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INTRALOG, intelligent autonomous truck applications in Logistics

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Abstract

INTRALOG is a project, started September 2015, in which Automated Guided Truck Applications will be developed. Automated systems typically perform the processes with less variability than human workers and can lead to better use of materials, thereby leading to improvements for People (better safety, lower physical work load), Planet (lower emissions and energy/fuel consumption) and Profit (more reliability, lower labor cost). It is the purpose of the INTRALOG project to investigate the PPP-value (People, Planet, Profit) of automated guided trucks (AGT's) when applied in real world logistics operation at distribution centers . The goal of INTRALOG is therefore: To prove and demonstrate that the logistic operations regarding People, Planet and Profit (PPP) is improved using AGT's, addressing (1) Stakeholder requirements and business strategies, (2) the logistics framework allowing AGT application, and (3) the AGT control design for automated docking.

This paper will address the business requirements and the logistic operations based a multi agent system approach for automated docking.

Keywords: Autonomous Guided Trucks, Logistic optimisation, Vehicle Control, Multi Agent Systems, business requirements AGVs

Introduction

The problem of autonomous driving in logistics is, despite of vision, the lack of knowledge; INTRALOG1 contributes to this knowledge deficit. According to the World Economic Forum, the Netherlands is the country of choice for European Distribution Centers: 57 percent of all American and Asian DC's on the European continent are located in the Netherlands (Holland.Trade, 2014). As a consequence of all this, the Netherlands have become one of the leading road transport nations in Europe. In addition to the sheer large volume, this is caused by taking aspects like sustainability, effectiveness, cost and innovation into consideration. Megatrends like Globalization and increasing worldwide economic integration, Technology – above all the growing speed of technological development and Climate change all have a major influence on today's developments in mobility (B.

1 INTRALOG - **In**telligent **Tr**uck **A**pplications in **Log**istics

Schwenker, 2013).

The increasing use of information systems in logistics has increased operations efficiency dramatically and the use of IT in logistics is still increasing rapidly. A very appealing new development is related to the transportation trucks themselves: autonomous driving. The potential of this technology is recognized by politicians and by the transportation sector, motivated by the business potential. Autonomous driving will reduce cost, fuel consumption and CO_2 emission (air drag reduction by close distance driving, efficient traffic routing) and safety (crash avoidance). In order to make various autonomous driving functions available, research and development has to be carried out in various disciplines: truck design (braking and steering), IT (software reliability, fail safe, standardization), legislation (liability), science (trajectory planning, vehicle dynamics modeling and control), social science (taking care of drivers' interests), logistics (integrate new features in logistic operation, allowing automated vehicle use) and business (earn money with new and advanced possibilities).

INTRALOG was funded[2] to establish significant contributions to the opportunities for society and the private sector of autonomous driving in the commercial transport sector. By making use of the expertise at knowledge institutes in the fields of logistics, automotive engineering, vehicle dynamics modeling and control, human machine interfacing and rapid control prototyping, supplemented with the knowledge and experience of private partners within the field of logistics, INTRALOG works on making autonomous driving available to the transport sector, starting with auto-docking and aspects of automated inter-terminal/intermodal traffic.

This paper focuses on the

State of the ART

The use of automatic guided vehicles in industrial logistics and port automation has reached a mature level. Industrial logistics applications using wire-guided vehicles have been around since 1960. Since 1980, laser- and landmark-based navigation systems have been developed providing more flexibility to change routing of the vehicles (Egemin, 2016), (Frog, 2016). The first container terminal having AGVs was ECT in Rotterdam. In 1985, the first prototype container carrying vehicles appeared at the Maasvlakte in the Port of Rotterdam. Several companies have developed AGVs for port applications. All successfully installed and operational AGV systems for port logistics are running in a fenced and separated area.

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2 The research was supported by the Netherlands Organisation for Scientific Research (NWO) of the Ministry of Education, Culture and Science through the RAAK-PRO project: “INTRALOG - Intelligent Truck Applications in Logistics”. RAAK-PRO focusses on the enhancement of applied scientific research by Universities of Applied Sciences, in cooperation with the industry.

AGVs for public transportation are still in a research stage. There do exist a few operational systems for outdoor and indoor operation (e.g. Parkshuttle Capelle a/d IJssel (2GetThere, 2016), Masdar City (MI, 2016), Heathrow airport (ARUP, 2016)). The biggest challenge is the safety validation of the application. A preliminary safety case needs to be reviewed before on-site tests can be conducted to further collect data that is necessary to construct the safety case.

