Content of 3-WP01 Advanced V2X communication for more efficient transportation

Coordinator of the WP

Czech Technical University, Faculty of Electrical Engineering, prof. Ing. Vladimír Havlena, CSc.

Participants of the WP

Herman Electronics, Dr. Ing. Ivo Herman

Skoda Digital, Dr. Ing. Daniel Pachner

FEE CTU, Dept. of Control Engineering, doc. Ing. Zdenek Hurak, PhD.

FEE CTU, Dept. of Computer Science, doc. Ing. Jiri Vokrinek, PhD.

FEE CTU, Dept. of Radioelectronics, prof. Ing. Jan Sykora, CSc.

Main Goal of the WP

Improved design of V2X communication unit hardware with high scalability, advanced localization and vehicle sensor fusion. The solution will communicate with municipal transport infrastructure (traffic light controllers) to provide priority for municipal transport (vehicles with predefined fixed routing) or first responders (vehicles with flexible trajectory planning). The software module will also support traction energy consumption minimization for trams.

Partial Goals for the Current Period

Selection of on-board unit hw, analysis of communication standards, design of core algorithms, collection of data and evaluation of core algorithms on simulated and real data.

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverables

- 3-WP01-001 | Advanced V2X communication unit with priority optimization, G-funk
  Due 12/2025 | CTU FEE 0.4 | Ivo Herman 0.6 |
- 3-WP01-002 | On board software modules for vehicle prioritization, R
  Due 12/2025 | CTU FEE 0.3 | Ivo Herman 0.4 | Skoda Digital 0.3 |
- 3-WP01-003 | Dispatch server software modules for vehicle prioritization, R
  Due 06/2026 | CTU FEE 0.8 | Ivo Herman 0.1 | Skoda Digital 0.1 |
- 3-WP01-004 | Evaluation of dispatch server optimization strategies by simulation, O
  Due 12/2025 | CTU FEE 0.8 | Ivo Herman 0.1 | Skoda Digital 0.1 |
- 3-WP01-005 | Pilot evaluation of on-board prioritization subsystem on V2X unit, O
  Due 12/2025 | CTU FEE 0.2 | Ivo Herman 0.7 | Skoda Digital 0.1 |
- 3-WP01-006 | Pilot evaluation of energy optimization of tram operation, O
  Due 12/2025 | CTU FEE 0.1 | Ivo Herman 0.1 | Skoda Digital 0.8 |
- 3-WP01-007 | Reporting and dissemination, O
  Due 06/2026 | CTU FEE 0.6 | Ivo Herman 0.2 | Skoda Digital 0.2 |

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-001 (Gfunk, Ivo Herman, Jan Sykora FEE CTU)

Advanced V2X communication unit with priority optimization

Improved design of V2X communication unit hardware with respect to optimal signal propagation, robust and efficient implementation on an operating system with high scalability and ability to process large number of messages. Basic solution will cover advanced localization and vehicle sensor fusion. For municipal transport and first responder vehicles, the unit will support prioritization and collaboration with dispatching server. In terms of radio propagation, the unit will be tested against a newly developed testbed, which will verify the unit's performance and compliance to standards (in V2X and/or 5G-V2X).

Methods: HW design, testing using testbed

Due 12/2025 | CTU FEE 0.4 | Ivo Herman 0.6 | Skoda Digital 0.0 |

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-001

Advanced V2X communication unit with priority optimization

- Goals
  - Long range V2X communication with computation power for decentralized decision making (priority optimization, integration to ADAS)
  - Integrate new radio technology (ITS-G5 – Wi-Fi, LTE-V2X, 5G-NR) with run-time switching
  - Security to allow CC certification (tamper detection)
  - Design and implementation of laboratory testbed for radio air-interface of V2X communication systems based on IEEE 802.11p and 5G NR C-V2X

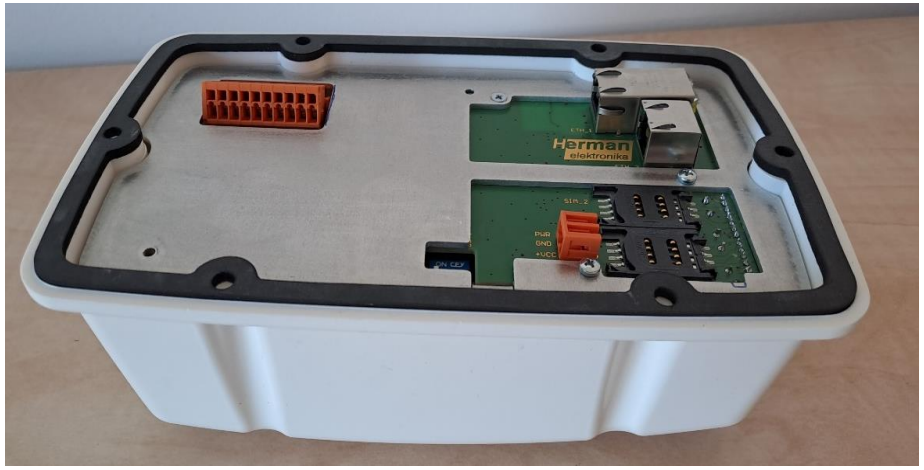
- Activities
  - Testbed design finished, testing of communication
  - New generation of the unit ready
  - Integration of new V2X sw module

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-001

Advanced V2X communication unit with priority optimization

- Results 1 – OBU
  - HW development (i.MX8, V2X 4G and/or 5G, run-time switch, GNSS L1+ L5 band, ultra-low power mode)
  - PCB redesign – signal propagation, power over 802.3af/at, internal capacitor backup
  - Two mechanical configurations, compatible (interior / roof top versions)

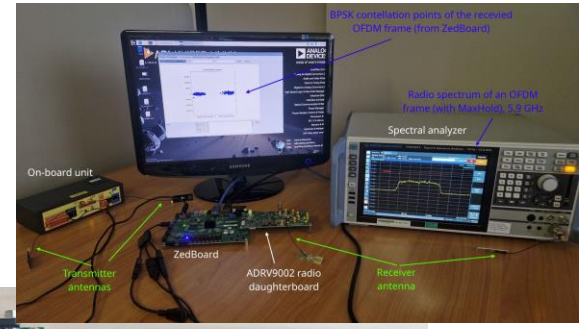


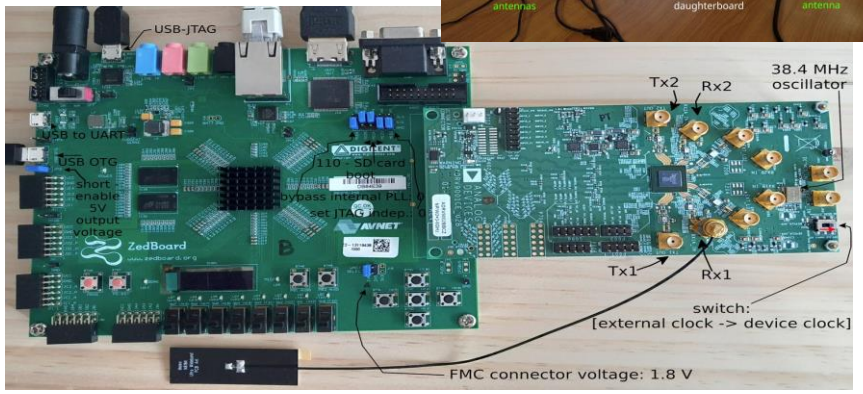
Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-001

Advanced V2X communication unit with priority optimization

- Result 2 – test bed (team of prof. Sykora, FEE CTU)
  - Software-enabled-radio approach
  - V2X communication standard, 8 modulation/coding pairs
  - ZedBoard Zynq 7000 AP – CPU (Linux) + FPGA
  - ADRV9000 radio board (3-6 GHz)
  - Tx implementation – C, IIO library from AD
  - Rx implementation – FPGA, Python GUI
  - Features
    - Simple ADRV9002 initialization and control (frequency, gains)
    - Frame reception (multiple modulations and coding rates)
    - RX debugging (intermediate results outputting)
    - Easily modifiable FPGA design
  - Performance test results – successful reception & decoding





ZedBoard development board + ADRV9002 radio-board

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-002 (R, Ivo Herman)

On board software modules for vehicle prioritization

Plug-in software modules for vehicle prioritization using V2X communication unit. The solution will communicate with municipal transport infrastructure (traffic light controllers) to provide priority for municipal transport (vehicles with predefined fixed routing) or first responders (vehicles with flexible trajectory planning). The software module will also support traction energy consumption minimization by providing departure time from stops and velocity profile to the next intersection.

