Small or medium-scale focused research project (STREP)

ICT Call 8

FP7-ICT-2011-8

Cooperative Self-Organising System for low Carbon Mobility at low Penetration Rates

COLOMBO: Deliverable 6.3

Exploitation Plan

Document Information	
Title	Deliverable 6.3 – Exploitation Plan
Dissemination Level	PU (Public)
Version	1.0
Date	23.09.2015
Status	Approved by project coordinator
Authors	Robbin Blokpoel (Imtech), Siebe Turksma (Imtech), Jaap Vreeswijk (Imtech), Stefan Hausberger (TU Graz), Daniel Krajzewicz (DLR), Wolfgang Niebel (DLR), Andreas Leich (DLR), Jérôme Härri (EURECOM), Thomas Stützle (ULB), Michela Milano (UNIBO)

Executive summary

The aim of this document is to indicate how the results of COLOMBO can be exploited. The document does not only focus on the duration of the project, but also assesses the possibilities beyond the end at 31st of October 2015. A good reference for the exploitability of the COLOMBO results is the Technology Readiness Level (TRL), which is used in the document to indicate the maturity and marketability of the results.

COLOMBO detection algorithms were developed for several situations. Data fusion between green phase duration and travel times from for instance navigation systems, can give useful estimates of traffic volumes. Full cooperative vehicles can give both queue estimates and traffic flow estimations and a work is being carried out on a separate traffic anomalies detection algorithm. All these solutions are either halfway or at the end of TRL 3. The COLOMBO SWARM algorithm for traffic light control is a promising concept, just like the control based on travel time measurements. However, both methods are still halfway TRL 3 and therefore not directly marketable. Next steps have been identified how to increase the TRL.

Apart from the detection and traffic control algorithms, COLOMBO also developed and improved simulation tooling to facilitate the work in the project. These improvements to irace and SUMO (including PHEMlight) are released to the general public as open source, with a relatively small license fee for additional vehicle data of PHEMlight. PHEM is licensed separately. These can therefore be considered at TRL 9. For the iCS and the evaluation toolkit the project still has to determine how to proceed with their release to the public, with possibly some integration development work required these are still at TRL 3.

In the following the exploitation of the results is considered. The timing is attached to achieving a certain penetration rate of cooperative vehicles. Correspondingly, the target market is (i) replacing existing static controllers or (ii) competing with static control in green fields up to 2021, when forecasts indicate 10% penetration is achieved. Therefore, to enter this market, the main bottleneck is increasing the TRL. Up to 2024, the penetration rate is between 10% and 20%. With these rates traffic volumes can be estimated with enough accuracy to replace centralized adaptive control systems, like SCOOT and SCATS, which slowly adjust cycle times, green ratio’s and offsets to optimize traffic flow. From 20% up to 90% the target market can be expanded to improve existing actuated controllers to perform as well as local agent based adaptive control systems like Utopia and Imflow. This saves the road operator the installation of the expensive link entry detectors as their distance to the intersection makes installation expensive. During this phase, the higher the penetration rate, the better the performance. Therefore, at some point queue estimates of existing adaptive controllers can be improved with cooperative data for better performance. Lastly, from 90% penetration, which is expected to be reached around 2031, the performance of the cooperative control should be enough to replace an entire detection field.

The document also reviewed exploitation from a stakeholder perspective. Road operators and governments will profit from the availability of a lower cost alternative to current traffic control solutions both in initial investment and maintenance. Road users benefit from more efficient traffic control, resulting in lower travel time and fuel savings. Having a cooperative system in the vehicle also guarantees the queue the road user currently is in, has been detected by the controller. Therefore, cooperative vehicles are expected to have a lower average travel time. Traffic engineers, consultants, industry and researchers benefit from the (open source) tooling released by COLOMBO for their work.

From the partner perspective the exploitation involves mostly buildup of knowledge and publishing research papers. SUMO is an important tool for DLR and the extensions to it will be used frequently in the future. TU Graz extended PHEM and introduced PHEM-light. This should

increase their market for the emission databases. For Imtech the increase of knowledge about traffic detection and control can lead to better product in the future, increasing profitability.

Table of contents

1 Introduction

1.1 COLOMBO Project

Traffic light control (TLC) as part of active traffic management aims at enabling safe and efficient passing of traffic flows at intersections. It requires determining the situation on the roads. These both actions make use of technologies which are becoming part of intelligent transportation systems (ITS).
Emerging cooperative techniques (C-ITS) like vehicle-to-infrastructure (V2I) communication via the IEEE 802.11-2012[1] standard may increase the knowledge about the traffic situation and open new channels for delivering information. However, most cooperative applications require large penetration rates in order to assure their functionality[2] [1], [2], making the first steps towards their deployment unattractive. Figure 1 depicts three introduction scenarios of cooperative vehicles. This external factor and its influence are described in chapter 4.

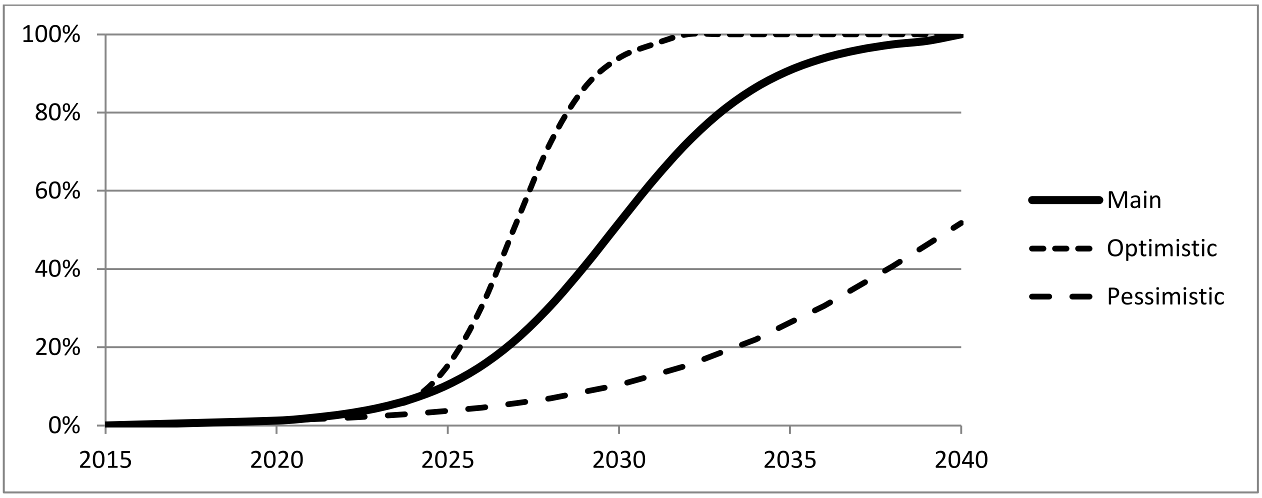

Figure 1: Main, Optimistic, and Pessimistic introduction scenarios of cooperative vehicles from 2015 – 2040, calculated using [3]

COLOMBO works on overcoming this hurdle by delivering a set of modern, self-organising traffic management components being applicable even at low OBU penetration rates below 10%, ensuring their usability from the very beginning of deployment on. For this purpose, an extension into a hybrid communication approach involving "probe vehicles" was pursued. This class of vehicles comprises traditional floating cars (→FCD) and "connected travelers" with their Bluetooth and GSM equipped PDAs etc., and is referred to as "Class B vehicle" within the COLOMBO documents.

COLOMBO focused on two traffic management topics: traffic surveillance and advanced traffic light control algorithms. It delivers the methodologies and software for the following urban traffic management components, which are designed to operate locally on road site units (RSUs):

- A cooperative traffic state monitoring system, including
    - Traffic state estimation (TSE);
    - Automatic incident detection (AID);
    - Emissions monitoring system (EMS);

---

[1] The former IEEE 802.11p extension for automotive application was merged into the basic standard in 2012.
[2] Exemplary, a Green Light Optimised Speed Advisory (GLOSA) can yield in waiting time reductions of 1..9% already at 10% penetration rate [2] and in reductions of ~15% at 20% OBUs [3]. Fuel and emission savings start at higher penetration rates between 30% [2] and 50% [3].

- A cost-effective, adaptive, and self-organising traffic light (SOTL) control without stationary detection;
- A tool for automatic TLC algorithm configuration and tuning.

These outcomes relate to several user needs described in the European ITS Framework Architecture also known as FRAME [4].[3]

COLOMBO also:

- Extends and implements available, well-established models for simulating vehicular pollutant emissions (PHEM), traffic (SUMO), and vehicular communication (iTETRIS and ns-3).
- Develops and implements a simulation-based optimization architecture, incorporating these tools.
- Extracts guidelines on
    - Emission-optimal driver behaviour adapted to the new traffic light control system,
    - Developing eco-friendly TLC, dedicated for traffic engineers.
- Assesses the environmental and traffic impacts of the traffic light control.
- Disseminates and exploits the project results including a fully functional educational kit.

1.2 Objective of this document

The aim of this document is to indicate how the results of COLOMBO will be exploited. The document does not only focus on the duration of the project, but assesses the possibilities beyond the end at 31st October 2015.

COLOMBO is a research project. This document has indicative character.

