Title: Reducing risks of near-incidents – Identify patterns and near-incident situations from large data-sets

Summary

During the spring 2021 several workshops were initiated by the AI Driven Mobility network within the focus group traffic safety. The idea was to find interesting topics where AI have a potential to improve traffic safety. Around eight suggestions on activities and initiatives were identified as interesting to explore further. The participants were asked to indicate their interest and also rank the activities and initiatives from 1-3 to indicate where they have the strongest interest. This resulted in a few topics that the participants in the group were extra interested in investigating further.

One of the areas that was identified and selected was *Reducing risks of near-incidents – Identify patterns and near-incident situations from large data-sets*. This topic was further investigated in a smaller pre-study during October to December 2021. This is a shorter report that aims to present the activities that have taken place in the pre-study and the conclusions that can be drawn from the included activities. The activity within the pre-study is restricted to the budget constraints of 100.000 SEK to be consumed within the timeframe of three month.

Purpose and goal

The purpose of the pre-study has been to get a deeper understanding of the ideas that were highlighted as interesting during the workshops in the spring of 2021 and to conclude on how AI-based methods could potentially be used in different ways to identify patterns and near-incident situations from large data-sets gathered from different types of measurement equipment's. The focus has been on traffic safety, but also traffic efficiency, and to some extent environmental impact, have been considered in the pre-study.

The goal has been to propose a project structure and contents that could be interesting to move forward with in a larger project. Hence, the expected outcome of the pre-study is a draft to a larger application. However, it is also a living document that can develop further in different directions based on later input from relevant stakeholders, as well as potential additional partners within the AI Driven mobility network.

Approach

First, a scanning of the area was done to get an idea of where the focus within this project should be and which initiatives that are already ongoing. Some of the partners within the AI Driven mobility network and the research area traffic safety that, during the spring, indicated an interest in participating in a larger project on *Reducing risks of near-incidents – Identify patterns and near-incident situations from large data-sets* have been asked to participate in one-on-one discussions. The goal with the one-to-one discussions has been to identify the interested partners research interests and how they might consider contributing to the larger project. Finally, a very broad literature scanning was performed to get an initial idea of the current state-of-the-art of the research area from the literature.

There are also partners that has indicated a more general interest in the project through possible correlation with on-going research activities in their organization, etc., or by being the owner of the project (transport administrators on regional and national levels), or in other ways have an interest in following and being part of the project later in the process. These partners have been addressed through a workshop. At the workshop the initial thoughts and ideas consolidated from the one-to-one discussions were presented to the participants and they were given the opportunity to provide input and feedback.

A few ongoing projects has been addressed based on their research topics. These projects are seen as interesting to continue to follow and the outcomes from the projects might be beneficial as input in this initiative. Further, there might also be possible overlaps with future initiatives related to the addressed projects.

Background – a first scanning of the literature

(Knoop, Van Zuylen, & Hoogendoorn, 2009) has studied the driver behavior during incidents using individual vehicle trajectories gathered from video recordings and multiple digital camera images taken from a helicopter during incident and non-incident traffic conditions. The conclusion is that drivers are distracted by the incidents and less attention is given to the driving tasks, resulting in a queue discharge rate per lane for the unblocked lane that is 30% lower than what is usually observed in such traffic conditions. This shows on the importance of avoiding incidents not only due to avoidance of long queues and congestion, but also to avoid a more inefficient traffic system compared to what is observed during normal traffic conditions.

One traffic situation that is a common source to conflicts and inefficient traffic flows are merging and lane-changing at bottlenecks (Chung, Rudjanakanoknad, & Cassidy, 2007; Srivastava & Geroliminis, 2013; Zhang & Levinson, 2004). In the study by (Xu, Zou, Oh, & Vu, 2021) a virtual reality driving environment is integrated with a microscopic traffic simulation to study the number of conflicts at freeway merging. As expected, the number of conflicts at freeway merging are increasing with increased traffic flows, but the number of conflicts can be substantially reduced by applying ramp metering. Hence, measures trying to relief the conflicts can be effective measures in preventing incidents resulting in accidents as well as congestion, i.e. both traffic safety and traffic efficiency, can be positively affected. By detecting and estimating the traffic conditions and conflicts at bottlenecks using large data-sets measured from advanced measurement equipment it is possible to increase the understanding of the merging behavior and identify problem areas. With new measurement technologies allowing for detection of individual vehicles from roadside equipment and gathering of individual vehicle data from connected vehicles it is also possible to refine the safety indicators even more.