Methods: Algorithmic/SW development, compliance testing (VDV435 standard)

Due 12/2025 | CTU FEE 0.3 | Ivo Herman 0.4 | Skoda Digital 0.3 |

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-002

On board software modules for vehicle prioritization

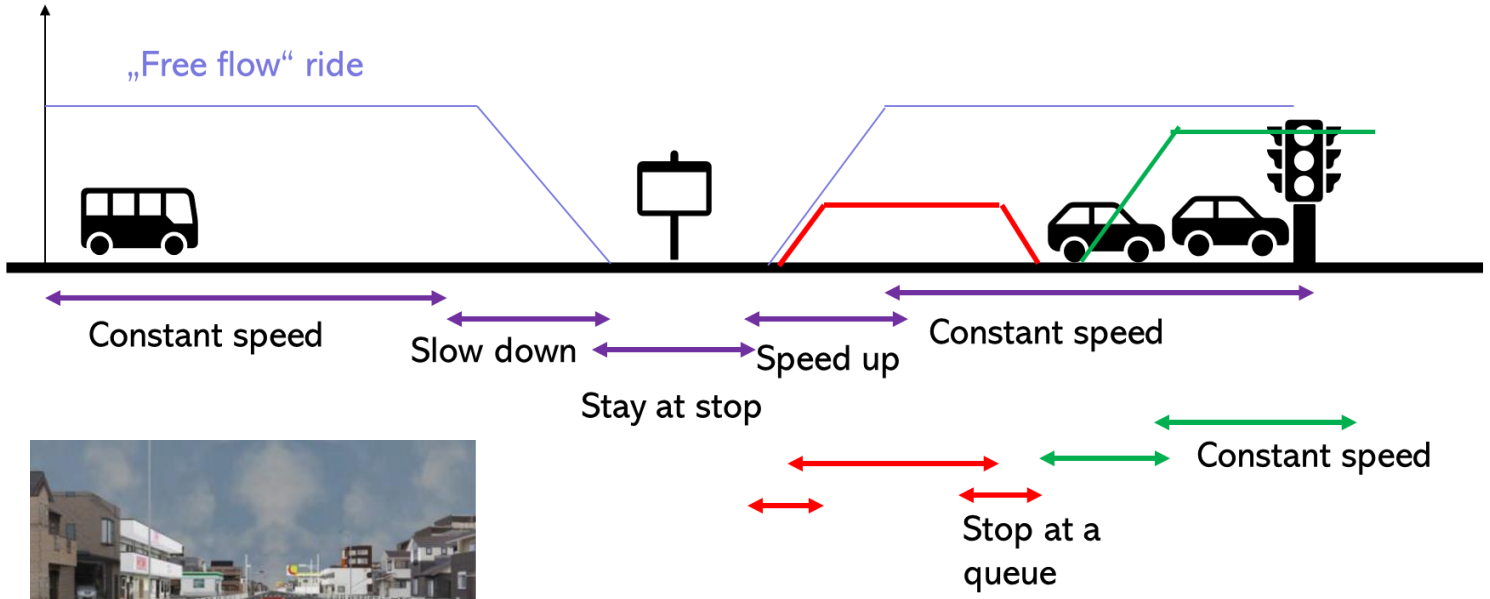
- Goals
  - Process all received information for better priority request control
  - Generate correct and norm-compliant request with reliable parameters (ETA)
  - Allow processing of traffic light controller response
- Activities
  - Change of paradigm – ETA estimate responsibility
  - Advanced ETA calculation and MAPEM processing for public transport
  - Processing of received route (EM+PT) and stop list (PT)
  - Ability to autonomous work without any connection to on-board computer (PT) / tablet (EM)
  - Data logging
  - Standardization of VDV 435 – first on-board protocol for PT with direct support of V2X
    - implementation ready, draft proposed to VDV (Association of German PT operators)

Content of 3-WP01 Advanced V2X communication for more efficient transportation

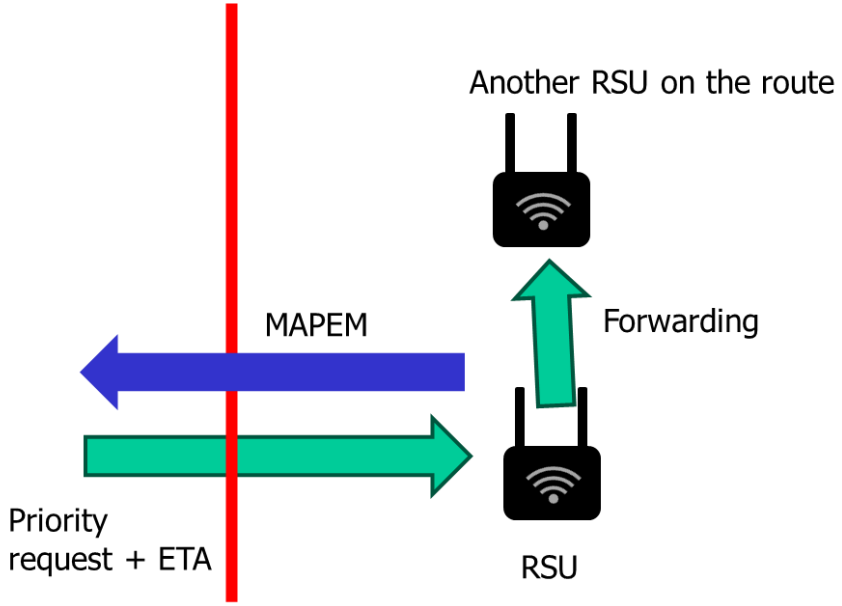
Deliverable 3-WP01-002

On board software modules for vehicle prioritization

Green Light Optimized Speed Advisory (GLOSA)



Traffic infrastructure



Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-003 (R, Jiri Vokrinek FEE CTU)

Dispatch server software modules for vehicle prioritization

Cloud level software for municipal transport / first responders trajectory optimization using intersection controller signal plan plans and other centrally available information. The optimization will combine data-centric approach based on archived historical data and AI methods, as well as analytical model-based approach.

Methods: Algorithmic and SW development

Due 06/2026 | CTU FEE 0.8 | IvoHerman 0.1 | SkodaDigital 0.1 |

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-003

Dispatch server software modules for vehicle prioritization

- Goals
  - Analysis of legacy AI powered algorithms and tools (46 relevant tools/libraries/demos) for dynamic path/trajectory planning
  - Standardization of algorithms implementation to build re-usable software modules
  - Design of server-based software stack for vehicle prioritization / transport optimization

- Activities
  - Two re-usable software libraries released
  - Based on legacy algorithms and tools for dynamic path/trajectory planning
  - New relevant problems defined
  - Algorithm and tool development started