1.3 Intended audience

The document is written for the project partners, external stakeholders as identified in chapter 3 (like public authorities, traffic planners and managers, and OEMs of relevant ITS products), as well for the European Commission. The reader is welcome to use this public deliverable for assessing which COLOMBO results could be transferred into his domain of work or business and contact any of the project partners for collaboration or extension of the plans.

1.4 Document structure

The results of COLOMBO are diverse and applicable in different areas. The exploitability along the four types of results is analysed in chapter 2. The exploitable results are then mapped onto the identified stakeholders of chapter 3. The important external factor of market introduction of cooperative vehicles was investigated by several other projects. The resulting scenarios together with the assumptions to choose a particular one for the exploitation plan of COLOMBO are presented in chapter 4. Five different business cases are made up in chapter 5. The stakeholders' benefits in chapter 6 and, separately, those of the project partners in chapter 7 are lined out at the end.

[3] Exemplary, TSE relates to user need 7.1.1.1 "The system shall be able to monitor sections of the road network to provide the current traffic conditions (e.g. flows, occupancies, speed and travel times etc.) as real time data."; AID relates partially to user need 7.1.1.7 "The system shall be able to monitor and record environmental (atmospheric and noise) pollution conditions, and provide an alarm when a certain threshold is exceeded.". This shows that the FRAME architecture is not fully applicable to the COLOMBO components and needs to be updated.

1.5 Technology Readiness Level

This exploitation plan will regularly refer to the term technology readiness level (TRL) [5]. In order to understand this concept a brief introduction to this will be given here. Figure 2 shows an overview of the 9 defined levels with a brief description.

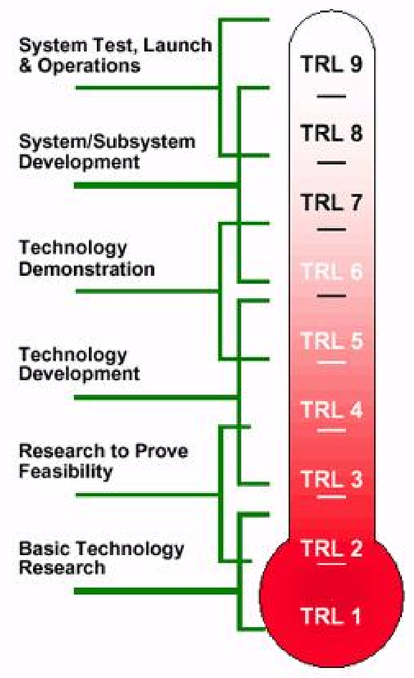

Figure 2: Technology readiness levels [6]

A description of the technology readiness levels and a mapping to the field of the COLOMBO project is given in Table 1. The current state of the project is TRL 3, where different parts have reached further into this level than others. This is further described in Chapter 2, where the results are discussed individually. The tools that have been improved during the project have often been released to the general public as open source tools. The requirements for quality and stability for an open source tool are lower than for a commercial project. This often means that TRL 4-6 are skipped and only some smaller tests for integration are executed before release to the public (integration tests belong to TRL7). For further application of the TRL concept an MS Excel tool can be used, which is described in [7].

Table 1: Technology readiness level mapping

TRL	Description	COLOMBO example
1	Basic principles are formed. An idea or hypothesis was formed and documented.	The project proposal described the basic principles of low penetration detection and swarm based control.
2	Technology concept and application formulated.	Use cases, scenario's and architecture created. This was done in the first phase of the project, for example in task 5.1 for the overall system architecture. In general each part of the system development started with a conceptual design.
3	Characteristic proof of concept implemented.	The swarm-based traffic control algorithm has been demonstrated on artificial scenarios. This can be seen as a step in between TRL 2 and 3. As a last step to

		reach the end of TRL 3, one real-world scenario will be used as a characteristic proof of concept.
4	Component validation in a laboratory environment.	For validation the subsystems have to be put to the test in more extreme conditions. Research questions for this phase can be as follows: Can the control algorithm cope with real world scenarios from all over the world? Can it handle very complex scenarios? What will happen when a gridlock occurs?
5	Component validation in a real-world environment.	This is similar to TRL 4, but then in a real-world environment. This means unexpected events could occur which were not taken into account during development. For instance what if an equipped vehicle parks near an intersection, will the subsystems think there is an incident? Interfaces with other already mature components to control the signal heads and operate the sensors, can still be realized provisory in this stage.
6	System model demonstrated in a real-world environment.	Here the whole system is integrated with other components required for real world marketing. For a traffic light controller this means the algorithm runs on a processor board connected to a real traffic light controller using a robust interface suitable to be produced, configured and maintained in large numbers.
7	Complete system prototype demonstration in real-world environment.	In this phase the COLOMBO components are fully integrated with other components and can also be produced, configured and maintained in large numbers themselves.
8	Actual system completed and tested.	Large scale production set up and first systems tested in the lab.
9	Actual system operational on several locations.	Several controllers operational in the field without problems.

2 Exploitable results

This chapter gives an overview of the COLOMBO results which are considered exploitable. A reference to the deliverable(s) with detailed description is given at each section's end. The results can be divided into traffic management solutions, simulation software tools, and knowledge/expertise. Another type of exploitable result can be services, but no such ones were established within the project. However they can be built onto the aforementioned outcomes.

The following overview shows how these simulation tools and the traffic management solutions are interacting in the project's scope.

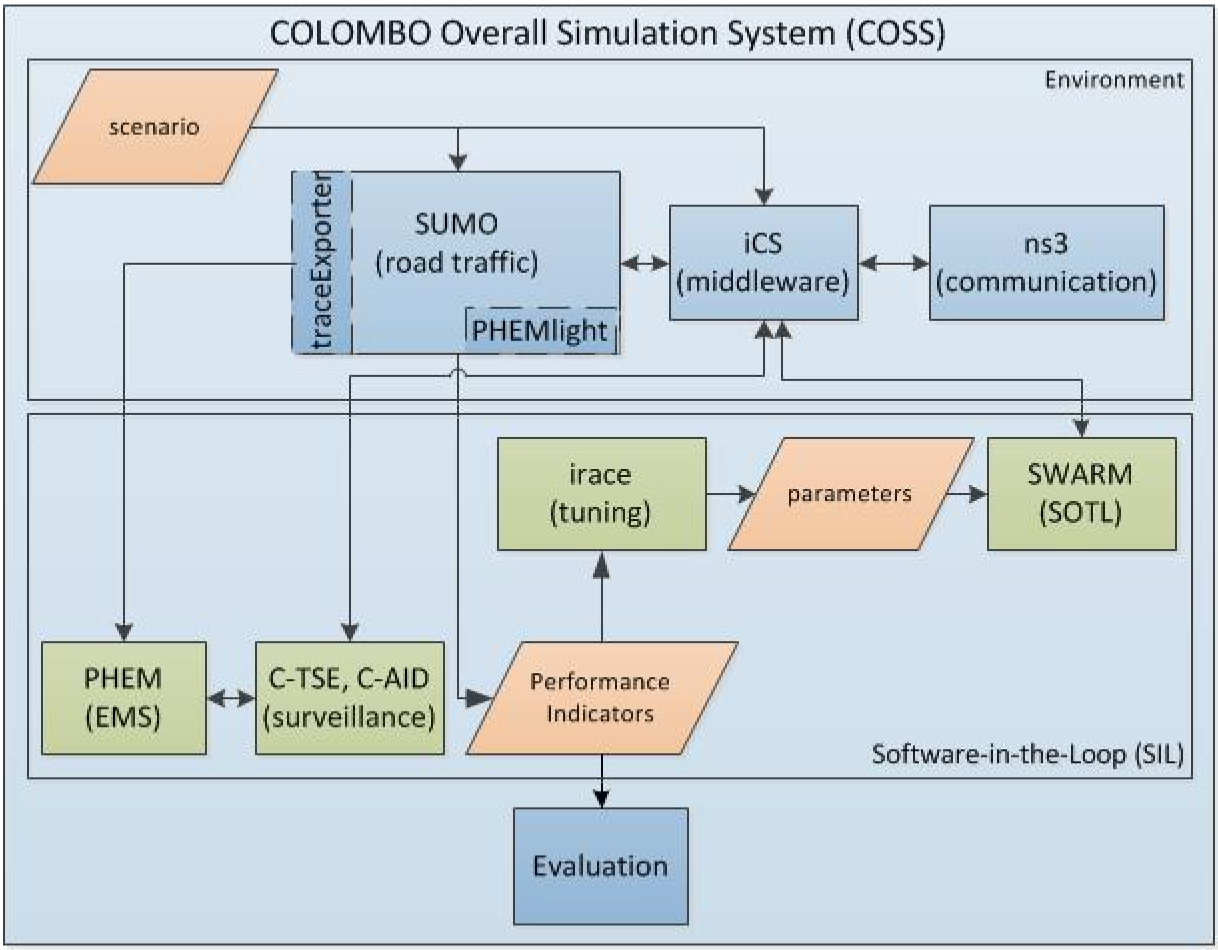

Figure 3: Building blocks of the COLOMBO Overall Simulation System (COSS)

2.1 Traffic management solutions

2.1.1 Traffic state estimation (TSE)

Cooperative vehicles can supply urban traffic with a wealth of data and information that can be used for different purposes, including improved control. As long as the penetration of cooperative vehicles is low, however, the data received is very fragmentary. COLOMBO develops algorithms to make the best out of limited data.