Automated reversing and docking of tractor-trailer combinations has been subject of research for a long time (Chiu, 2012). It did however not result in commercial applications due to various reasons, especially; manoeuvring (multiple) trailers using a (terminal) truck is complicated, especially when performing reverse movements that require turns. It has been subject to scientific research for the last three decades (A. Gonzalez-Cantos, 2001), (C. Altafani, 2002). However, the volume of goods transported as well as the number of commercial vehicles in Europe has increased substantially over the past decade (Kural K. B., 2012). As the Dutch experience reveals, the legalization of longer and heavier vehicles (LHV) on highways makes transportation of goods more efficient, sustainable and is applicable even in highly populated regions (Kural K. B., 2012). Thus an increasing number of double articulated vehicles are to be expected, which is confirmed by CBS data: (@CBS data).

Trajectory control of reversing (multi articulated) tractor-trailer combinations is usually based on geometric or kinematic models. Restrictions to steering actuator performance and also the inclusion of vehicle dynamics complicate the stability analysis. Scientific research regarding the stability and robustness of trajectory control under parameter uncertainty is limited. However, several experimental setups exist and in professional contexts developments have been started. Kural (2014) investigated the driver behaviour during reverse driving of a double articulated vehicle, related to directional stability of the vehicle. Eye tracking glasses enabled to detect the driver's gaze direction, which helps to understand the driver behavior during rearward driving (Kural K. B., 2014). The design of trajectory control is usually based on simplified models, mostly using kinematic and geometric models. Question is if these assumptions are fair. Therefore, the controlled system (reversing tractor-trailer and trajectory controller) should be verified and validated. The impact of various modelling assumptions needs to be assessed. This can be done using model-based techniques (MIL, SIL, HIL).

Goals of INTRALOG

The central research question of the INTRALOG project is:
To prove and demonstrate that the logistic operations regarding People, Planet and Profit (PPP) is improved using AGT's, addressing (1) Stakeholder requirements and business strategies, (2) the logistics framework allowing AGT application, and (3) the AGT control design, for two applications:

1. *Automated docking*
2. *Automated inter-terminal transport.*

The feasibility of these scenario's is demonstrated by physically implementing AGT's for the selected logistic operations on non-public roads, with their impact on PPP-related quantities derived, like energy consumption, emissions, total cost of operation, driver acceptance of the technology, increased use of trains and/or barges (intermodal transport), etc. In short: INTRALOG "proves by doing".
The next step is then to upscale the use of AGT's to more general logistic conditions, by using the business model and other models, derived and validated during the INTRALOG project.

The project INTRALOG consists of two main parts:

Part A: Determination and validation of operation related requirements on the AGT's in the logistics operation

Part B: Technical realization of AGT's with advanced capabilities, dedicated to the specific logistic operation at hand

Part A addresses the business model and stakeholder requirements, as mentioned in the research question, and it includes the field trials for the assessment of the PPP-improvements. Part B is required in order to create the functionalities that allow part A to reach its goals. Examples of these advanced capabilities are:

- Automated docking should be possible for trailers. This requires precise and stable control of the AGT at low speeds over a longer distance, for a large part in rearward direction.
- During such reversing, the entire combination needs to be kept controllable and stable, in order to prevent jack-knifing. In other words, a potentially unstable combination (under rearward driving) needs to be guided towards a final position (docking) with high precision in terms of position, orientation and speed.
- This manoeuvring needs to take place under all possible external conditions, like adverse weather and therefore road conditions (rain, snow), road shape (slopes, friction).
- AGT's are not the same. Control strategies need to accommodate differences in trailers, weight distributions of the vehicles, performance change due to wear, etc.

Consortium and ambitions

The INTRALOG consortium consists of the following partners (see Figure 1 - INTRALOG consortium):

1. Business: DAF (OEM), Port of Rotterdam, ROTRA (Logistics Party) and TERBERG (OEM),
2. Scientific Knowledge Centers: Technical University of Eindhoven and University of Twente,
3. Applied Knowledge Centers: Rotterdam University of Applied Science (HR), HAN University of Applied (HAN)
4. Branch Partners: Carrossie NL & ACE (Automotive Centre of Expertise, including HAN and HR**)**

The interest of the truck suppliers (DAF, Terberg) lies in the increase of knowledge on both the end user applications and the technical implications for the design of their trucks in hard- and software. The end user companies (Rotra, Port of Rotterdam) want to have a clear picture of the benefits of the application of the AGT's by business modelling and validation.
The knowledge partners (UT, TU/e, HAN, HR) want to strengthen their knowledge position in the field, to acquire hands-on experience with AGT's and, to profit from knowledge exchange within the project network**.**