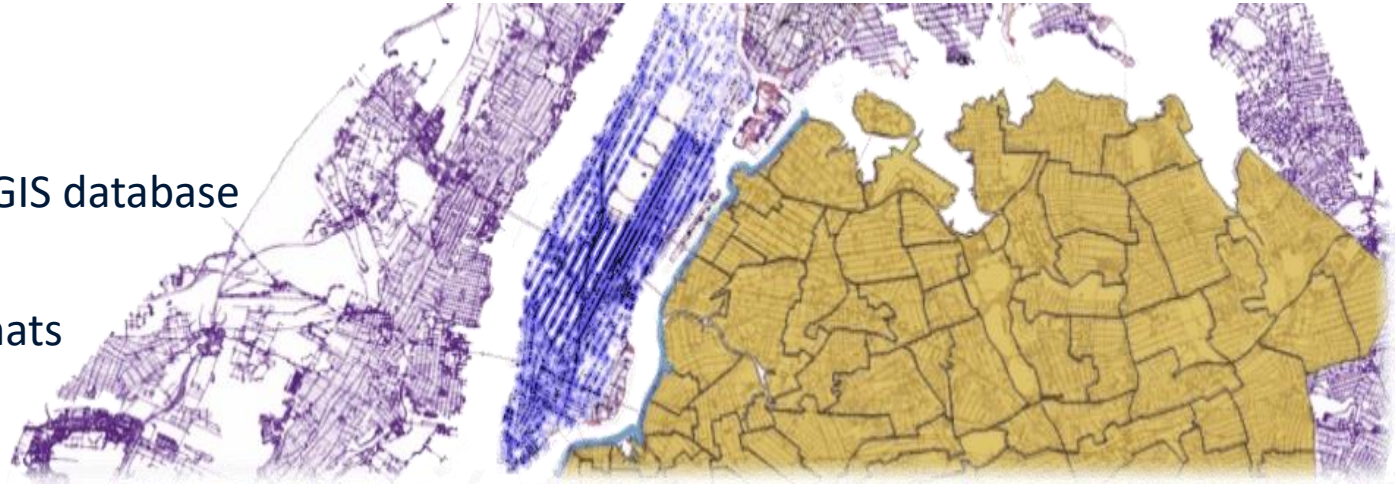
Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-003

Dispatch server software modules for vehicle prioritization

Road Graph Tool

- Tool for processing various data inputs into problem instances for transportation problems
- Main Transformation: Open Street Map -> Road Graph
- Properties
  - Fast, handle large data sets
  - Favorable properties of output graphs
- Python scripts powered by PostgreSQL/PostGIS database
- Input formats: OSM (XML), PBF
- Output formats: CSV, Shapefile, custom formats
- Available at GitHub



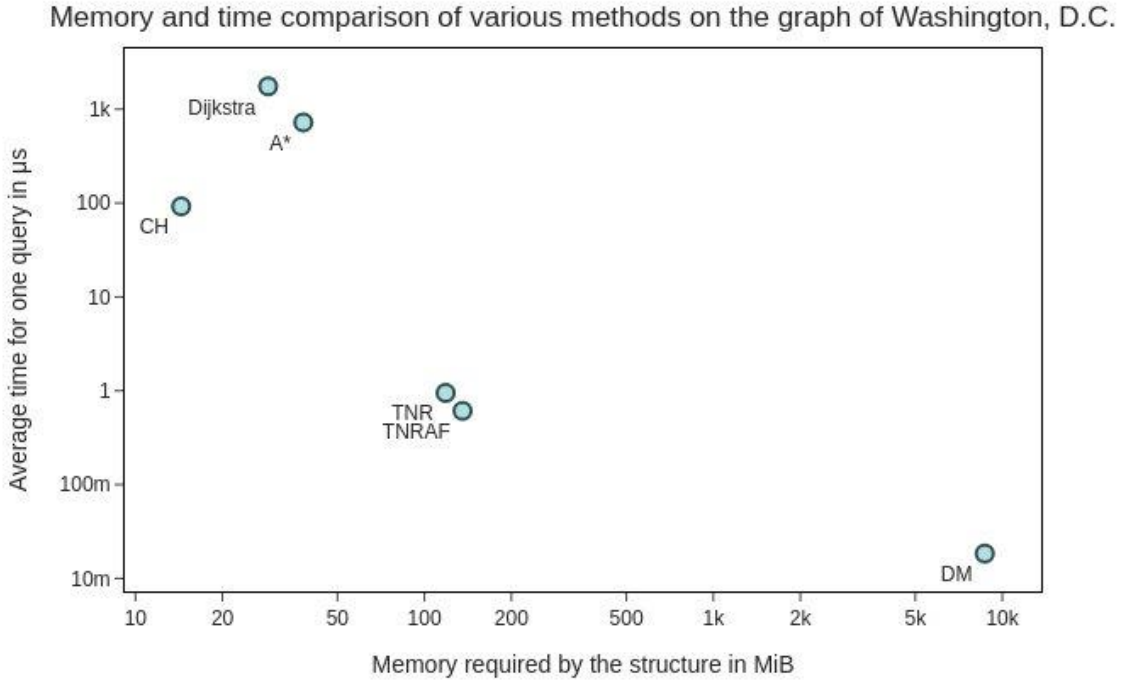
Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-003

Dispatch server software modules for vehicle prioritization

SHODI Tool

- Tool for fast shortest distance queries
- Some structures can be used to compute shortest distance faster than the widely known algorithms (A*).
- Implemented algorithms and structures
  - Classical: Dijkstra, A*
  - Distance Matrix
  - Contraction Hierarchies
  - Transit Node Routing
- Available at GitHub



Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-004 (R, Jiri Vokrinek FEE CTU)

Evaluation of dispatch server optimization strategies by simulation

This simulation-based feasibility study will provide evaluation of alternative planning and optimization strategies and collaboration with intersection controllers using simulation models. Models will be calibrated using historical data. Short-term and predictive long-term strategies will be evaluated. The model will also provide a "what if" analysis tool for municipal dispatch operators.

Methods: SW validation using advanced simulation models

Due 12/2025 | CTU FEE 0.8 | Ivo Herman 0.1 | Skoda Digital 0.1 |

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-004

Evaluation of dispatch server optimization strategies by simulation

- Goals
  - Validate optimization strategies for selected use-cases by simuation
  - Provide scalable tool covering micro to macro simulation (from vehicle to traffic flow)

- Activities
  - Simulation of selected scenario (whole Hradec Kralove city area)
  - Other locations ready to be simulated
  - Integration of available real data
  - Simulation of priority vehicles
  - Ready for implementation of various optimization approaches for evaluation

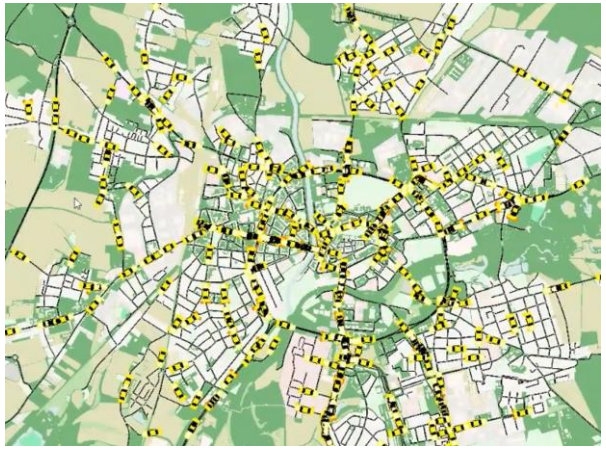
Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-004

Evaluation of dispatch server optimization strategies by simulation

City area simulation

- Simulation of selected scenario (whole Hradec Kralove city area) using SUMO
- Based on Open Street Maps
- Priority traffic – realistic public transport
- Traffic calibration using real data and traffic lights control (OSM)
- Ready for integration of real data (“Herman dataset”)
- Ready to implement various optimization strategies and evaluation



Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-005 (R, Ivo Herman)

Pilot evaluation of on-board prioritization subsystem on V2X unit

This feasibility study will provide real-life evaluation of pilot application of on-board software module for vehicle prioritization for municipal transport and first responders in Brno city and comparison of the performance with historical data.