The results can be exploited in the following situations:

- There is an existing detection system with a very limited detection field. In this case COLOMBO's results can improve the existing data or give extra information about the traffic situation to traffic managers.

- There is an existing system with an extensive detection field. In this case the system input can be enriched with e.g. the detection of anomalous situations or more accurate turning predictions. With increasing penetration parts of the existing detection field can be removed (saving cost).

The state of the art for low penetration cooperative data is currently most visible for connected navigation system providers. They collect travel time information from users and use it to evaluate the travel time for different route alternatives. Sometimes further processing of the data is done to calculate average speed and estimate volumes based on the fundamental diagram of traffic flow, which describes the relation between speed and traffic flow. However, in environments with traffic lights, the capacity is not limited by the road, but by the green ratios of the controller. Therefore, COLOMBO went beyond this state of the art by also taking traffic control data into account. The combination gives a reliable estimate on traffic volumes that can be used for fixed time plan changes or other traffic management decisions. The technology readiness level of the current status is level 3. Calibration and validation with large data sets will be the next step. Integration with other intersections in a network and with other components, like traffic anomalies detection is also a vital remaining research topic. Another open point is map data fusion and conversion. The algorithm needs the information of the travel time between 2 intersections (to be precise measurement sections start and end just after a stop line); while a navigation system may have a different topology.

In case of an existing controller with an extensive detection field, the COLOMBO system can deliver enhancements to the queue estimation. The corrections compensate for two problems, accumulated queue estimation errors due to sensor counting error differences between entry and exit of a queue, and turning percentage estimation errors. The latter is especially interesting in scenarios where the turning percentage of the arrival flow varies strongly over time. Depending on the situation, the potential of the enhancements is a 69% reduction of the queue estimation error, which can lead to 30% delay reduction. These results are only for one scenario and at 100% penetration rate. More results are expected to be ready at the end of the project, but the potential of the queue enhancements has been demonstrated. Therefore, the technology readiness is level 3.

One of the key driving factors for initiating the COLOMBO project is the high cost of installing and maintaining sensors. Since penetration rates are not expected to raise quickly, more research was done to evaluate in which areas the largest benefit could be realized with a low penetration rate. This resulted in the conclusion that entry detectors are the most expensive to install as the distance to the intersection requires a longer cable in the ground with expensive installation, or additional wireless repeaters. The traffic control algorithm requires 100% penetration to skip a green phase based on stop line detection, but can work with queue estimates to replace entry detection. Therefore, replacing these entry detectors with cooperative detection leads to the largest cost-wise benefit while having low penetration requirements. Research on this topic is still ongoing to determine a more precise indication of penetration rate-benefit estimates and can therefore be considered technology readiness level 3.
Within COLOMBO, a data fusion concept is being investigated which fuses the results of two types of low cost detectors: a) a V2I message receiver at low penetration rates and b) in-vehicle Bluetooth devices at a certain penetration rate of 30%[4]. In this context, vehicle speeds and vehicle counts are being estimated using a Bayesian maximum a-posterior probability (MAP) estimator. This approach is promising for commercial exploitation in traffic light controller applications. The technology readiness level of the fusion algorithm is 3.
The TSE is described in D1.2.

[4] The penetration rate of in-vehicle Bluetooth devices in developed countries has reached the order of magnitude of 30%, as measurements at the project partner DLR's road lab show.

2.1.2 Automatic incident detection (AID)

A separate application is the traffic incident[5] detection, intended for situations that are hard to detect with traditional sensors. A traffic jam can be due to too much demand or due to another incident. For traditional sensors it is hard to determine what the cause of the jam is and - if the cause is an incident - the precise location of it. The V2I based solution developed within COLOMBO addresses this problem. The solution is currently under development in the last phase of WP1, and therefore at Technology readiness level 2.
The AID is described in D1.3.

2.1.3 Emission monitoring System (EMS)

The emission monitoring system determines the amount of pollutants emitted by vehicles that cross an intersection or other defined street section. Single trajectories are the input for the PHEM software (cf. sect. 2.2.3) to externally calculate their pollutant emissions. Based on vehicle counts, types, and additional parameters the overall emissions of a section or junction can be estimated and monitored in HD.
The simulation results show that even with a low penetration rate of 1% the relative error of the estimated emissions is around 5% after 1 hour of learning time. The relative error is decreasing with higher penetration rates. It has to be mentioned that the used simulation scenario is very simple so with more complex traffic conditions the error could probably be higher.
The EMS is described in D1.3.

2.1.4 Self-organising traffic control (SOTL)

COLOMBO has developed a traffic light control system directly inspired by the research in swarm intelligence. Swarm intelligence is a discipline that studies natural and artificial systems that are composed of a large number of (typically identical or very similar) individuals (“agents”), which coordinate using decentralized control and self-organisation. Recent research results have shown that the principles underlying many natural swarm intelligence systems can be exploited to engineer artificial swarm intelligence systems that show many desirable properties and effective solutions.

It is not intended that COLOMBO finishes with a full-fledged commercial product, but the results can definitely be the starting point for self-organising traffic control that is:

- easy to configure.
- easy to maintain.
- low in infrastructure cost.
- flexible to uncertain or even missing information.

Globally, the majority of urban traffic control implementations have a very limited sensor field (or none at all), which have at best automatic plan-selection capabilities. Combining the SOTL with low-penetration cooperative TSE results in an adaptive system that could replace the widely deployed state of the art urban traffic control systems.

In this context, there will initially be a lot of room for research institutes to prove the benefits of cooperative adaptive SOTL control and improve an evolving product that can be deployed by industrial parties.

It is to be expected that the capabilities of self-organising traffic control will grow with experience gained in the overhaul of simple plan-selection based traffic control systems, and that within a few years also more advanced traffic control systems can benefit from COLOMBO’s self-organising

[5] The term “Traffic incidents“ is used for a broad range of events, and can comprise driving anomalies on a disaggregated microscopic (vehicle) level up to macroscopic occurrences like traffic jams.

features. COLOMBO has achieved a fruitful stage for research as well as industrial parties in this area.

Currently work is still on-going in COLOMBO WP5 to evaluate the performance of the swarm algorithms at varying penetration rates. It is expected that the performance increases with increasing penetration rates. Important benchmarks for the solution are at which penetration rates the performance of the system is comparable to vehicle actuated control and traffic adaptive control. When those penetration rates are achieved on the street, the exploitation of the system can expand to replace those types of control or can be used as a solution for a green field situation. Currently, the status is halfway technology readiness level 3, but at the end of the project when WP5 is finalized, this should be at the end of TRL 3.

As mentioned in the section about traffic state assessment, data from connected navigation systems is already available. When this is combined with the data of the signal phase timings, an estimate of the traffic volume can be made. COLOMBO also developed a control algorithm based on fixed time control that slowly adapts the green duration based on the estimated flow. The research on this algorithm is at technology readiness level 3. Initial tests have been carried out and shown promising results with a performance similar to a well calibrated fixed time controller, while gaining the ability to adapt to changing traffic demand. However, the algorithm still needs to be calibrated using more data, longer simulations and more scenarios. Specific algorithms for congestion also seem to be necessary to have a complete solution.

The SOTL is described in D1.3 and D2.1 to D2.4.

2.1.5 Automatic configuration software

The COLOMBO project used and improved automatic algorithm configuration software and developed new software that can be useful in the area of automatic algorithm configuration. One software package is the tuning tool kit that was already made available as free software under the GNU general public license. During the COLOMBO project also improvements to available automatic algorithm configuration software have been developed, in particular, to the *irace* package. The irace package is available also as free software under the GNU general public license. As such, the improvements in the COLOMBO project are available to the increasing number of users of the software. The software is therefore also available to traffic engineers and the COLOMBO project provides several case studies that show the potential that these techniques have for tuning traffic light control software. Technology readiness level of the improvements of irace can be considered at 9, as the update is released to the general public.

The configuration software is described in D3.1, D3.2, and D3.3.

2.2 Simulation Software Tools

COLOMBO uses a large set of established tools for simulating traffic and communication. The solutions developed in COLOMBO are developed as models that can be simulated using these tools. Most of the involved tools are originally developed by the COLOMBO project partners. The continuation of work on these tools and accordingly implemented extensions and improvements are thereby of immense importance for the according consortium partners.

Most of the simulation software tools are given to the scientific and engineering communities as open source applications and are thereby used by other research groups, even within other EC projects, as well.

2.2.1 SUMO

SUMO (Simulation of Urban Mobility) is an open source traffic simulation environment that has been steadily extended since its inception in 2002. The non-proprietary and transparent nature of

SUMO under the GNU General Public License distinguishes it from commercial micro-simulation environments. This makes it an important open and transparent research platform in an area where there is still a fair amount of "black magic" – undisclosed models and behaviour.

SUMO is already in use by a large community, mainly for short term student projects, but as well in larger research projects. Slowly, the software gets accepted by academics as a long-term tool used for both, teaching, as well as within projects. A survey on publications that cite SUMO examines more than 350 scientific papers, showing that a) SUMO is used by an international community, located in the European Union and the USA mainly, b) the number of people using it increases, and c) the major application topic is the simulation of vehicular communications. As well, it shows that it is used within Master and PhD theses.