Project setup

The project is setup according to the following components (Figure 2 - INTRALOG project set up):

1. Business models and stakeholder requirements
2. Logistic model design
3. Vehicle controller design
4. Testing of models and controllers
5. Real life testing

AD1 Business models and stakeholder requirements

Key to the success of the INTRALOG project is a stakeholder analysis as part of the requirements engineering, business modelling process and the project information coordination process. This analysis is currently being done using stakeholder mapping, guiding the urgency of information supply, and a stakeholder information matrix, which guides the flow of information and data. The requirements obtained from the stakeholders must be translated into system requirements, like the admissible velocity range on site, available physical envelope of the vehicle for manoeuvring, accuracy of positioning for docking, etc.

For the assessment with respect to the PPP aspects we use the following methods:
People: By using interviews we assess the effects (acceptance, experience, workload, safely experience, job satisfaction, etc.) on all stakeholders (drivers, warehouse personnel, management, regulating bodies, etc.) of the introduction of AGT's.
Planet: Using a Chain analysis, including a well to wheel analysis we will assess the carbon footprint, the energy consumption and the effect on operation emissions of the AGT's.
Profit: The assessment of the Total Cost of Operation will give a clear insight in the impact that AGT's have on the profitability of the operation. The effect AGT's will have on shifting from road to rail and/or barge (intermodal) transport will also result from the chain analysis.

AD2 Logistic model design comprising all relevant parts of the AGT operation and interaction with its environment.

The routing of AGT's within the operational area is of major importance with respect to the productivity and efficiency. INTRALOG will translate the system requirements into the operational requirements and focuses on the definition of a stable and robust planning and control system. In recent years, agent technology has proven to be a successful means in realizing such a system. A multi-agent system (MAS) is particularly suited to guarantee collision-free routing of multiple automated guided vehicles at low transportation speed. A key issue being solved in the project is how to configure agents such that their self-interested behaviour yields a near-optimal solution for the network as a whole. As a part of INTRALOG the framework of vehicular communication systems, to communicate with other vehicles (V2V) and between vehicles and infrastructure (V2I) will be investigated.

AD3 Vehicle controller model design and controller implementation
INTRALOG incorporates the definition of a model-based framework for design, verification and validation that will be used for developing the AGT controller. The requirements, originate from the logistic model design and business model. Knowing the trajectory of the vehicle, the driver inputs (steering and the velocity) should be controlled autonomously or the driver supported such that the difference between the reference and reality is kept minimal.

AD4 A test environment for the models, controllers and subsystems.
For higher level verification of the models, controllers and subsystems within INTRALOG simulation software will be used to assess the proper performance of both hard- and software. This simulation software emulates the behaviour of the AGT and its components and subsystems. The models focus on those aspects that are deemed most relevant for the AGV operation, like the weight distribution (which may obviously vary), the tire properties, the capabilities of the steering and driving system, but also the trajectory the AGT has to follow. Various techniques are available, which are used for testing controller hard-and software in different development stages.

AD5 Real-life test environment(s) for validating the initial business model and asses PPP performance.
Within INTRALOG the AGT's are tested in a real life application on-site in cooperation with the business partners. Applications are: automated AGT docking and automated inter-terminal transport. The performance of the AGT's will be assessed on all aspects expressed during the requirements engineering phase.

Business models and stakeholder requirements

Within INTRALOG business models and stakeholder requirements are elaborated for main stream transportation, such as in the Port of Rotterdam and the hinterland, such as ROTRA intermodal distribution centre at Doesburg (NL) and Velp (NL) (Gerrits, 2016). In both cases the feasibility study is the achievement of autonomous and sustainable (container) transport in 2020. The first case elaborated in INTRALOG is the Port of Rotterdam (PoR).

The stakeholder requirements originate from a large number and variety of industries and the whole ecosystem is taken into account in present and future transport, e.g. handling of containers. The Port Vision 2030 (PoR, 2016) describes different scenarios on future development of the port and policy. In view of the constant change and unpredictability of developments in the environment this vision is now considered as a guideline rather than a defined plan. Actions are now being taken in line with current developments. The PoR considers autonomous driving as one of the main issues to improve the competitive position. In line with the Rotterdam Climate Initiative (RCI, 2016) the PoR pursues a number of environmental objectives, which includes the pursuit of zero-emission in transport in the Harbour Industrial Cluster (HIC). Next to a number of measures to improve congestion the PoR has planned a Central Exchange Route (CER) for container exchange between Maasvlakte 1 (MV1) and 2 (MV2). This CER will be a closed route and is planned to be operational in 2019 and open to minimal EURO VI vehicles only. Therefore the CER would ideally be suited for zero emission autonomous driving. The PoR, CER leading stakeholder considers to leave the transport and billing to a third party. This is a totally different set up compared with the public road.