Methods: V2X unit HW/SW testing in real life municipal environment

Due 12/2025 | CTU FEE 0.2 | Ivo Herman 0.7 | Skoda Digital 0.1 |

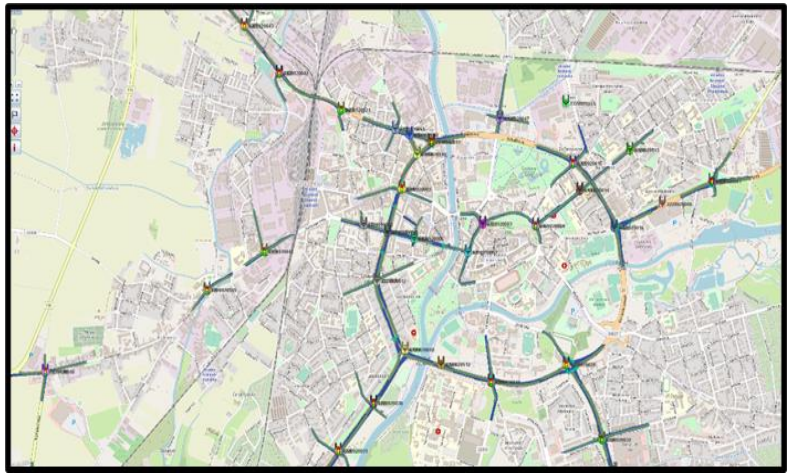
Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-005

Pilot evaluation of on-board prioritization subsystem on V2X unit

- Goals
  - Evaluation of pilot operation of on-board software module for vehicle prioritization for municipal transport and first responders
  - Comparison of the performance with historical data

- Activities: pilot sites running
  - Ludwigsburg DE (80 OBUs PT, 20 OBUs EM, 100 RSUs)
  - Hradec Králové (40 intersections, 130 OBUs PT, 10 EM)
    - **Awarded in C-ROADS Urban C-ITS Contest**
  - Plzeň – in installation (400 PT vehicles)
  - Ústí nad Labem – in installation (130 PT, 40 EM, 15 RSUs)



Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-006 (O, Daniel Pachner, Skoda Digital)

Pilot evaluation of energy optimization of tram operation

This feasibility study will provide real-life evaluation of pilot application of on-board software module for minimization of tram traction energy consumption based on communication with intersection controllers. Target algorithm will be used in driver assistant system advising the driver when to start from the tram stop and how to control the speed to pass intersections freely.

Methods: Testing using digital twin and real city transport operation

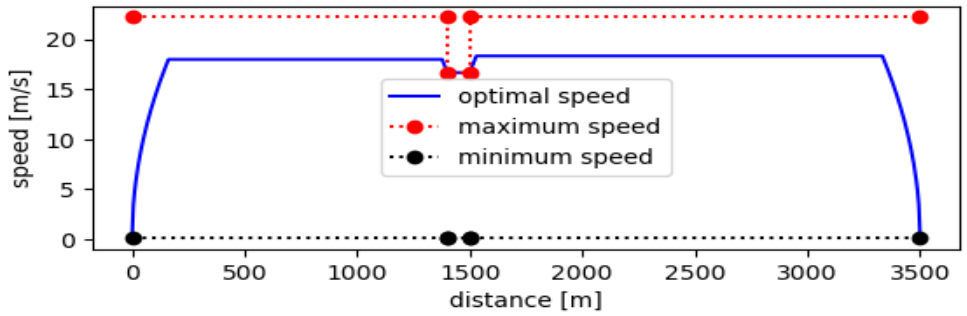
Due 12/2025 | CTU FEE 0.1 | Ivo Herman 0.1 | Skoda Digital 0.8 |

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-006

Pilot evaluation of energy optimization of tram operation

- Goals
  - Evaluation of impact of prioritization on tram energy efficiency
  - Performance of on-board software module for minimization of traction energy consumption
  - Solution based on V2X communication with intersection controllers
- Activities
  - Multiple white box models of losses → lumped model
  - Data-centric approach developed
  - Optimized speed profile

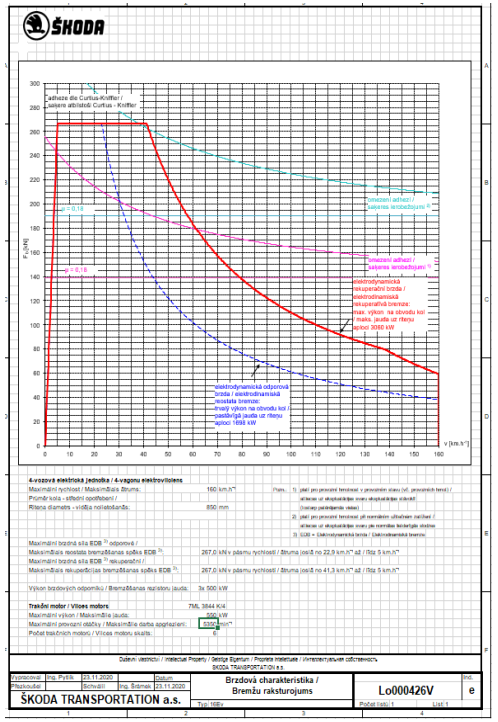


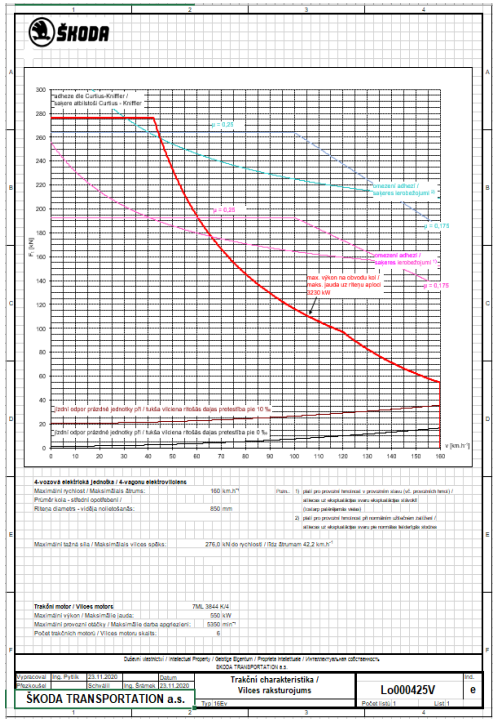
Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-006

Pilot evaluation of energy optimization of tram operation

- Classical approach to the problem
  - white box models of losses
- Example
  - efficiency map of a traction motor



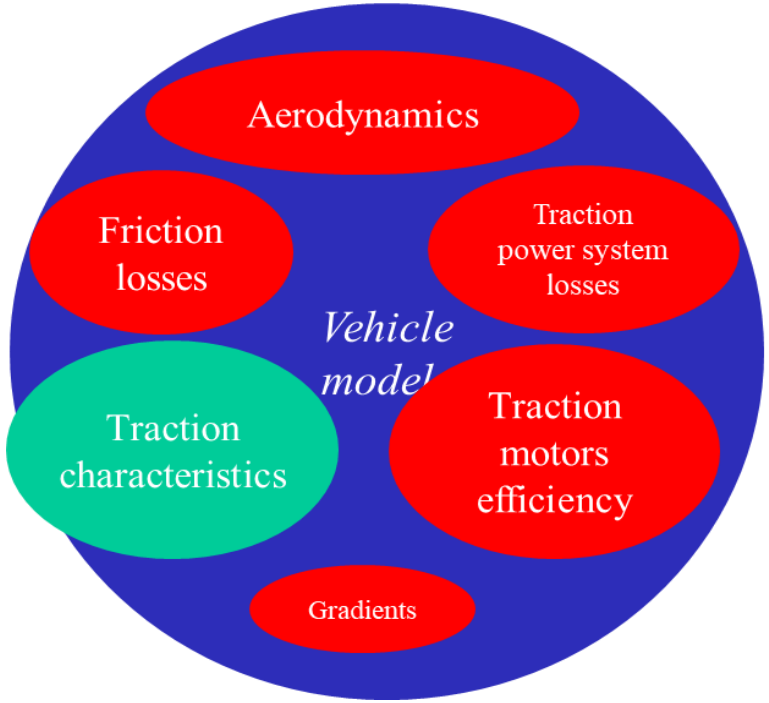


Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-006

Pilot evaluation of energy optimization of tram operation

Empirical approach proposed



Ideal lossless model

traction force F_T is the rate of mechanical energy increase along the path.