The additions within COLOMBO comprise simulation of pedestrians, bikes, and public transport. It was already shown that the quality of SUMO's representation of motorized road traffic is improved when taking into account the infrastructure used by pedestrians. Just for this reason, the extensions move SUMO into the circle of direct competitors to commercial traffic simulations. Additionally, SUMO was planned to cover inter-modal trips from the very begin on. The inclusion of pedestrian dynamics closes the missing gap and allows modelling all modes and each participant – may it be a motorized vehicle, a bicycle, or a pedestrian –on a microscopic scale. The open interfaces used to embed different pedestrian dynamic models can be used by other parties as well.

The inclusion of a new emission model named PHEMlight allows to replicate nowadays and near-future vehicle population completely. The given clear distinction between emission classes enables users to investigate traffic policies, e.g., regulatory constraints like forbidding certain vehicle emission classes in certain areas. It also enables the replication of the emission classes' development over time. Besides the availability of PHEMlight the work on emission models resulted in a large set of tools and open interfaces that may be reused in later development of new emission tools.

The SWARM algorithm for traffic light control (cf. sect. 2.1.4 "SOTL") was implemented as a SUMO component, which is publicly available but not part of the official release. TLC investigations are one of the major applications of microscopic road traffic simulations and COLOMBO extends SUMO's usability in this field.

A major brick for traffic lights evaluation is the according "traffic lights algorithm evaluation system" developed in COLOMBO. This artefact – mainly a set of dynamically chosen benchmarking scenarios for the used traffic simulation – shall help a traffic light algorithm developer in determining the strong and weak points of his algorithm. This set of benchmarking scenarios with many real world and synthetic simulation setups was made available to the public. They can be used by the scientific community for comparing their proposed solutions without investing into resource consuming building, calibration, and validation of own scenarios. Using identical base case scenarios also makes the results of the investigated research scenarios better comparable and could thus state a quasi-standard as it has been shown that nowadays reports do not allow it due to different performance indicators, scenarios, and simulators.

SUMO is given to the scientific community as open source and is as well used in EC projects by third parties. Thereby, SUMO increases research performance within other EC projects as well. The COLOMBO additions to SUMO made it significantly more useful and will further extend the user community.

The extensions to SUMO are described in D2.1 to D2.4 (SOTL), D4.2 (PHEMlight), and D5.2.

2.2.2 iCS

The iTETRIS project has developed an open, ETSI standard compliant, and flexible simulation platform named iCS ("iTETRIS Control System") that will create close collaboration between engineering companies, road authorities, and communications experts. iCS integrates wireless communications and road traffic simulation platforms in an environment that is easily tailored to specific situations allowing performance analysis of cooperative ITS at city level. The accuracy and scale of the simulations leveraged by iCS will clearly reveal the impact of traffic engineering on city road traffic efficiency, operational strategy, and communications interoperability.

COLOMBO extends the scope of iCS with augmented traffic micro-simulation capabilities, realistic cooperative traffic state estimation and easy to configure self-organising traffic control. This strengthens the iCS as the platform for combined communication and road traffic simulation. The project is still unsure how to release the iCS to the general public, possible integration with the latest developments of the current administrators of the iCS may still be necessary. TRL is therefore considered to be 3.

The iCS extensions are described in D1.1, D1.2, and D5.1.

2.2.3 PHEM

The emission model PHEM is a commercial tool. By extending its database by modern vehicle types, TU Graz increases the quality of PHEM and keeps it up-to-date with real-world development. PHEM is already well-accepted, but new users are attracted by the increased functionality as well.

Besides being a commercial product for its own, PHEM as well provides the emission values for the traffic situations in the “HBEFA” and also feeds the model “COPERT” with emission factors. Its extensions are thereby usable by a bigger community than the users of the commercial product only.

The software PHEM-light was realized during the COLOMBO project for an efficient integration with SUMO. This adds another application to the model and could lead to customers buying the model to use it in combination with SUMO for evaluation of emissions of their traffic scenario. The PHEM-light model in SUMO is delivered with an average EURO 4 vehicle. Data for all other vehicle classes is available and can be ordered for licence fees. As it is available to the general public, the TRL can be considered at 9.

The PHEM-light emission simulation tool enabled the elaboration of a simplified traffic simulation model which calculates fuel consumption, pollutant emissions, travel time, and stops of road traffic on a road. It allows the optimisation of traffic light control parameters (“NITRA” tool). This software will be used for engineering work in future by TU Graz and may also become commercial software later on.

The PHEM extensions and PHEMlight are described in D4.2 and D4.3.

2.2.4 Evaluation tool

The TLC evaluation tool will enable researchers to benchmark traffic lights in a well-defined way. The software tool and parts of its methodology are new, therefore discussions with the community must be done first to raise their acceptance.

The tool in its current state is considered as an add-on module to SUMO for traffic engineering applications. In the future extensions could be made to support different data input formats. The methodology behind the toolkit and the current toolkit itself were published as project results. The current toolkit was made with limited programming effort. Therefore, each company can easily create a toolkit for their own application using COLOMBO’s public deliverables.

The evaluation methodology and tool are described in D5.3.

2.3 Knowledge and Expertise

The knowledge gained while researching and developing can be exploited by passing it on via

- Academic publications,
- Teaching and teaching tools like guidelines,

but also by turning it into wisdom to offer services like

- Evaluation of pilot implementations, and
- Consultancy to end-users of the COLOMBO products as well as commercial/industrial parties.

3 Stakeholder Identification

The key stakeholders named in the project's Description of Work (p. 38) are

- Public authorities and road operators,
- companies delivering traffic management solutions, i.e.,:
    - original equipment manufacturers (OEM), in the TLC sector and
    - service and content providers,
- and research institutes.

Further stakeholder groups might be

- road users and inhabitants,
- traffic engineers and consultants, and
- standardising and regulating bodies.

The project partners are a subset of these stakeholders, namely research institutes and the OEM& consulting company Imtech.

The following matrix relates these stakeholders to the aforementioned project results of chapter 2. It must be noted that not all stakeholders are direct customers of results, for example road users will use but not buy traffic light control. This case is denoted with brackets (x).

Table 2: Mapping of stakeholders to exploitable results

Results / Stakeholder	Traffic Management Solutions				Simulation Software Tools	Knowledge & Expertise		Service
	Incident monitoring and information	Emission monitoring system	Traffic control system (SOTL)	Algorithm configuration	Simulation software	Guidelines for emission-optimal driver behaviour and	Education Toolkit	Consulting
Road operator		x	x	x	x	x	x	x
OEM	x	x	x	x		x	x	x
Service provider	x	x		x				x
Researcher	x	x	x	x	x		x	x
Road User			(x)			x		
Engineers		x	x	x	x	x	x	x
Regulating body		x				x		x

4 C-ITS Introduction scenario

The key external factor for the COLOMBO traffic management solutions to be marketed is the penetration rate of cooperative vehicles. The other types of exploitable results are not directly affected by this factor.

Different forecasts for this rate have been conducted. Figure 4 shows four scenarios for the expected development of cooperative penetration rate. The first scenario assumes all new vehicles will be equipped from 2015. The second scenario assumes new cars will be equipped when a next generation of the model is introduced. This means it takes approximately 6 years before all new cars will be equipped and then another 12 years before the last non-cooperative car is end of life. This resembles the optimistic scenario from Figure 1. The third scenario in Figure 4 assumes it takes 10 years before all new vehicles will be cooperative and is based on the underlying assumption that at first only the premium models will have this functionality, while only later on the budget cars will incorporate it as well. This resembles the main scenario from Figure 1. The last scenario assumes only premium cars will be equipped.

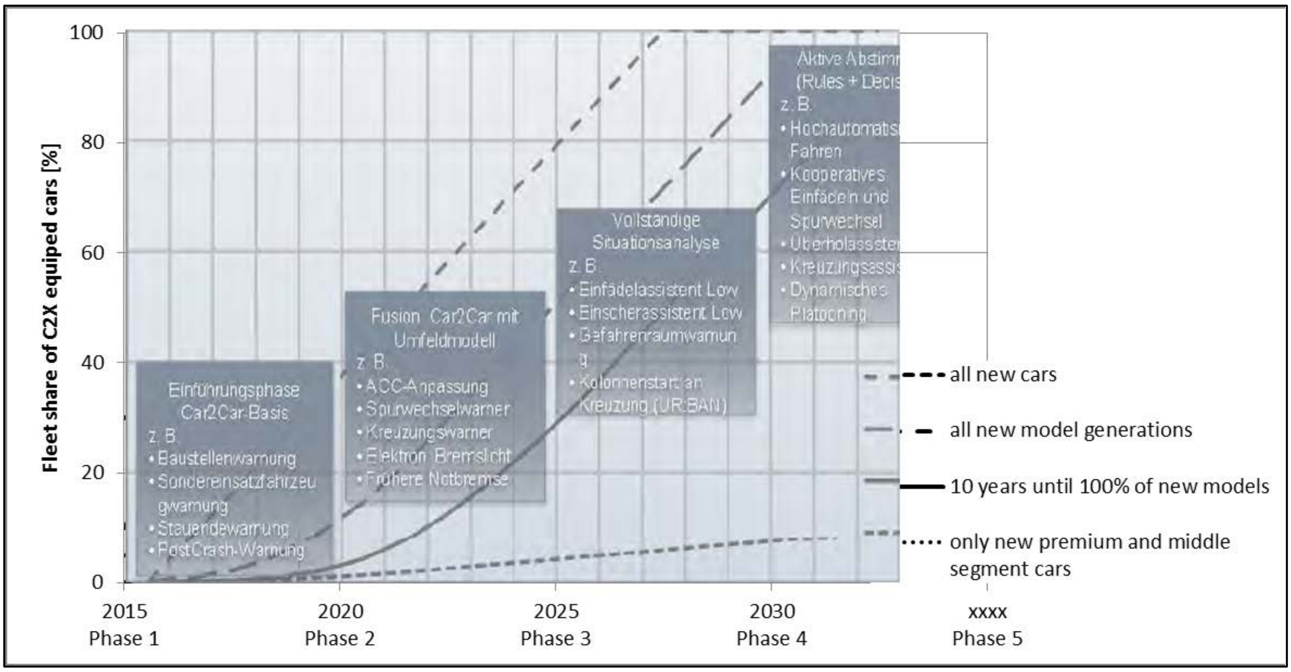

Figure 4: Phases and scenarios of C2C introduction according to [8]

