route assignment by using a dynamically changing data base for the routing algorithm. The advantage is that this algorithm does not use states like 'congested' or 'non-congested'. Instead, it uses edge travel time values as an input for the conventional shortest path algorithm.

## 5. Simulation Scenario to Evaluate Our Results

To simulate our algorithm, we coupled several simu-

lation tools with the help of our simulation architecture VSimRTI. We use the open source simulator SUMO [11] to simulate the vehicle traffic. SUMO offers the runtime interface TraCI [12] to control and influence the vehicle behaviour at runtime of the simulation. The traffic generated by SUMO is used as input for the communication simulator JiST/SWANS [13]. We have implemented an extension for JiST/SWANS that allows us to synchronize the internal scheduler, modify node positions, and send and receive packages. Furthermore, we use the extensions for JiST/SWANS by Ulm University for the simulation of the V2X communication network. The third integrated component is the VSimRTI-specific application container to deploy applications on a vehicle. The environment simulator eWorld[1] is the fourth integrated component. We use eWorld to import real road map data from OpenStreetMap [14], enhance them with location-based information, and export them as SUMO input files.

## 5.1 The Simulation Scenario

To evaluate the effectiveness of our algorithm and to identify potential problems, we selected a simulation scenario which is as simple as possible. For this reason, an excerpt of the city of Cologne, the area around the Luxemburger Straße street, was chosen because it provides an adequate road structure for our tests. In our scenario, most vehicles drive on an almost straight road, the street Luxemburger Straße, from the southwest to the northeast. The route is shown in figure (dark grey line). A vehicle flow of 2,880 vehicles per hour is defined and the overall simulation time is set to one hour. Some changes to the real traffic conditions were made to simplify the scenario:

- The maximum speed of all roads is reduced to a limit of 50 km/h. This is necessary to apply a higher priority to side roads and downgrade the main road so that in case of congestion vehicles rather choose the side roads to circumnavigate than stay on the main route.
- To create congestion, a traffic light system (TLS) is used at the crossing of Luxemburger Straße and Gottesweg. Another TLS at the intersection of Luxemburger Straße and Weißhausstraße is altered to create another cause of congestion (see both shaded dots in Figure 3). At both TLS, the logic is set to create a long

red and short green phase on Luxemburger Straße. All succeeding TLS on intersections of the Luxemburger Straße are removed to ensure vehicles flow off at the end of the main road.

The scenario is designed to benchmark our algorithm instead of trying to create a scenarios that is as real as possible. All unnecessary or unpredictable factors that might influence the results such as random traffic or complex traffic light systems are avoided in order to provide significant results.

## 5.2 Simulation Parameters

An important factor for the analysis is the percentage of V2X-based vehicles in comparison to all vehicles in a simulation run. In this paper, this factor is to be called the V2X penetration rate. After introducing the V2X technology to the market, the rate of V2X-based vehicles will start at a low percentage and, then, increase continuously. To evaluate at which penetration rate the vehicle driver can experience a noticeable improvement, the penetration rate in our simulations is increased from 0% to 100% in steps of 5%. We analyse the influences on both the classical and the V2X-based vehicles. To detect the



**Figure 3.** The Luxemburger Straße Street Scenario.

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[1] http://eworld.sourceforge.net

performance of our algorithm depending on the V2X penetration rate, the travel time is used as the most important parameter. One characteristic penetration rate is 0% V2X-based vehicles which represents the current traffic situation. By incrementing the penetration rate, the impact on the travel time of both classical and V2X-based vehicles, compared to 0%, is analyzed.

## 6. Results

As long as the penetration rate of V2X-based vehicles is 0%, all vehicles drive on the main road Luxemburger Straße. The more the V2X penetration rate increases, the more vehicles use alternative routes to circumnavigate the congestion of Luxemburger Straße. Figure 3 shows the most widely used alternative routes that V2X-based vehicles chose (light grey lines).

Figure 4 illustrates the benefit of decreased travel time for regular (classical) vehicles as well as for V2X-based ones depending on the V2X penetration rate. In the diagram, the benefit of 0% stands for a mean travel time of 1,023 sec. This is the mean travel time at a V2X penetration rate of 0%. 100% benefit stands for a mean travel time of 230 sec. This is the physical minimum travel time assuming a vehicle passing the main road with the maximum allowed speed without stopping at intersections and traffic lights.