$$F_T(s) = \frac{dE(s)}{ds}$$

Dissipation term modeled as spline functions

Empirical model: $$F_T + f(s, v, a, \dots) = \frac{dE(s)}{ds}$$

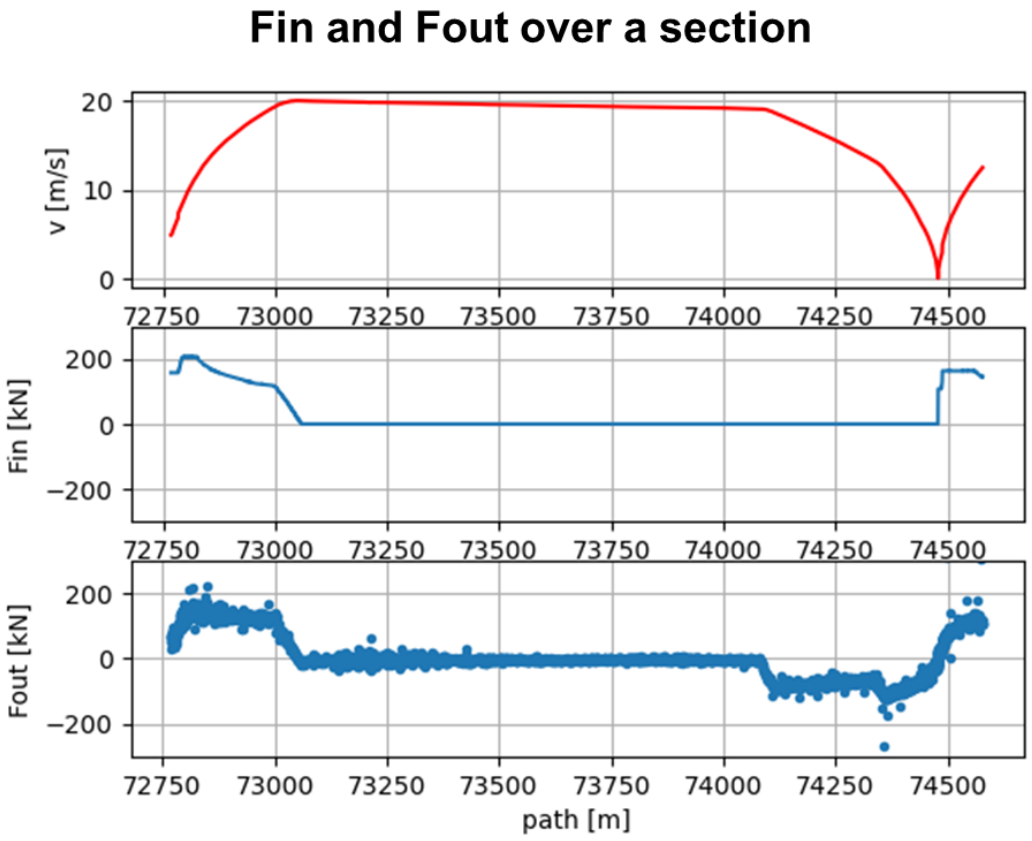
Empirical I/O model: $$\frac{dE_{in}(s)}{ds} + f(s, v, a, \dots) = \frac{dE_{out}(s)}{ds}$$

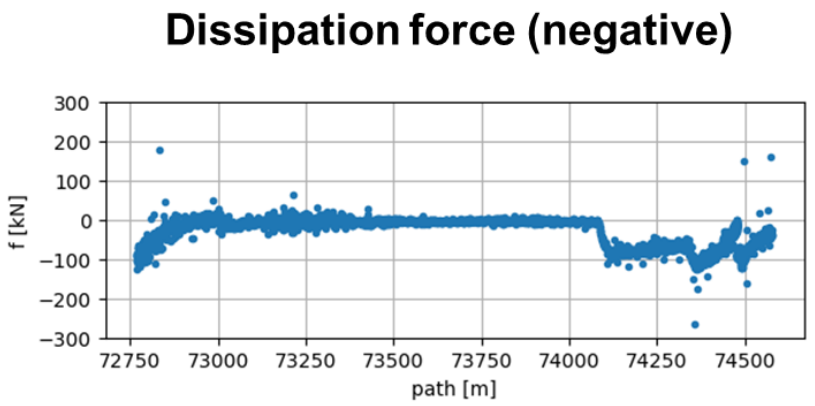
$$F_{in}(s) + f(s, v, a, \dots) = F_{out}(s)$$

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-006

Pilot evaluation of energy optimization of tram operation





Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-007 (O, Vladimir Havlena, FEE CTU)

Reporting and dissemination

Interim reports on individual project milestones, publications in journals and conferences, diploma and PhD theses.

Due 06/2026 | CTU FEE 0.6 | Ivo Herman 0.2 | Skoda Digital 0.2 |

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Deliverable 3-WP01-007

Reporting and dissemination

Industrial standards

- Standardization of VDV 435 – first on-board protocol for PT with direct support of V2X – first implementation ready, draft proposed to VDV (Association of German PT operators)

Conference papers

- J. Kašpar, V. Fanta and V. Havlena: Tram Positioning with Map-Enabled GNSS Data Reconciliation. Submitted to ECC2025 (main topic: Resilient Control Systems with Performance)

Summer internship reports

- Matěj Kříž: Odhadování dojezdové doby vozidla ke křižovatce a zpracování signálních plánů řadiče křižovatky
- Štěpán Ošlejšek: Vyhodnocování palubních jednotkou vozidla zaznamenaných jízdních dat

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Conclusions and future outlook

- Standardization of VDV 435 – first on-board protocol for PT with direct support of V2X – first implementation ready, draft proposed to VDV (Association of German PT operators)
- HW and SW development for a next generation on-board unit completed
- First hands-on experience, collection of real time data for performance evaluation
- Ongoing / future efforts
  - Analysis of traffic light RSU communication
  - GLOSA design
  - Algorithmic development for municipal transport / first responder's vehicles prioritization
  - Links between prioritization and energy optimization
  - Continuing deployment and testing in multiple cities (CZ, DE)

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Current State of Deliverables and Fulfillment of Goals

- No binding deliverables (Gfun, R) in 2024
  - 1 deliverable O (ECC 2025 paper)
- Goals for 2024 close to completed, no major delays
  - HW platforms and embedded SW available and running
  - First hands-on experience, collection of real time data for performance evaluation
  - Design of software architecture and core algorithms

Added Value of 3-WP01 results

- Saving on a single crossing with V2X based priority (controlled departure from the stop) exceeds 150000 CZK/year (calculated by DP Brno, crossing Mendel square x Pekarska street)
- V2X based preference using SREM/SSEM messages is becoming C-ROADS industrial standard
  - Necessity to succeed in tenders with EU municipal transport operators
  - Big market potential for early adopters

Content of 3-WP01 Advanced V2X communication for more efficient transportation

List of Due Deliverables and Their Added Value

- 3-WP01 has no due deliverables in 2025

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Assessment of the Contribution of Deliverables

- Advanced localization developed in 4-WP01 by academic partners will be also used in OBU development in 3-WP01 (scaled down version, no Lidar and optical sensors)

- V2X expertise of the 3-WP01 team will be reused by Skoda Digital industrial partner in 4-WP01

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Assessment of the Formal/Administrative Goals of the Work Package

	Herman Electronics	Skoda Digital	FEE CTU
Finance	**OK**	**OK**	**OK**
Commercialization	**OK**	**OK**	**OK**
Deliverables	**N/A**	**N/A**	**OK**

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Acknowledgment

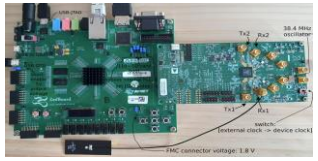
This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Center II, project # TN02000054 Božek Vehicle Engineering National Center of Competence (BOVENAC).