For this exploitation plan it is assumed the third scenario with a timeframe of 10 years before all new vehicles are equipped is most likely. This is because no new types with cooperative technology have been announced so far. The car2car consortium made an agreement to introduce a cooperative car model in 2015 [9], but so far none has been brought onto the market. Additionally, professional drivers will be the first to adopt, with very small localized equipped fleets for FOT projects. These projects will likely continue on a commercial basis after their test period and will slowly grow both geographically and in number of participating vehicles. This results in a very slow rise of equipment rate from 2015 up to 2019. Afterwards it is expected that regular consumers will also start to have a significant impact on the penetration rate. When penetration is over 50%, there are again several scenarios possible. The benefits of having the cooperative system may be significant enough for owners of older vehicles to purchase an after-market add-on system, possibly integrated in their smart phone. This would speed up achieving 100% penetration.

Another possibility is a government regulation with either a fiscal stimulation or simply a law to make cooperative equipment mandatory like discussed in the USA[6] [10]. This leads to quick market penetration as can be seen in Figure 5 [11].

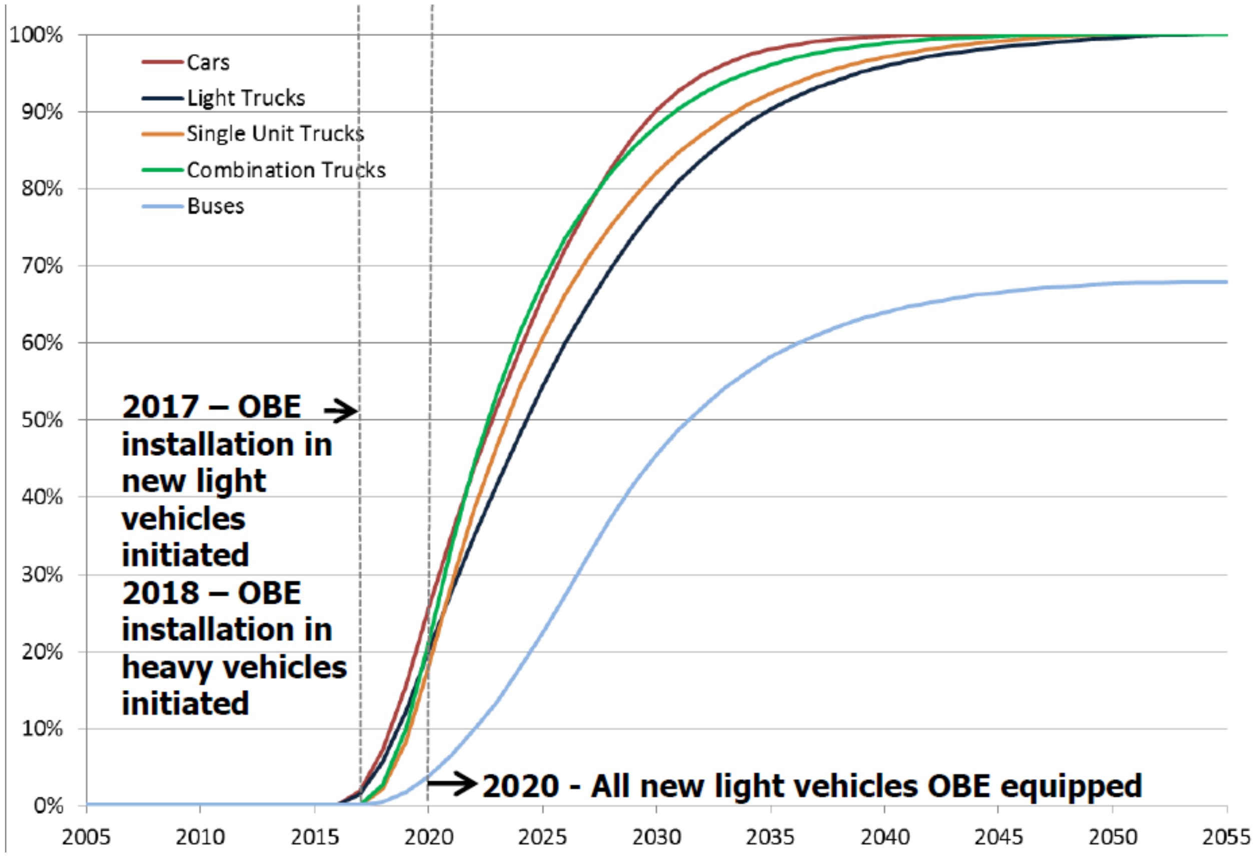

Figure 5: Percentage of fleet with On-Board Units according to [10]

A last possibility is none of the above, resulting in a long time until the order of magnitude of 100% is achieved as some vehicles stay more than 30 years on the road. Taking all these considerations into account, the expected penetration rate will be as depicted in Figure 6.

[6] In August 2014 the U.S. Department of Transportation's (DOT) National Highway Traffic Safety Administration (NHTSA) issued an Advance Notice of Proposed Rulemaking (ANPRM) to begin implementation of V2V communications technology for light vehicles [9]. After having gathered input from the public and stakeholders the Notice of Proposed Rulemaking shall be published by 2016.

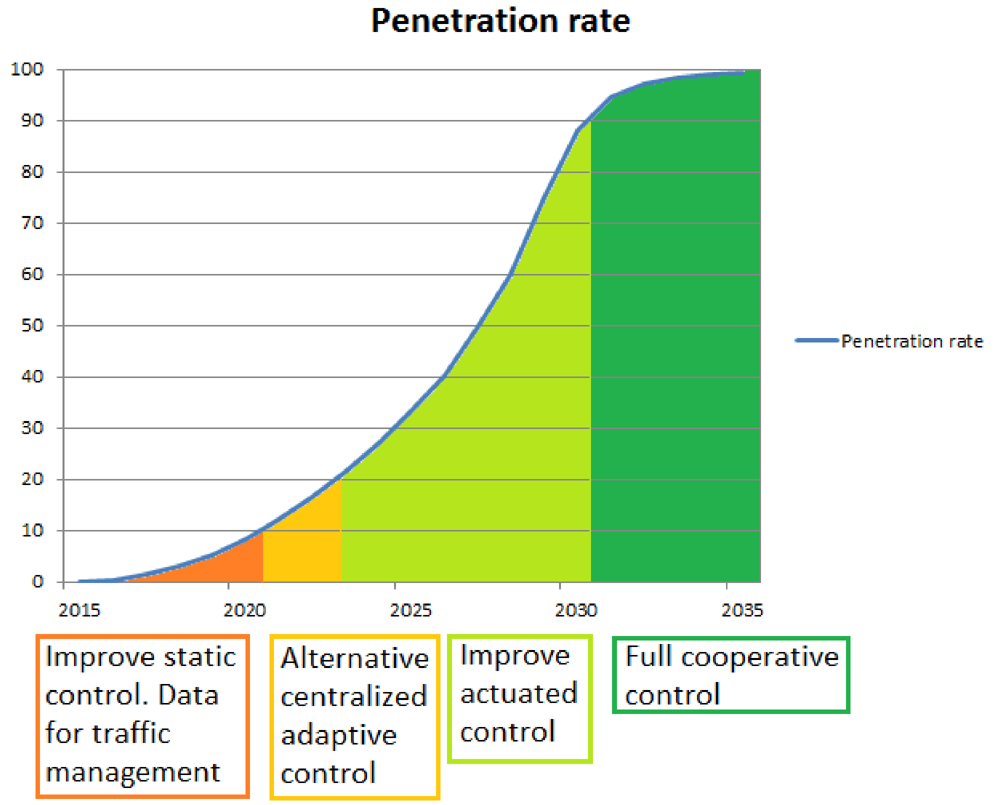

Figure 6: Expected penetration rate

Work on the evaluation of the solution is still ongoing and will only finish at the end of the project. Therefore, all penetration rate requirements are based on the results of simple simulations carried out on synthetic scenarios. The first area under the graph starts in 2015 already. This is improvement over static control and comes in two varieties. The first is with connected navigation system data, which is already possible. The second uses the complete COLOMBO solution, but would need at least 5% penetration rate to have a stable performance. From 10% penetration rate, estimated in 2021, the performance of the total COLOMBO solution should be at least equal to older centralized adaptive control systems like SCOOT and SCATS. From 20% penetration, estimated in 2024, there should be enough data to get acceptable queue estimations to improve existing actuated controllers to perform similar to modern traffic adaptive controllers like Utopia and Imflow. However, this still requires stop line detection. From 30% existing adaptive controllers can also be improved thanks to enhanced measurements of the turning ratios. Lastly, from 90% penetration, which is expected to be reached around 2031, the performance of the cooperative control should be enough to replace an entire detection field. However, up to full 100% penetration the addition of stop line detection will still improve the overall system as it will not be possible to skip green phases without traffic when there may be a non-cooperative vehicle waiting.