Our results show a benefit of almost 50% travel time reduction for both classical and V2X-based vehicle at a V2X penetration rate of 80% or higher. Comparing regular and V2X-based vehicle travel times, V2X-based vehicles already benefit at a low V2X penetration rate (e.g. approx. 20% benefit at 20% penetration rate), whereas regular vehicles only benefit at higher states (e.g. approx. 30% benefit at 60% V2X penetration rate). Between 0% and 25% penetration rate, regular vehicles even sustain a marginal loss which lies below 5% travel time increase. This results from V2X vehicles cutting back into the main road at unsignalized intersections and, thus, force other regular vehicles to stop or slow down. One interesting fact is that at a high penetration rate of 80% both regular and V2X-based vehicles' benefits are almost equal (48% and 47% resp.). However, it is interesting that the regular vehicles outperform the V2X-based vehicles at approx. 75% V2X penetration rate. An explanation is that regular vehicles always stay on the main route. More and more vehicles of V2X-based leave the main road to circumnavigate. Their choice is based on theoretical values which are not entirely valid, especially in case of traffic lights that are not included within the algorithm. Traffic lights are problematic because of their timing and when their existence is not known to the algorithm. Hence, it assumes a freely passable road which is presumably not given. This causes vehicles using an alternative route that is theoretically faster, but practically, more time is needed due to one or more TLS on that way. The more V2X-based vehicles use this route, the more the rating decreases and subsequent vehicles will avoid using this slower route.

## 7. Conclusion

The aim of this research work was to develop and evaluate an approach based on the Vehicle-2-X (V2X) technology eliminating the drawbacks of conventional traffic management solutions and, thus, help improve traffic efficiency. In this paper, we presented a solution where vehicles send their average speed information of a road segment to other vehicles in their vicinity. The received information is used by vehicles to update their travel route reflecting the current traffic situation in its neighbourhood. Simulations were carried out to evaluate the improvements that can be achieved. The developed algorithm shows a good performance in terms of travel time reduction for both regular and V2X-based vehicles.
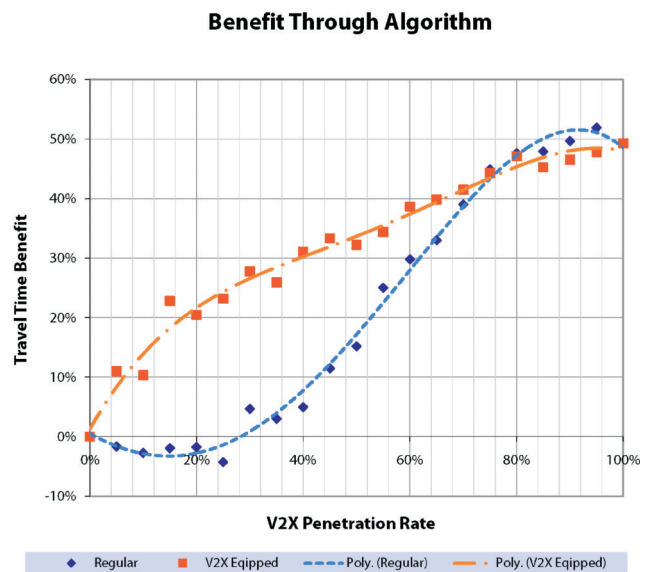


**Figure 4.** Simulation results.

Our results show that navigation systems using the V2X technology for a more intelligent route calculation can improve the traffic efficiency of future transport systems.

## 7.1 Future Work

In our next steps, we shall perform further simulations. Another interesting point is the evaluation of inner city areas with a high number of vehicles. Here, several problem aspects influence the results. The V2X message transmission could be limited by high buildings and much more packet collisions may occur. In contrast to this scenario, the number of packet collisions should be negligible in rural areas. But, because of the scattered road network and the low traffic density, the transmission of multi-hop messages could be limited and additional road-side units become necessary.

Moreover, the results of our future simulations are to be used to achieve further improvements to our approach.

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