One way to identify traffic safety and behavioral effects on merging at freeways is by using individual vehicle trajectories gathered from video recordings. An example is proposed by (Jackson, Miranda-Moreno, St-Aubin, & Saunier, 2013) where vehicle trajectories are used to calculate surrogate safety measures such as time-to-collision which might be used to indicate conflicts that might lead to incidents/accidents. By knowing the gap between vehicles for road-side detectors or vehicle data it is possible to estimate the risk and thereby apply appropriate control measures based on this information. (Charly & Mathew, 2019) propose a slightly modified version of time-to-collision, also taking account the lateral position and the width of the vehicles. If such information could be gathered this could be used to refine the risk indicator. In another study by (Kondyli & Elefteriadou, 2011), it is concluded that there is a higher probability of decelerations before a breakdown. Hence, the author suggests that such indicator could be used to predict breakdowns. Hence, information from individual vehicles communicated to the cloud and used together with other indicators could be input to a traffic control system. However, the author also state that more data is needed to verify the correlation between a high probability of decelerations and a breakdown.

Additionally, by more sophisticated traffic safety indicators it is possible to apply traffic control earlier and only when necessary. Common traditional control strategies that can be used to control the traffic flows at bottlenecks are ramp metering and variable speed limits. Ramp metering is well-established and proven to be useful for relieving the traffic conditions on the roads (Middelham & Taale, 2006). The goal is to reduce the inflows to the main road by only allowing vehicles to enter if there is enough space (by a traffic signal). Another measure that are commonly applied at larger roads are variable speed limits. The goal is to adjust the speed limit based on the prevailing traffic conditions (Abdel-Aty, Dilmore, & Dhindsa, 2006; Carlson, Papamichail, & Papageorgiou, 2011; Maunsell & Parkman, 2007; Nissan & Koutsopoulos, 2011; Soriguera, Torné, & Rosas, 2013; van den Hoogen & Smulders, 1994). Different studies have shown that variable speed limits can improve traffic efficiency and/or traffic safety both in real life and in simulation environments. With more sophisticated risk indicators these measures can be finetuned to only become active when necessary, from a safety perspective (or efficiency if this is the focus).

With the possibility to communicate information to and from connected and automated vehicles it is also possible to resolve the congestion at merging with the control of individual vehicles. For example (Tianchuang et al., 2020) propose a centralized merging control strategy for connected and automated vehicles. The authors emphasis that this will result in more efficient and safer merging processes due to the coordination of vehicles. Another example is proposed by (Rios-Torres & Malikopoulos, 2016). It is shown by traffic simulation that the proposed optimal coordination of connected and automated vehicles at merging zones is reducing fuel consumption and trave time. Similar findings have also been concluded by other authors, such as for example (Park & Smith, 2012) and (Hu & Sun, 2019). Also, control of speeds can be done individually by for example geofencing. This allows for control of individual vehicle speeds, instead of applying roadside variable speed limits.

In (Smith, Park, & Hayat, 2016) a closed-track field test environment in Virginia, USA merging enhancing functions was tested through reduced speed limits, lane change recommendations and merging control advisory. The results indicate that driver compliance was higher when a direct lane change advisory was given compared to if speed limits were used to try to force lane changes. Further, the traffic flow level has a high influence of the compliance rate. If only small gaps between vehicles were present, the compliance rate was low. This shows that control strategies aiming at influencing the gaps between vehicles are of importance.

Since most studies on more advanced traffic control strategies with connected and automated vehicles are performed in a simulation environment it is harder to conclude on effects on safety and driver acceptance. Hence, real-life trials are of importance for gathering of information and for proper design of control strategies.

In Sweden there are a few ongoing interesting and highly relevant projects to be considered. One example is the AI Aware project (AI Aware, 2021) where the goal is to combine different data sources from the traffic system in a city environment and apply AI-algorithms to identify and predict events in the traffic systems. The focus within the project is on two use cases: accidents and flooding. However, another use case could potentially be merging at on- and off-ramps, where risk indicators, making use of predictions of near-incident events, could be developed. Another example is the project Intention Recognition for Real-time Automotive 3D situation awareness (IRRA) (IRRA, 2021). In the project, the aim is to develop algorithms to provide the automotive industry with intentional recognition for an improved situation in and around autonomous vehicles. An interesting use case within the project is to predict drivers' intention to change lane. Such indicators can be used to predict the risks of incidents as a result of lane-changes and merging at bottleneck area/on- and off-ramps.