When looking from a detector replacement perspective it can be concluded that strategic count points can be replaced from 0-20% penetration, from 20-90% entry detection for queue modelling can be replaced, and afterwards the stop line detection can be replaced.

Since improvements to static control can already be realized with the current fleet of connected navigation systems, the main bottleneck for market entry is the technology readiness level. The research phase has almost been finalized, but more research and validation is still required to get willingness from company management to invest in development of a market-ready system. Therefore, the best way to proceed is a new research project with an FOT in the end phase of the project.

5 Exploitation

This chapter provides an overview of aspects related to exploitation of COLOMBO results.

The different project results of COLOMBO yield different business cases which are:

1. Commercial launch of a cost efficient traffic state estimation solution based on floating car probe vehicle data (FCD)
2. Commercial launch of a cost efficient traffic state detector based on the hybrid approach comprising Bluetooth (Class B) and V2I detection and data fusion
3. Commercial launch of a cost efficient V2X based traffic controller based on low penetration cooperative traffic state estimation combined with the self-organising control (SWARM) algorithms.
4. Generation of commercial consulting project revenues for the use of SUMO with PHEMlight for simulating of emissions and the possible impact of traffic management measures on emissions.
5. Generation of commercial consulting project revenues for analyzing the possible improvement of traffic flow in bottleneck situations of traffic flow by advanced traffic light control algorithms using the COLOMBO evaluation tool.

The following sections highlight the business cases in more detail.

5.1 Target Market

For the business cases 1, 2, and 3 the main market for the short term horizon will be the improvement of existing fixed time controllers and as a competitor in so called “green fields”. Green fields are new intersections in which no detection or traffic lights are present yet and therefore the COLOMBO system has a major advantage in not requiring investment in detection. Similarly, existing fixed time control can be upgraded with less investment than upgrading to vehicle actuated control. To replace existing vehicle actuated control, the performance of the novel COLOMBO solutions need to

- either perform significantly better, which is not foreseen to happen with low penetration rates,
- or deliver a performance in the same order of magnitude for significantly lower acquisition or maintenance cost respectively.

Moreover, there needs to be considered that especially larger cities prefer more centralized solutions that allow to manage their entire traffic network in one environment. The amount of operator intervention varies, some cities prefer to have the possibility of full manual control over all parameters when needed, while others prefer to keep maintenance as low as possible and want a fully automated solution to which they don’t need to pay any attention. The COLOMBO SWARM algorithm is strong in the latter, but through software a manual override can always be integrated and integration in a city wide network management system should also be possible.

We think that business cases 1, 2, and 3 can be successful in developing countries and countries with large urban growth. These countries have either many new intersections without existing detection investments or static controllers that can be upgraded with little cost. From 2021 countries with existing SCOOT and SCATS systems can be targeted with the SWARM system for new intersections and gradually also for replacement of existing systems as V2X penetration raises. We suggest that after 2024 all countries worldwide can be targeted with the SWARM solution to improve actuated control both in new and existing intersections. Gradually also existing modern adaptive systems can be enhanced with COLOMBO data and finally, when close to 100% penetration has been achieved, all controllers can be replaced. It should be noted that by now less than 5% of all controllers are modern adaptive controllers. So despite the long required time to reach such a high penetration, the low penetration requirements for other COLOMBO solutions can still cover at least 95% of the market by 2024.

Based on these considerations we assume market potential of 200 installations per year in the Netherlands and 1000 installations per year worldwide. We estimate maximum sales numbers of 1,000 units per year with a 10 year ramp up phase.

5.2 Traffic State Estimation based on Probe Vehicle Data

This business case comprehends the estimation of the traffic state for traffic control based on floating car data as described in COLOMBO deliverable 1.2, section 4.4 and more comprehensively in [[12]]. The idea here is to deduce the traffic state and especially queue lengths from probe vehicle trajectories that are being collected online by a navigation system provider. The floating car data is collected and distributed to the traffic light controllers by software. The software is running on a central server. The quality of the traffic state data would allow delivering traffic control performance higher than fixed time control but lower than with inductive loop data at significantly lower cost. The benefit for the user is visible when comparing running and installation cost:

- an equipped 4 arm intersection would require an installation cost of 12,000 € and running cost of 1,700€ per year (See COLOMBO D1.2)
- the probe vehicle data solution could be marketed for an initial cost of 1,000€ and a running cost of 100€ per year

Since the probe vehicle data solution is much highly efficient in terms of installation and maintenance cost, a higher (compared with ~40% sector average) gross margin of 66% can be assumed in this business case. We further assume an operating margin of 33% for the same reason.

Table 3: Estimated profit from probe vehicle data traffic state estimation

Year	Sales number (worldwide)	Cumulated sales number	Revenue from installations	Revenue from maintenance	Profit
1	10	10	10.000 €	1.000 €	3.630 €
2	100	110	100.000 €	11.000 €	36.630 €
3	200	310	200.000 €	31.000 €	76.230 €
4	300	610	300.000 €	61.000 €	119.130 €
5	400	1010	400.000 €	101.000 €	165.330 €
6	500	1510	500.000 €	151.000 €	214.830 €
7	600	2110	600.000 €	211.000 €	267.630 €
8	700	2810	700.000 €	281.000 €	323.730 €
9	800	3610	800.000 €	361.000 €	383.130 €
10	900	4510	900.000 €	451.000 €	445.830 €
11	1000	5510	1.000.000 €	551.000 €	511.830 €
12	1000	6510	1.000.000 €	651.000 €	544.830 €
13	1000	7510	1.000.000 €	751.000 €	577.830 €
14	1000	8510	1.000.000 €	851.000 €	610.830 €
15	1000	9510	1.000.000 €	951.000 €	643.830 €

The development of a market ready solution would require a fixed cost development budget of estimated 200.000€ to bring the solution to TRL 9. Table 3 illustrates that the business case is attractive, reaching break even after 4 years if the expected sales numbers hold. However, we see the risk that the market does not accept the solution. The outlook to secure a financing for a related product development project is not yet clear.

5.3 Traffic State Estimation based on Fusion of Bluetooth and V2I Data

The estimation of traffic state using Class B vehicle information could deliver traffic state information needed by traffic light controllers for lower acquisition and maintenance cost than state of the art inductive loop detectors. A cost estimation made within COLOMBO gives a potential for cost reduction by 75% in a Green Field or induction loop replacement scenario.

Class B Vehicle based traffic state estimation comprehends introducing a new type of road side unit to the transport systems technology market. The new RSU is detecting the unique network IDs of mobile devices that are equipped with Bluetooth and/or Wi-Fi, processing the data and delivering estimated vehicle counts and/or vehicle speeds to the traffic controller. The benefit for the user is explained at hand of comparing running and installation cost:

- an equipped 4 arm intersection would require an installation cost of 12,000€ running cost of 1,700€ per year (See COLOMBO D1.2)
- the probe vehicle data solution could be marketed for an initial cost of 6,000€ and a running cost of 400€ per year

The estimated cost for bringing the solution to TRL 9 is 300.000 €. The development comprehends extending an existing V2X RSU with a Bluetooth detection device and integrating the software into that existing solution. An established company providing RSUs on the transportation systems market would be contracted as a manufacturer of the hardware with a special firmware. The gross margin for this type of business is assumed to be 40%. We further assume here an operating margin of 10% because of expenses for mounting hardware in the field.

Table 4: Estimated profit from Bluetooth and V2X sensor fusion traffic state estimation

Year	Sales number (worldwide)	Cumulated sales number	Revenue from installations	Revenue from maintenance	Profit
1	10	10	60.000 €	4.000 €	6.400 €
2	100	110	600.000 €	44.000 €	64.400 €
3	200	310	1.200.000 €	124.000 €	132.400 €
4	300	610	1.800.000 €	244.000 €	204.400 €
5	400	1010	2.400.000 €	404.000 €	280.400 €
6	500	1510	3.000.000 €	604.000 €	360.400 €
7	600	2110	3.600.000 €	844.000 €	444.400 €
8	700	2810	4.200.000 €	1.124.000 €	532.400 €
9	800	3610	4.800.000 €	1.444.000 €	624.400 €
10	900	4510	5.400.000 €	1.804.000 €	720.400 €
11	1000	5510	6.000.000 €	2.204.000 €	820.400 €
12	1000	6510	6.000.000 €	2.604.000 €	860.400 €
13	1000	7510	6.000.000 €	3.004.000 €	900.400 €
14	1000	8510	6.000.000 €	3.404.000 €	940.400 €
15	1000	9510	6.000.000 €	3.804.000 €	980.400 €

Table 4 illustrates that the business case is attractive, reaching break even after 3 years if the expected sales numbers hold. Again, we see the risk that the market does not accept the solution. An additional risk is that the market penetration with V2X is less than expected. The outlook to secure a financing for a related product development project is not yet clear.