Content of 3-WP01 Advanced V2X communication for more efficient transportation

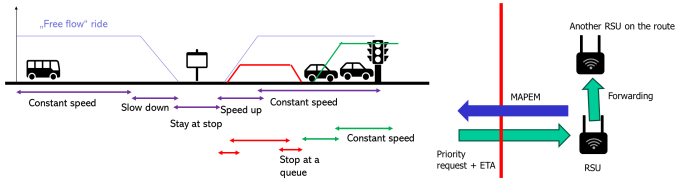
Summary of results 2023-2025

Herman + CTU + SD: next generation V2X unit

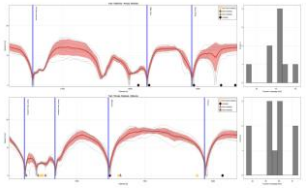
OBU HW upgrade / compliance (VDV435 standard) / test bed

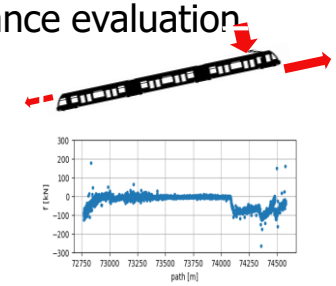


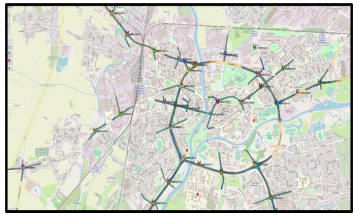
Prioritization algorithms, GLOSA



Testing, performance evaluation

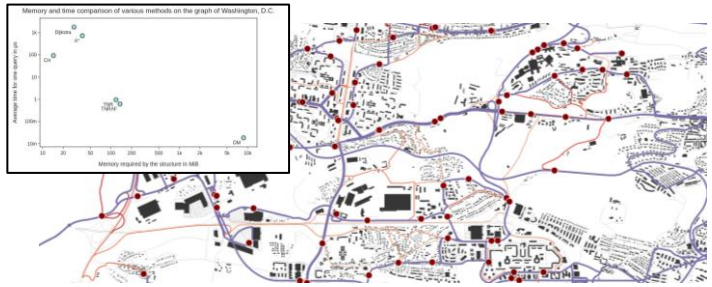




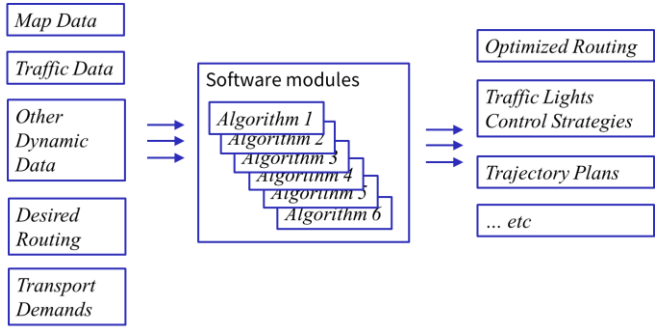


Herman + CTU: next generation V2X unit

Simulation of PT using big data/ML



SW for priority optimization



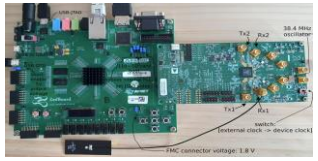
Multimodal transport optimization

Content of 3-WP01 Advanced V2X communication for more efficient transportation

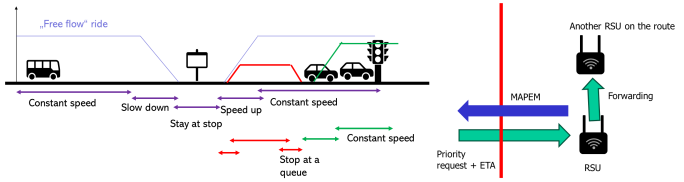
Výtah z prací 2023-2025

Herman + CTU + SD: next generation V2X unit

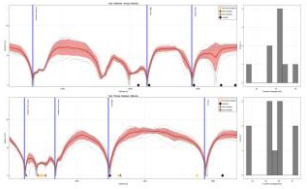
Upgrade V2X jednotky / standardizace (VDV435) / test bed

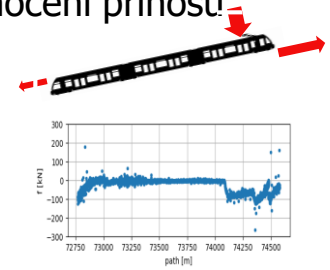


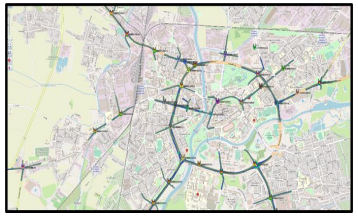
Algoritmy prioritizace, asistenční systémy



Testování, vyhodnocení přínosů

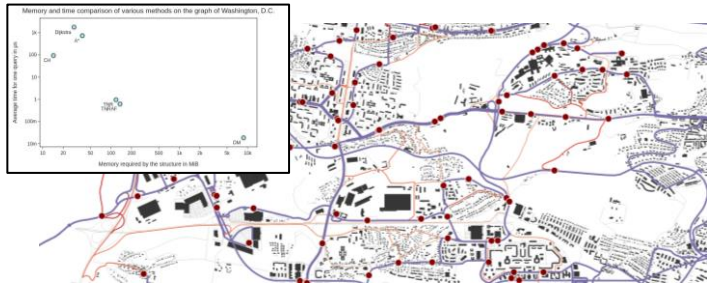




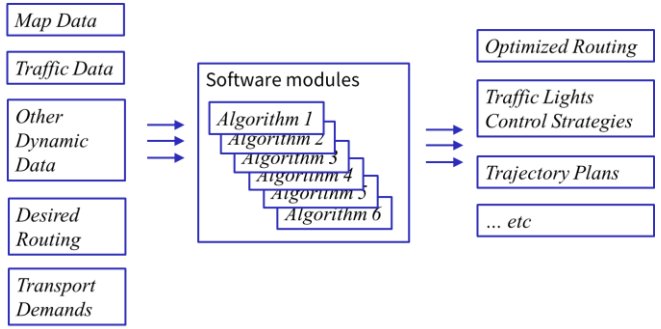


Herman + CTU: next generation V2X unit

Simulace městské dopravy s využitím metod big data/ML



Dispečerský SW pro optimalizaci



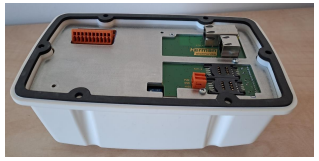
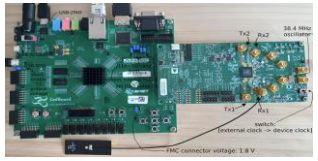
Multimodální doprava

Content of 3-WP01 Advanced V2X communication for more efficient transportation

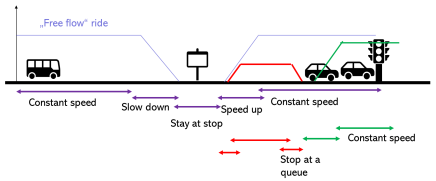
Summary of results 2024

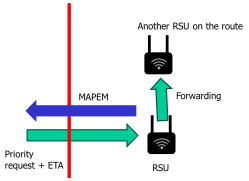
Herman + CTU + SD: next generation V2X unit

OBU HW upgrade / compliance (VDV435 standard) / test bed

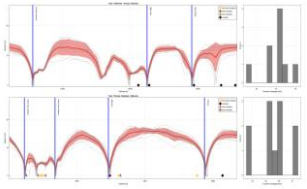
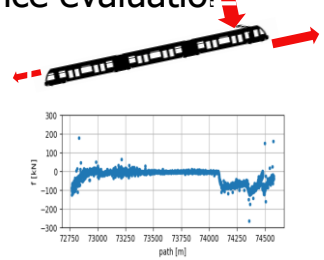