Proposed project proposal

Below is a presentation of a draft project proposal which is the outcome of this pre-study.

Motivation to the project

Merging at on- and off-ramps on urban motorways are a large source to incidents. The large traffic flows in and out from the city centre during peak-hours is creating congestion and at on-and off-ramps. Large variations in speed, merging, lane-changing actions, accelerations/decelerations at such traffic flows are the cause of many incidents.

Promising control measures to improve the traffic safety (and traffic efficiency) at on-and off-ramps have previously been introduced and exists on many urban motorways today. The most common ones are variable speed limits and ramp metering. In the case of variable speed limits, low speed limits are used to warn approaching drivers about an upcoming incident. Commonly speed and/or traffic flow are the indicators of an incident, and the control measures are applied first when there is an observed "incident" (defined at low speed and flow situations), i.e. when it is too late to avoid the incident and the measures are therefore only used to mitigate the effects of incidents and to avoid further incidents as the result of the first incident. Ramp metering is used to limit the inflow to the motorway, by only letting vehicles enter when there is space on the motorway. Ramp metering is mainly used to improve traffic efficiency, but by supporting efficient merging at on-and off-ramps (due to the limiting of the on-ramp flows) incidents can be avoided.

If near-incidents situation can be detected, control measures can be applied already when there is an increased risk of incidents. Thereby, the number of incidents can possibly be reduced. By reducing the number of incidents, traffic safety is of course improved, but also the traffic conditions and the environmental impacts at locations with frequently observed incidents can be improved due to less congestion. The traffic control measures can be based both on in-vehicle and/or traffic system control. Additionally, new control measures based on in-vehicle control can be applied to allow for even more efficient traffic control at bottlenecks.

The purpose of the project

The purpose of the project is to build knowledge and increase the understanding on how near-incidents and risk indicators can be calculated in real time at on-and off-ramp locations using different data sources and how these near-incident/risk indicators can be used to find problematic areas at on-and off-ramp locations and as input to a control strategy at the on- and off-ramp locations with the goal to improve traffic safety.

The goals

The goals in the project are the following:

1. To propose risk indicators that can be used to indicate risks of near-incidents at on- and off-ramp locations. The risk indicators can be calculated using measurements from different types of data sources. The data sources that should be considered in the project are stationary detectors, video-based measurements from stationary sensors and vehicle sensors.
2. To propose control strategies for dynamic control in real time at on- and off-ramp locations with risk indicators from (1) as input to the control strategies.
3. To draw conclusions about the traffic safety and efficiency effects that are identified when using dynamic traffic control according to (1) and (2).
4. To evaluate how different types of data sources affect the possibility to use different risk indicators and to design control strategies with the goal to have real-time control strategies

with more sophisticated input data than what is used for control strategies at on- and off-ramp locations today.

Method and models

In the project, methods are developed to calculate risk indicators in real time with different data sources. The data sources that will be considered in the methods are roadside detectors, smart infrastructural sensors based on for example stereovision-based infrastructure sensors, radar or lidar technologies and app data from equipped vehicles.

Roadside detectors are commonly used today. It is mainly flow and speed measurements that can be collected through these types of detectors. But also additional data such as time-stamps and speeds of individual vehicles can be collected and used to estimate risk indicators from such detectors. This has previously not been investigated and is therefore of interest in this project.

From smart infrastructural sensors it is possible to extract aggregated measures such as traffic flow and average speed, but it is also possible to get information about distance/time gap between vehicles and speed profiles from individual vehicles. Even near-incident situations can be detected in real-time. Methods will be developed to estimate conflict measurements at the on- and off-ramp locations. The methods are based on 3D and AI-based stereovision algorithms that detect, classify, and track individual road users in real time, and through that measure both individual trajectories and overall traffic conditions. Anonymized traffic data can also be stored and used for analysis of the traffic situations, traffic efficiency and traffic safety for a baseline scenario and to quantify the effect of different traffic control measures if control measures are applied in real life. Furthermore, 3D & AI algorithms will be further developed and adapted to the requirements imposed by traffic control strategies at on- and off-ramp locations.