5.4 SWARM Traffic Light Controller

This business case is an overall system containing low penetration cooperative traffic state assessment combined with the self-organising traffic control. The main advantage of the solution is less installation costs: no sensors are required, only an RSU will be sufficient. Additionally, the system should be self-organising and therefore require little effort to configure. Parameters like safety timing and intersection layout still need to be configured. Contemporary traffic controllers, on the other hand, need many extra parameters like detector location and function, stage planning, signal group timing and possibly network coordination parameters.

The SWARM traffic light controller is a new electronic control unit which works solely on the basis of Car2I data collected by a RSU. The benefit for the user is running and installation cost for detection (we assume the traffic light controller hardware for SWARM is the same as for conventional control, only new SWARM control software needs to be installed):

- an equipped 4 arm intersection would require an installation cost of €12,000 and running costs of €1,700 per year (See COLOMBO D1.2)
- The standard road side unit can be marketed for an initial cost of 5,500€ and a running cost of €350 per year (See COLOMBO D1.2)

The estimated cost for bringing the solution to TRL 9 is 500.000 €. The development comprehends porting of the software to an embedded platform and software qualification. The gross margin for the business of selling the turnkey solution inclusive controller and RSU is assumed to be 40%. We again assume an operating margin of 10% because of the expenses for mounting hardware in the field.

Table 5: Estimated profit from SWARM traffic control

Year	Sales number (worldwide)	Cumulated sales number	Revenue from installations	Revenue from maintenance	Profit
1	10	10	260.000 €	4.000 €	26.400 €
2	100	110	2.600.000 €	44.000 €	264.400 €
3	200	310	5.200.000 €	124.000 €	532.400 €
4	300	610	7.800.000 €	244.000 €	804.400 €
5	400	1010	10.400.000 €	404.000 €	1.080.400 €
6	500	1510	13.000.000 €	604.000 €	1.360.400 €
7	600	2110	15.600.000 €	844.000 €	1.644.400 €
8	700	2810	18.200.000 €	1.124.000 €	1.932.400 €
9	800	3610	20.800.000 €	1.444.000 €	2.224.400 €
10	900	4510	23.400.000 €	1.804.000 €	2.520.400 €
11	1000	5510	26.000.000 €	2.204.000 €	2.820.400 €
12	1000	6510	26.000.000 €	2.604.000 €	2.860.400 €
13	1000	7510	26.000.000 €	3.004.000 €	2.900.400 €
14	1000	8510	26.000.000 €	3.404.000 €	2.940.400 €
15	1000	9510	26.000.000 €	3.804.000 €	2.980.400 €

Table 5 illustrates that the business case is profitable and break even can be reached within 3 years if the expected sales numbers hold. However, the highest risk is that the market penetration with V2X is less than expected. The outlook to secure a financing for a related product development project is weak, because V2X penetration is less than expected in 2015.

5.5 Emission and Flow Assessment Consulting

In the course of the project, the COLOMBO partners have gained expertise in testing new traffic light control algorithms in a given real world environment. This expertise can be used for providing consulting services to public authorities willing to assess the impact of more efficient ways of traffic control in terms of level of service and emissions. Reference studies were conducted within COLOMBO for the cities of Bologna, Monza and Helmond. It is difficult to see the market volume at this moment, therefore more detailed information on this business case cannot yet be given.

The project partners discussed a commercial perspective for the evaluation tool. In their point of view, the willingness-to-pay for a generic add-on tool license would be about €500. Transforming the current tool into such a generic one would be a major development effort of over 500 hours. Assuming the cost per development hour at €50 and the optimistic estimation of 25 licenses sold per year, the investment cost of €25.000 require two years of revenue at €12.500 p.a..

An option for the evaluation tool is to release it open source as part of the educational toolkit. This way, parts of the code can be reused for specific applications and as it increases the ease of use of the total SUMO solution it should help growing the SUMO community. For now technology readiness level is at 3, the tool has been used for a few specific COLOMBO publications only and will be used further in WP5. Release with the educational toolkit requires some adjustments to the code to increase user friendliness, but would increase TRL to 9. Any of the partners could provide consulting services for deployment or case specific adaptation of the evaluation tool to different customers.

6 Stakeholder Benefits

This chapter discusses the exploitation potential of the COLOMBO results from the perspectives of the identified stakeholders beside the involved project partners.

6.1 Public authorities and road operators

The total COLOMBO solution will give governments the option of buying a less expensive cooperative traffic control system. This is not only the initial investment, but also the maintenance. Apart from the signal heads only an RSU is required as opposed to traditional detection. Often sensor installation and maintenance requires temporal road closure, which is something road operators try to avoid. The self-organising nature of the system also saves on software maintenance. When traffic demand changes, the system automatically adapts to it and no configuration update is required.

When compared to static traffic control, there is slightly more investment cost, but the increased performance should weigh up to this. Additionally, when traffic demands change a static controller's performance deteriorates quickly and requires reconfiguring. Therefore, depending on the dynamics of the traffic over time, the yearly costs of the COLOMBO system may actually be lower because no reconfiguring is necessary.

6.2 Road users and inhabitants

For road users the effects of COLOMBO's TLC on the traffic flow will result in lower travel time, and for inhabitants in lower pollutant immission levels. This counts especially in the scenarios where it is used as an upgrade. This can be for example an existing fixed time controller or, when a higher penetration rate is achieved, an upgrade for a vehicle actuated controller.

A less straightforward advantage for road users is their detectability when approaching a COLOMBO traffic light. For non-equipped vehicles this is based on average travel times of equipped vehicles that passed before them and may be surrounding them. For an equipped vehicle this is different. When it arrives in a queue which is longer than the controller expects based on what the average of previous cycles, then the location where the vehicle stopped immediately gives away the queue length and the traffic controller can adapt to it. Therefore, equipped road users are expected to travel through the network faster and with lower fuel consumption. With sufficient intersections equipped with SWARM and/or GLOSA, this could give a reason to consumers to buy equipped vehicles, giving a boost to equipment rate.

6.3 Traffic engineers and consultants

For traffic engineers and consultants the benefits of COLOMBO mostly come from the simulation tools. The further development of the iCS over the state after the iTetris project enables usage for RSU planning. It can also be used for analyzing communication channel loads when checking if certain new cooperative applications would overload the available bandwidth.

For traffic simulation extensions to SUMO, especially the new pedestrian model and the addition of PHEM light, give extra possibilities to model and evaluate traffic systems. The COLOMBO system itself can also be investigated by traffic engineers and consultants, giving them an additional tool in their toolbox for traffic solutions. This does not necessarily have to be the complete solution, but parts can be used as well for instance for measurements or as detection trigger for a traffic management scenario.

The evaluation toolkit speeds up the use of SUMO for traffic control related simulations. Similarly, the educational toolkit will speed up the process of traffic engineers and consultants understanding how to use all tools released by COLOMBO and to discover all available features and possibilities.

A good example is the pre-commercial-procurement project CHARM, which is now using SUMO in their development phase. This project is a cooperation between different companies and the highway operator organizations of The Netherlands and the United Kingdom, which aims to create a platform for C-ITS spanning from the central level to individual RSUs and vehicles. The choice of using SUMO was for a large part based on extensions realized in COLOMBO: coupling of external traffic light controllers and detailed emission evaluations with PHEM were considered essential features for the central traffic modelling. These features are also present in commercial simulation models, but those lack the flexibility to interact with and make changes to the traffic in the simulator during runtime. The latter is essential for traffic management applications and therefore it is expected that more traffic management systems will operate with SUMO in the future.

6.4 Companies

The benefits for the industry are the same as for traffic engineers and consultants as the tasks carried out by them are also carried out in industrial companies in the traffic sector. However, on top of that the availability of COLOMBO adds a major application for cooperative systems. This can significantly boost the penetration of RSUs on the road and the amount of equipped vehicles. A major problem for the ITS industry is the cyclic problem of penetration rate. RSUs will not appear on the roads as long as there are no cooperative vehicles and the same the other way around: vehicles will not upgrade to cooperative technology if there are no applications and RSUs to interact with. COLOMBO can help solving this chicken-egg problem, by starting with the connected data, but giving extra service to equipped vehicles (implicitly just by detecting them better) boosting the penetration of vehicles.

6.5 Researchers

Researchers again have the same benefits as traffic engineers and consultants, but they have the additional benefit of the large share of open source software resulting from COLOMBO. This enables them to contribute to the software in ways that make their research possible.

7 Project partner perspectives

7.1 DLR

The COLOMBO project is led by the Traffic Management department of the Institute of Transportation Systems at the German Aerospace Center (DLR). Traffic management requires information about the state on the roads, and performs actions on different level to cope with a growing and changing demand. Given this, COLOMBO's major topics are exactly in-line with the department's topics. The work performed in COLOMBO covers different traffic management topics, extending DLR's scope. This did not only yield in a set of publications produced during the project's life cycle, but will probably in subsequent continued elaboration of such solutions that will be presented as publications as well. In accordance, the gained expertise will strengthen DLR's visibility in the field of traffic management, vehicular communication, and environmental issues, making the DLR an attractive partner for further research.