However autonomous driving, even though considered to be feasible and realistic after 2020 by PoR and the industries present, is not general accepted. The labour union FNV forced the use of manually operated Multi Trailer Systems (MTS) for the CER, leaving autonomous driving possible at the inland terminals and DCs.

Autonomous driving is high on the agenda of Ministry of Infrastructure and Environment (NL-U, 2016). Recently important steps have been taken in the legalisation of autonomous driving, resulting in the Declaration of Amsterdam, a result of developments in the automotive, ICT and telecoms sectors. The introduction of connected and automated vehicles[3] (see Figure 5 - Mobility will change more in the next twenty years than in the past one hundred years) (NL-U, 2016) opens opportunities for initiatives, such as INTRALOG. However: “0% risk and completely safe”, though an obvious requirement, is a must have for the local authorities, being in charge for public infrastructure in their area. Though developments in autonomous technologies are not yet mature and blur their scope on

[3] Connected includes cooperative driving: communication between vehicles and also with the infrastructure (C-ITS). Automated driving refers to the capability of a vehicle to operate and manoeuvre independently in real traffic situations, using on-board sensors, cameras, associated software, and maps in order to detect its surroundings. In the medium to long-term, automated driving functions will be expanded with the help of connectivity. Automated includes highly-automated and the development towards driverless vehicles (NL-U, 2016).

infrastructural developments.

Discussion with INTRALOG consortium partners showed different business model requirements for a variety of usage cases (see Table 1 Business model – transport requirements). In addition to this, they require for transport after the (private) terminal :

- 24/7 availability under all conditions, even in case of emergencies
- Smooth transport flow and efficient handling process.
- Acceptable cost
- Automatic data exchange plus easy tracing of the whereabouts of the containers.

Concluding: up time and efficiency (i.e. speed and price) are their main concerns!

Distribution Centres and Logistic Service Companies are cost oriented and they focus on auto docking rather. For auto docking they want above all the technical adjustments to the dock, then on tractor or terminal tractor, not the trailer. Their staff considers shunting in the open air as lonely and monotonous work. Especially during night shifts. Staff are generally positive towards new working methods and further automation.

Carriers, the transport companies, await and hold on to developments at tractor manufacturers. They see LNG as the most suitable fuel for many years to reduce emissions.

In order the research the feasibility of the criteria Equipment manufacturers are also interviewed. Parties like suppliers of terminal Tractors, AGVs, tractor manufacturers, trailer manufacturers, Energy suppliers and network companies. Tractor manufacturers are mainly focused on platooning and not on short distance transport. Manufacturers of terminal tractors might be well positioned to take the lead in the new AGV development.

Logistic model design comprising all relevant parts of the AGT operation and interaction with its environment

A multi-agent system (MAS) is particularly suited to guarantee collision-free routing of multiple automated guided vehicles at low transportation speed. A key issue being solved in the INTRALOG project is how to configure agents such that their self-interested behaviour yields a near-optimal solution for the network as a whole. The concept of Multi-Agent Systems (MASs) is not new (Gerrits, 2016). Literature about MASs have been around since the mid-1990s and have in the recent years gained popularity in scientific research as well as in the industry. Wooldridge (2009) mentions five important trends in the history of computing:

- Ubiquity
- Interconnection

- Intelligence
- Delegation
- Human-orientation

Ubiquity is nowadays still a continuing trend and means the constant increase of computing power against lowering costs. This has led to increased processing power in many applications and devices which would have been unimaginable or uneconomic in the past. This omnipresence of technology and smart devices has transitioned our society and businesses from closed and ill-informed to open and well-informed.

The *interconnection* of technology has led to large, complex distributed systems which typically are more powerful than closed, stand-alone systems. For example, smartphones enable us to share and process information at anytime, anywhere with anyone across the globe. But also business delegate their processing power across the globe using high-speed connections to solve large-scale problems which simply would not be possible to solve alone.

Increasing *intelligence* of all systems also provides new opportunities for many people and businesses. For example, navigation systems are able to pro-actively alter current routes to find faster routes to the users destination based on current traffic information or road closures. This proactiveness makes systems more intelligent than solely active or reactive systems.