The project could possibly also use measurements from equipped vehicles. AI-based methods such as computer vision, machine learning, deep learning and image processing can be used in this part of the project to compute risk indicators that could be an input to different control strategies at on-and off-ramp locations. For example intentions to change lane could be an interesting input, such as the methods developed in the Swedish project (IRRA, 2021).

To develop risk indicators that can be used to indicate risks of incidents and as input for traffic control, measurements from one or more on- and off-ramp location is needed. Hence, a field trial is required to measure the traffic conditions with different types of sensors, including traditionally stationary sensors, 3D sensors and possibly vehicle data.

Thereafter, control strategies will be proposed with a focus on increased traffic safety at the on- and off-ramp location/locations. As a background for the choice of control strategies, identified problem areas from field trials and the availability of real-time estimations of risk indicators are used. The starting point is the control strategies that have so far been used in Swedish traffic environments, but with the ambition that the control strategies can be developed and become more sophisticated and precise with new and more detailed input. The control strategies that will be considered in the project are ramp metering and variable speed limit systems. But also in-vehicle control strategies will be considered.

To evaluate how the estimated traffic conditions and the investigated control strategies perform, evaluation methods are used that are based on field trials in real traffic and/or based on traffic simulation studies, depending on what is applicable in specific cases. The control strategies are first tested in a traffic simulation environment to get an idea of how traffic efficiency is affected when the different control strategies are implemented. The most promising control strategies from the traffic simulation study are prioritized based on:

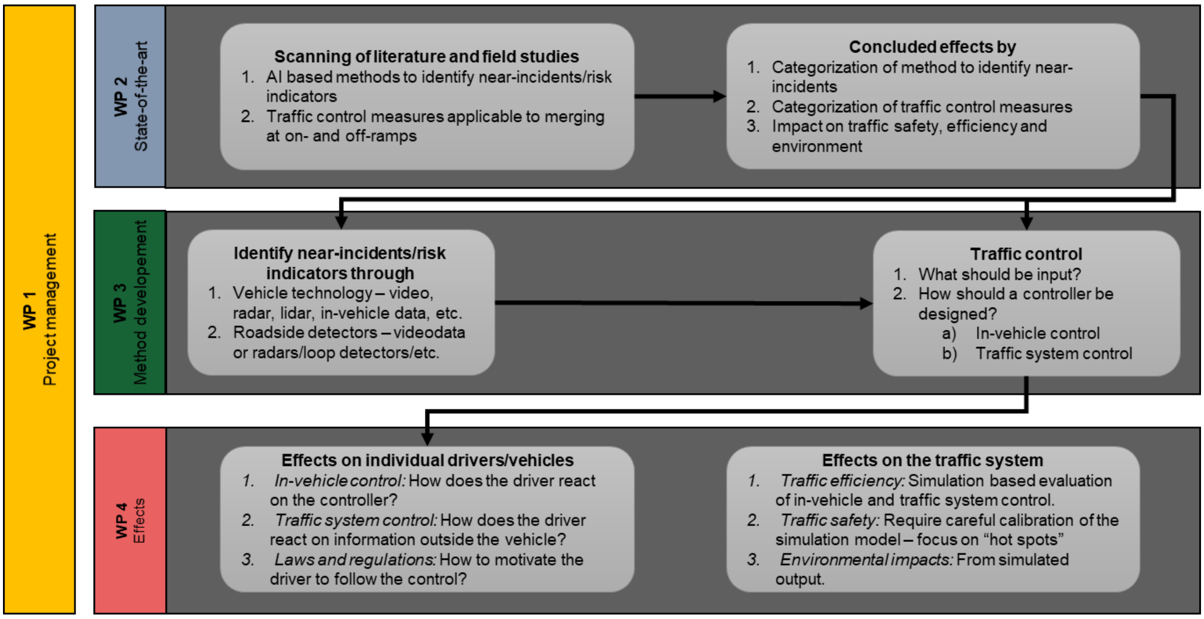
1. Traffic safety
2. expected positive effects on traffic efficiency
3. how straightforward it is to implement in real-life traffic conditions given today's rules and regulations

The most promising control strategies based on all these aspects are then evaluated in a traffic simulation study to get a picture of how traffic safety and traffic efficiency on a system level are affected by control. Both traditional traffic control measures with the proposed risk indicators as input, as well as, more visionary control strategies, such as for example control of vehicles through geofencing, is tested in the traffic simulation environment. However, it is well-known that it is hard to evaluate safety aspects in a traffic simulation environment. Therefore, to be able to conclude on safety effects, a careful calibration of the driver behavior and merging maneuvers are necessary. Otherwise, the results with respect to traffic safety will become too uncertain due unrealistic modelling of the merging behavior. The evaluation of traffic safety effects may, instead or additionally to, be done through driving simulator trials. This provides a picture of how drivers behave under controlled conditions in a closed research environment. Here, too, there are opportunities to conduct interviews and surveys to get an overall picture of how drivers perceive the control strategy.