The developed traffic management and control solutions can be evaluated in the field at DLR's test sites in Berlin, Brunswick and Halle. National market-enabling funds may be used for this purpose.

While DLR itself will probably use PHEMlight in most cases, other parties may be interested in implementing their own models. This is in so far interesting for DLR as it continuous the basic applications of SUMO: the comparison of traffic models of different kind. The implementation of further models into SUMO can be offered as a commercial support action.
Courses where the usage of both the solutions developed in COLOMBO as well as the usage of the SUMO software can be offered.

7.2 UNIBO

UNIBO will exploit the results of the project in a number of ways.

- By producing publications in top tier conferences and journals in Europe and outside of Europe;
- By using the COLOMBO results as the base for further research (supported by an ever improving simulation environment). Although the COLOMBO will result in a fully operational system, there are still many improvements possible. Some examples are: integration with smart navigation systems using the information that are harvested from the monitoring system, more pervasive traffic alerts in case of traffic anomalies, decision making algorithms for selecting intersections to be controlled by using sophisticated optimization techniques;
- the possibility to attract funding on H2020 calls and also on national calls on traffic monitoring, and traffic control systems;
- knowledge gain, which can be exploited in new fields. Specifically knowledge acquired in developing the swarm based control system, its automatic algorithm configuration and tuning methods will be exploited also in other contexts. For instance applications similar to the traffic management are energy efficiency in servers and multi core applications, where self-organization could be potentially beneficial (resource allocation/scheduling) and simulation could play a fundamental role;
- potential new and enhanced relationships with public authorities managing the traffic network of Bologna and Emilia Romagna.

7.3 ULB

ULB considers exploitation of the project results in the following directions.

- Publications in high quality conferences and journals;
- the possibility of obtaining further funding in H2020 calls for research on automatic algorithm configuration and its application in challenging tasks;

- the possibility of attracting further funding and collaborations in the area of traffic management and engineering, where the gained expertise may be relevant;
- the development of further automatic configuration software that improves over the currently available one in terms of performance and user friendliness;
- possibility of the creation of a spinoff company the focuses on the exploitation of the gained experience in automatic algorithm configuration in the traffic engineering and other domains.

7.4 Imtech

Imtech can use several of the COLOMBO outputs, some almost immediately and some as opportunity in the long term.

7.4.1 Low penetration cooperative traffic state assessment

When the findings in COLOMBO are positive, the low penetration cooperative traffic state assessment is a direct candidate for implementation in at least one of Imtech's adaptive urban traffic control solutions (ImFlow). Combined with generic cooperative functionality it can be used to increase overall system performance and function as a tool to detect anomalies (e.g. a blockage, an excessive queue). With increasing penetration of cooperative vehicles it can be used to decrease system cost (initial as well as maintenance) by making (part of) the expensive existing detection field obsolete.

7.4.2 Self-organising traffic control

The maturity of the SWARM self-organising traffic control is as yet too low for turning into a commercial product. In a mature form, there is a positive outlook for marketing in cost-driven areas. Even in its current research stage, it is of value as traffic control algorithms are a core technology for Imtech.

Similarly the low penetration algorithm for fixed time improvements based on data from connected navigation systems is not yet mature enough to market. Large scale validation and research into the coupling with navigation system provider data has to be carried out in order to estimate the potential of the technology better.

7.4.3 SUMO

SUMO has proven to be a valuable environment for Imtech's control algorithm research. The additions to SUMO give more power to the platform and form an improved home ground for Imtech's research traffic controller and distributed network control systems.

7.5 TU Graz

For TU Graz also the possibility to improve the vehicle emission simulation methods on a scientifically founded basis is a main benefit of the project. Based on the systematic and well-founded research on this topic TU Graz has reached a high standard which is certainly also exploited in several activities

The simulation tool PHEM is available as commercial tool (see http://www.ivt.tugraz.at/). Due to the COLOMBO project, most recent vehicle and engine technologies are now included in the PHEM data base which makes the tool even more attractive.

The PHEMlight is a new product resulting from COLOMBO which has the chance to become a standard emission tool to be integrated in micro-scale traffic models (as PHEM is for EU emission factors). Exploitation is planned via licensing for the complete data set of vehicle and emission properties

The simulation tool NEMO (Network Emission Model) from TUG uses the detailed output from PHEM to compile emission factors for road network simulation. Consequently to the PHEM extensions in COLOMBO also NEMO data base was extended. NEMO is also a commercial software product at TUG which is used by several regions and municipalities.

With the base of proper models and the knowledge from related research TU Graz is active as consultant in the field of emission and air quality simulation. Customers are coming e.g. from industry, from municipalities, from ministries and from the European Commission (DG Enterprise, DG CLIMA). From these activities also a spin-off company was founded (FVT, Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH) which has in the meantime more than 40 employees.

7.6 EURECOM

EURECOM intends to release and maintain the extensions to iTETRIS and ns-3 as open source and increase the community around it. For instance, the virtual machine with the platform can be reused for education purposes, in particular for lab works in the Post Master program on Communications for ITS[7]. The platform and virtual machine is and will also be used as a reference platform in ETSI ITS and the CAR 2 CAR Communication Consortium.

By relying on the iTETRIS platform and the COLOMBO system for its publication work, it will increase references to the iTETRIS platform. EURECOM will further contribute and maintain the educational toolkit in order to ease the community penetration and increase the platform's popularity. A close collaboration between the original iTETRIS community will be maintained for coherent platform updates and support.

Finally, EURECOM will also use the iTETRIS platform and the COLOMBO system as input to attract further funding and collaboration in the area of intelligent traffic management and connected vehicle technology.

Also, EURECOM participates until the end of 2018 in the French National project SINETIC (Integrated Data System for Cooperative ITS), using and extending the COLOMBO version of iTETRIS and iCS as following:

1) Scalability test of system design: scalability test of C-ITS applications that have been already developed at short scale. The applications are addressing either safety (accident warning) or efficiency (fleet monitoring).
2) Remotely connecting an external simulator to iTETRIS by using a special iTETRIS application recoded to act as a 'hub': The external app does not see it is connected to the iCS, as it thinks it is directly connected either to ns3 or to SUMO. This is used when people do not want to 'recode' their algorithms according to the iTETRIS interface 'formalism', but still want to use the power of iTETRIS.

EURECOM collaborates with the Principality of Monaco on Smart Mobility aspects and will disseminate COLOMBO's results and dissemination materials to the COLOMBO urban planning office. Monaco has several inbound/outbound corridors creating congestions when reaching their urban intersection. EURECOM will propose to model one of these inbound/outbound corridors and evaluate COLOMBO's smart TLC w.r.t traffic mitigation.

[7] http://www.eurecom.fr/en/teaching/post-master-degree/intelligent-transport-systems

8 References

[1] eCoMove project, *Simulation results for validation and impact assessment*, Deliverable D5.10 (restricted), 2013.

[2] Konstantinos Katsaros, Ralf Kernchen, Mehrdad Dianati, David Rieck, *Performance study of a Green Light Optimized Speed Advisory (GLOSA) Application Using an Integrated Cooperative ITS Simulation Platform*, IEEE, 2011.

[3] Wolfgang H. Schulz, Isabella Geis, *Deployment strategies for cooperative driving including standards and business models*, Deliverable D11.5 (restricted), http://www.drive-c2x.eu/publications, 2014.

[4] E-FRAME project, *Consolidated User Needs for Cooperative Systems*, Deliverable D13 (public), http://www.frame-online.net, 2011.

[5] J.C. Mankins, *Technology Readiness Levels*, NASA white paper, 1995.

[6] NASA website, http://web.archive.org/web/20051206035043/http://as.nasa.gov/aboutus/trl-introduction.html, 2004.

[7] C.P. Graettinger, et al., *Using the Technology Readiness Levels Scale to Support Technology Management in the DoD's ATD/STO environments*, special report for U.S. army CECOM, 2004.

[8] sim^{TD} project, *TP5-Abschlussbericht – Teil B-4 Ökonomische Analyse*, Deliverable D5.5 (public), http://www.simtd.de/index.dhtml/object.media/deDE/8109/CS/-/backup_publications/Projektergebnisse/simTD-TP5-Abschlussbericht_Teil_B-4_Oekonomische_Analyse_V10.pdf, 2013.

[9] Car2Car Communication Consortium, *European vehicle manufacturers working hand in hand on deployment of cooperative Intelligent Transport Systems and Services (C-ITS)*, Press statement, http://www.car-to-car.org/index.php?id=20, 2012.

[10] NHTSA, *U.S. Department of Transportation Issues Advance Notice of Proposed Rulemaking to Begin Implementation of Vehicle-to-Vehicle Communications Technology*, press statement, http://www.nhtsa.gov/About+NHTSA/Press+Releases/2014/NHTSA-issues-advanced-notice-of-proposed-rulemaking-on-V2V-communications, 2014.

[11] Emily Pindilli, *Applications for the Environment: Real-Time Information Synthesis (AERIS) – Benefit-Cost Analysis*, webinar slides, U.S. DoT, 2012.

[12] Blokpoel, Robbin, and Siebe Turksma, *TRAFFIC CONTROL USING PROBE VEHICLE DATA*, 10th ITS European Congress, Helsinki, Finland, 16–19 June 2014.