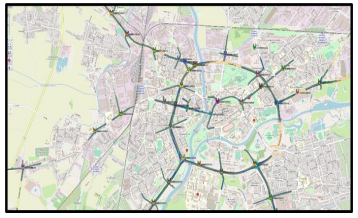
Prioritization algorithms, GLOSA



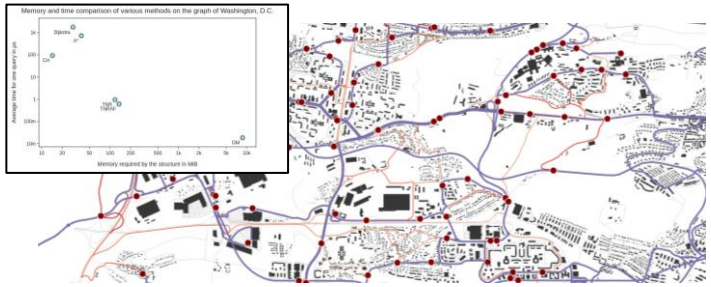
Testing, performance evaluation



Herman + CTU: next generation V2X unit

Server-side sw for priority optimization, simulation, big data/ML




Multimodal transport optimization

Personal transportation

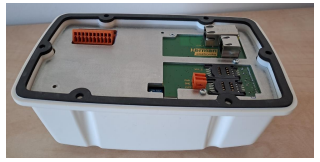
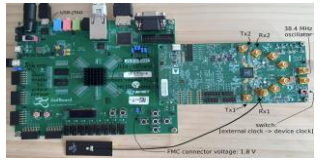
Logistics


Content of 3-WP01 Advanced V2X communication for more efficient transportation

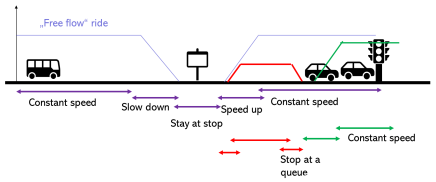
Výtah z prací 2024

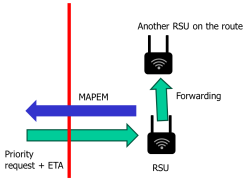
Herman + CTU + SD: next generation V2X unit

Upgrade OBU HW / standardizace (VDV435) / test bed

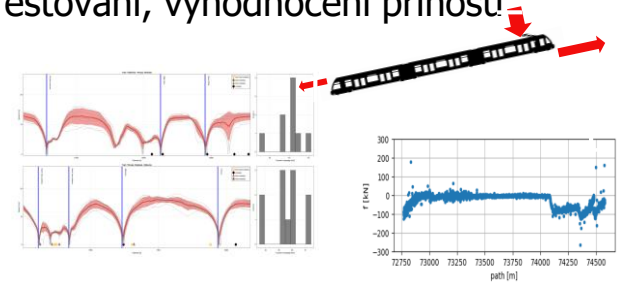




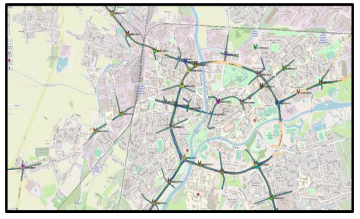
Algoritmy prioritizace, asistenční systémy (GLOSA)



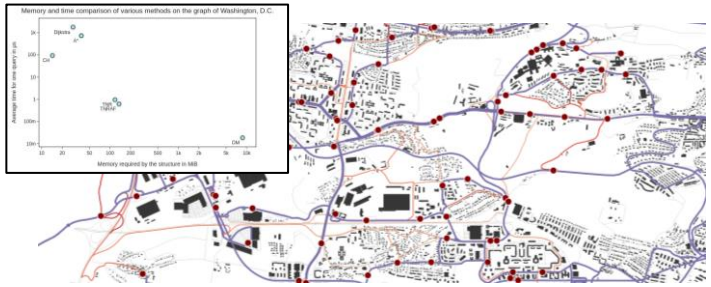
Testování, vyhodnocení přínosů





Herman + CTU: next generation V2X unit

Simulace městské dopravy s využitím metod big data/ML




Optimalizace multimodální dopravy

Osobní doprava

Logistika


Content of 3-WP01 Advanced V2X communication for more efficient transportation

Abstracts of publications 2023-2025

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Abstracts of publications 2023-2025

Jakub Kašpar: Algoritmy pro palubní odhadování pohybových stavů vozidla pomocí multisenzorické fúze (bakalářská práce FEL ČVUT, 2023)

Byl navržen a otestován lokalizační algoritmus určený pro tramvaje. Algoritmus využívá rozšířeného Kalmanova filtru k fúzi měření z přijímače satelitní navigace, inerciální měřicí jednotky a odometrie.

An extended Kalman filter based localisation algorithm intended for trams has been developed. The algorithm fuses measurements of satelite based navigation system, inertial measurement unit and wheel encoder odometry.

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Abstracts of publications 2023-2025

Matěj Kříž: Platforma pro prototypování algoritmů pro palubní odhadování pohybových stavů vozidel multisenzorickou fúzí (bakalářská práce FEL ČVUT, 2023)

Tato práce se zabývá vývojem jednodeskové platformy pro sběr dat ze senzorů pohybových stavů vozidel a pro prototypování algoritmů, které tato data fúzují. Tato platforma by měla zjednodušit záznam dat a standardizovat jejich formu pro zlepšení znovupoužitelnosti pro další projekty. Dále se zabývá dalšími podklady pro snadnější implementaci algoritmů, jako je práce s mapovými podklady a geografickými referenčními systémy.

This thesis describes development of embedded platform for recording data from vehicle motion state sensors and for development of algorithms using fusion of such data on board vehicles. This platform should simplify recording and standardize data format for reusability in future projects. The thesis also describes other improvements including algorithm simplifications concerning usage of maps and geographic reference systems.

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Abstracts of publications 2023-2025

Vít Fanta: Energeticky efektivní řízení kolejových vozidel (diplomová práce FEL ČVUT, 2023)

Cílem této práce je představit problém optimálního řízení vlaku a implementovat open-source softwarový balíček, pomocí něhož je jej možno řešit. Řešením je rychlostní profil, který bere v úvahu trakční limity vlaku, celkový čas cesty a výškový profil tratě a zároveň minimalizuje celkovou vynaloženou energii.

Optimální strategie spočívá v přepínání několika jízdních režimů: maximální trakce, držení rychlosti, optimální brzdění, výběh a maximální brzdění. Na ploché trati má optimální strategie podobu maximální trakce – (držení rychlosti) – výběh – maximální brzdění. Na obecné trati může docházet k většímu množství přepnutí kvůli příliš strmým úsekům. Řešení bylo implementováno v jazyce Julia a je dostupné veřejnosti v podobě balíčku na GitHub. I přes to, že je program obecně funkční a příklady výpočtu jsou uvedeny. Některé funkcionality stále chybí (především možnost zahrnout rychlostní omezení). Současné řešení je však možno dále vyvíjet díky jeho open-source povaze.

The goal of this thesis is to present the problem of optimal train control and implement an open-source software package able to solve it. The solution is a speed profile which takes train's traction capabilities, total journey time and the track gradient into account while minimising the total required energy.

The optimal control strategy is a switching strategy between a small number of modes: Maximum Power, Cruising, Optimal Braking, Coasting and Maximum Braking. On a flat track, the optimal strategy has the form Maximum Power – (Cruising) – Coasting – Maximum Braking. On a general track, more switching can occur due to the steep uphill and steep downhill sections of the track. A solution has been implemented in the Julia programming language and is available to the public in a form of a package accessible on GitHub. The solution is functional and examples of speed profile calculation are shown. Some features are still missing, most notably inclusion of speed limits. Functionality of the implemented solution can be further developed thanks to its open-source nature.