Project activities

The work packages suggested in the project are summarized in Figure 1. First, a thorough review of available literature and earlier studies on the subject is performed in work package 2. A categorization of methods to identify near-incidents/risk indicators, as well as control measures are done to identify the most promising methods. In work package 3, a field trial is suggested to be included for collection of data to be used in the development of methods to calculate risk indicators. Also included in work package 3, is the design of control strategies based on the available risk indicators. The control strategies and methods to estimate near-incidents/risk indicators are thereafter evaluated in work package 4 with respect to traffic safety, traffic efficiency and, if possible, environmental impacts.

Work package 1 consists of the project management, such as economic follow-up, reference group meetings, follow-up of activities and the time management in the project.



Figur 1. Projektoutline

The project activities are outlined briefly below. The project partners that are listed are the ones that have shown an interest in the project. However, there is still a need for additional partners. The activities where additional partners are required are marked at the relevant activity.

- State-of-the-art (VTI)
- Collection of data through
  - smart stereovision-based infrastructural sensors (Viscando)
  - road-side sensors that exists on the motorway control system on equipped motorways in Stockholm and Gothenburg (VTI and possibly TrV as owner of the data)
  - vehicle data (not yet decided)
- Development of risk indicators and estimation of traffic conditions/merging behavior
  - methods based on data from smart stereovision-based infrastructural sensors (Viscando)
  - methods based on data from road-side sensors that exists on the motorway control system on equipped motorways in Stockholm and Gothenburg (VTI)
  - methods from vehicle data (not yet decided)
- Development of traffic control strategies at on- and off-ramps based on risk indicators and estimation of traffic conditions/merging behavior from previous step. Control strategies are developed as in-vehicle control or through infrastructural solutions, such as ramp metering or variable speed limit systems (VTI).
- Evaluation of control strategies in traffic simulator environment (user interface/driver behavior) and in traffic simulation environment (impact on the traffic system) (VTI).
- If possible, field trials, in real-life environments, with the proposed control strategies might also be applicable. In that case, it is necessary to comply with the current Swedish laws and regulations, why the control strategies cannot be too futuristic. (VTI/Viscando).

Suggested project organization

The project group is suggested to consist of VTI, Viscando and additional partners not yet decided. Other partners might be added to the project group based on interest through the AI Driven Mobility network.

Additional project partners are required to fulfill the goals of the project. Especially, a partner from the vehicle industry is requested, since they can contribute with valuable input about vehicle data, as well as interesting in-vehicle control strategies to consider. Ideally, it correlates with an ongoing initiative where there is current ongoing development within the company.

A problem owner is required to find a suitable on-and off-ramp location to investigate and to get useful information about the needs and requirements from the city or the national road network.

Suggested control measures

In-vehicle control measures:

1. *Control* through geofensing (speed limitations, prohibiting merging at "hot-spot" locations, limiting inflow to motorway)
2. *Warnings* of risks of incidents and/or recommendations on how to drive

Traffic system control measures:

3. Improved input and design of control strategies in *variable speed limit systems* based on more sophisticated safety indicators than today (both from individual vehicles and roadside detectors)
4. Improved input and design of control strategies in *ramp metering* based on more sophisticated safety indicators than today (both from individual vehicles and roadside detectors) and focus on safety actions (not efficiency) for the controller

Next steps

The next steps are to

1. Adapt the scope of the project based on possible interested future partners. This will be done in dialog with the potential partners and a potentially interested problem owner. The resulting outcome should be a small enough scope to be doable within one project. The whole project is quite large and a division into appropriate tasks/smaller projects might have to be done depending on possible final budget.
2. Evaluate potential financing of the project and adapt the proposal to the template provided by the funder. This can be done first after the scope has been decided in 1, which will require some time and effort due to potential new partners that might have other interests in the project.
3. Finalize the application and apply.

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