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Abstracts of publications 2023-2025

J. Kašpar, V. Fanta and V. Havlena: Tram Positioning with Map-Enabled GNSS Data Reconciliation. Submitted to ECC2025

This paper introduces a method for tram localization using custom processing of GNSS observables and a track map. The approach addresses challenges in dense urban areas where obstructed satellite views cause multipath signal issues. Based on the iterated extended Kalman filter (IEKF), this technique offers linear complexity relative to the number of GNSS measurements, contrasting with more complex methods that also mitigate multipath effects. Validation on simulated and real data shows improved accuracy over a baseline localization method. Results from real-world data confirm similar improvements when orthogonal projections onto the track are used as reference positions. This proof-of-concept may be enhanced by adding a bank-of-models method or χ2-based filtering of erroneous GNSS measurements.

Tento článek představuje metodu pro lokalizaci tramvají, která využívá speciální zpracování GNSS dat ve spojení s mapou trati. Tato metoda řeší problémy v hustě zastavěných oblastech, kde omezený výhled na satelity může způsobit vícecestné šíření signálu. Metoda je založena na iterovaném rozšířeném Kalmanově filtru (IEKF) a má lineární složitost vzhledem k počtu GNSS měření, což je výhoda oproti složitějším metodám pro zmírnění vlivu vícecestného šíření. Ověření na simulovaných i reálných datech ukazuje vyšší přesnost ve srovnání se základním přístupem k lokalizaci. Výsledky z reálných dat potvrzují podobné zlepšení při použití ortogonálních projekcí na trať jako referenčních pozic. Tento koncept by mohl být dále vylepšen přidáním metody banky modelů nebo filtrováním chybných GNSS měření pomocí χ2 testu.

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Abstracts of publications 2023-2025

Matěj Kříž: Estimation of vehicle range time to the intersection and processing of signal plans of the intersection controller

Navrhovaný projekt byl přípravnou fází pro projekt, jehož cílem je navrhnout metodiku pro automatické doporučování energeticky optimální rychlosti vozidla MHD blížícího se ke světelně signalizované křižovatce. Podkladem budou: odhad aktuální pozice a rychlosti vozidla, záznamy stejných veličin z palubních jednotek z minulých jízd stejného či další vozů na stejném úseku trati, a bezdrátovou komunikací přijatý signální plán od řadiče křižovatky. Náplní navrhovaného projektu bylo řešit alespoň některé z dosud identifikovaných (případně dalších nově identifikovaných) dílčích problémů. A to konkrétně:

1. Na základě poskytnutých záznamů z palubních jednotek (ang. onboard unit, OBU) vozidel z minulých jízd ve zvoleném úseku před křižovatkou postavit statistický předpovědní model pro dojezdovou dobu k nadcházející světelně signalizované křižovatce – v případě normálního rozložení střední dobu a rozptyl. Komplikací je situace, kdy vozidlo bylo zpomaleno nutností zařadit se na konec fronty vozidel před křižovatkou čekajících na zelenou.
2. Pozemní komunikační jednotkou (angl. roadside unit, RSU) vysílaný signální plán vykazuje značnou míru nespolehlivosti. Nespolehlivosti v tom smyslu, že v průběhu příjezdu vozidla ke křižovatce bývá měněn, a to několikrát. Zejména ve smyslu oddalování zelené (vozidlo přijíždějící do křižovatky z jiného směru mohlo dostat přednost), ale i naopak. Schopnost na toto reagovat musí být zakomponována do algoritmu využívajícího vysílaný signální plán.
3. Vysílaný signální plán aktuálně obsahuje pouze čas nadcházejícího přepnutí "barvy semaforu". Taková informace má ale užitečnost omezenou na vzdálenost od křižovatky, kterou lze za tu dobu ujet (nebo i těsně neujet). V případě, že je vozidlo ještě o dvě stě metrů dále, není tato informace bezprostředně použitelná a vozidlo nemá žádný podklad pro výpočet své optimální příjezdové rychlosti. Navržen byl prvotní algoritmus, který tu informaci přece jen využije (společně se záznamy předchozí komunikace) pro predikci signálního plánu pro relevantní budoucí časy.

The proposed project was a preparatory phase for a project to design a methodology for automatically recommending the energy-optimal speed of a public transport vehicle approaching a signalized intersection. The basis will be: an estimate of the current position and speed of the vehicle, records of the same variables from on-board units from past runs of the same or other vehicles on the same section of the line, and a signal plan received by wireless communication from the intersection controller. The scope of the proposed project was to address at least some of the sub-problems identified so far (or other newly identified sub-problems). Specifically:

1. Construct a statistical prediction model for the travel time to the upcoming signalized intersection - mean time and variance in the case of a normal distribution - based on the provided on-board unit (OBU) records of vehicles from past trips in the selected segment before the intersection. A complication is the situation where the vehicle has been slowed by the need to line up at the end of the queue of vehicles ahead of the intersection waiting for the green light.
2. The signal plan transmitted by the Roadside Unit (RSU) has a significant degree of unreliability. It is unreliable in the sense that it is changed several times as the vehicle approaches the junction. In particular, in the sense of delaying the green light (a vehicle approaching the intersection from another direction could get the right of way), but also vice versa. The ability to react to this must be built into the algorithm using the transmitted signal plan.
3. The transmitted signal plan currently contains only the time of the upcoming 'traffic light colour' switch. However, such information is of limited utility to the distance from the intersection that can be travelled (or even just missed) in that time. If the vehicle is still two hundred metres away, this information is not immediately useful and the vehicle has no basis for calculating its optimum approach speed. An initial algorithm has been designed that does use that information (along with previous communication records) to predict a signal plan for relevant future times.

Content of 3-WP01 Advanced V2X communication for more efficient transportation

Abstracts of publications 2023-2025

Štěpán Ošlejšek: Evaluation of the driving data recorded by the on-board unit

Cílem projektu bylo navrhnout a softwarově implementovat metodiku pro offline vyhodnocování a vykreslování dat zaznamenaných vozidlem na dané trati. Primárním podkladem byla data zaznamenávaná (a komunikovaná) palubní jednotkou jako jsou především pozice, rychlost, zrychlení. Dalším podkladem byly digitální mapa trati a digitální model terénu (výšková mapa). Dalším zamýšleným, ale bohužel v projektu nedostupným údajem, byl údaj o okamžité energetické spotřebě – elektrický proud. Motivací pro tuto práci je získání kvalitativního i kvantitativního vhledu do energetické efektivnosti jízdy tramvaje řízení lidským řidičem. Pro poskytnutá data z palubní jednotky byla zvolena vhodná datová strukturu, která bude podporovat následnou analýzu. Zvolen byl i vhodný formát uložení, který bude podporovat správu potenciálně velkého množství datových souborů. Zobrazena byla uvedená data v závislosti na okamžité pozici vozidla, tedy ujeté vzdálenosti podél trati. Vzhledem k té stejné nezávislé proměnné byl počítán a zobrazen i sklon trati. A zobrazen bude (při pokračování tohoto studentského projektu) i proudový odběr. Při dostupnosti měření z více jízd toho stejného či různých vozidel na té stejné trat byla tato data vyhodnocena statisticky a zobrazeny průměrné trajektorie a okolo nich pásmo neurčitosti.

The aim of the project was to design and implement in software a methodology for offline evaluation and plotting of data recorded by the vehicle on a given route. The primary basis was the data recorded (and communicated) by the OBU, such as position, speed, acceleration. Other inputs were a digital map of the track and a digital terrain model (elevation map). Another intended, but unfortunately unavailable in the project, data was the instantaneous energy consumption - electric current. The motivation for this work is to gain qualitative and quantitative insight into the energy efficiency of tram driving by a human driver. A suitable data structure was chosen for the provided on-board data to support the subsequent analysis. A suitable storage format was also selected to support the management of potentially large numbers of data sets. The data provided was displayed in relation to the instantaneous position of the vehicle, i.e. the distance travelled along the track. Given the same independent variable, the slope of the track was also calculated and displayed. And the current draw will be displayed (as this student project continues). When measurements from multiple runs of the same or different vehicles on the same track were available, this data was evaluated statistically and the average trajectories and the uncertainty band around them were displayed.