Another important trend is the continuing *delegation* of control to software systems. Nowadays we trust software to perform better than humans in certain safety-critical tasks. Take for example an automatic pilot on an aircraft or all advanced electronics in passenger cars to assists us or take control of our driving (e.g. adaptive cruise-control).

The final trend is the *human-oriented* view of programming and software. Increasingly software systems are user-oriented with user-friendly Guided User Interfaces (GUIs) and real-time interaction with the user. A good example is Google's "OK Google" or Apple's "Siri" which processes voice input and displays information based on the user' input using intelligent algorithms to determine *what* the user is saying and what the user is *trying to say*.

These five trends pose challenges to software developers as systems become more and more intelligent, interconnected and need to act on behalf of the user. To resolve these problems, the field of multi-agent systems has emerged.

Definition and characteristics

The concept of multi-agent systems is relatively easy to grasp. The main idea is that an agent is a computer system which can act *autonomously* on behalf of its user to reach its design objectives. This means an agent can determine its own course of action instead of following pre-determined executable code. A multi-agent system has multiple agents, most likely different types of agents, with different kind of goals and objectives, that are able to interact with each other, typically using certain protocols or messing passing within a computer system. In order to interact, agents must be able to cooperate, coordinate and negotiate with each other, similarly to our everyday lives (Wooldridge, 2009).

Although there exist different kinds of definitions of agents, where the lowest common denominator would be “proactive objects” (Parunak, 1998), the most commonly adapted definition throughout the literature is the following:

“An agent is a computer system that is *situated* in some *environment* and that is capable of *autonomous action* in this environment in order to meet its design objectives.” (Wooldridge, 2009)

From this definition the following characteristics can be derived (Farahvash & Boucher, 2004), (Padgham & Winikoff, 2005)

- *Situated*: Agents are situated in an environment which is most often dynamic, unpredictable and unreliable.
- *Autonomous*: Agents can work independently of other agents as well as without interference of human intelligence.
- *Interactive*: Agents affect other agents or may be affected by other agents. Communication and interaction is key in the design of a MAS.
- *Intelligent*: Some level of intelligence must be present in an agent to guide decision-making in order to fulfill its design objectives in an efficient and effective way.
- *Flexible*: Agent systems should consider different environmental states and configurations and act properly to different situations.
- *Proactive:* Agents should continue to pursue their goal(s) over time and these goals are persistent.
- *Robust:* An agent must be able to overcome failure by continuing to achieve a goal despite of previous failed attempts.

For our case study at Royal Rotra we focus on the design of a multi-agent system for the planning and control of autonomous vehicles for the automatic handling of semi-trailers at a cross-dock including rearward docking. Within this case study the agents are *situated* at the stackyard area of a distribution center where semi-trailers arrive and depart and have to be loaded and unloaded. The shunting of these semi-trailers is done *autonomously* by automatic yard tractors (YTs) and the MAS *interacts* with these YTs (which are also agents) to optimally dispatch shunting jobs. The *intelligence* within the MAS emerges from scheduling algorithms, nearest-available heuristics, shortest-path calculations and conflict resolutions. The latter makes sure the environment is collision and conflict free, providing a *flexible* environment for the YTs by avoiding deadlocks. Due to the dynamic nature of a cross-dock one of the agents (the Demand Manager) is responsible for feeding information on arrivals and departures to the MAS. This agent in particular exemplifies the *proactive* and *robust* characteristics of the MAS as it continuously searches for new jobs and maintains connections with external databases.

MAS as mid-level control

The MAS different control levels (see Figure 3 - MAS within the different hierarchal levels of control at a DC), illustrates how our MAS fits within the different hierarchal levels of control at a DC. For brevity of writing we do not delineate the design of the MAS and present the agents *as is* with a single descriptor (Gerrits, 2016).

Observe that jobs are dispatched from the planning system of Royal Rotra to MAS through the Demand Manager. Within the MAS the jobs (i.e., arriving or departing semi-trailers) are assigned parking slots via the Parking Manager from which will be the pick-up location of the job. From here the Vehicle Scheduling agent interacts with the YT Managers and the Vehicle Routing agent to determine which YT is assigned to the job. Time- and location specification information of the job is send to the vehicle positioning controller which controls the YT in real-life. Various internal and external data sources are used to monitor the system which is in itself input to the MAS (e.g., via the Battery Manager and the Conflict Manager).

Planning

The project is expected to last 4 years (48 months; 31.09.2015 until 31.08.2019) and consists of two phases. The project planning is organized according to the V-Cycle (H. Mooz, 1991) product-development process,. In the first stage, design is established at different system levels. The second phase of the project includes validation, according to the validation design, being addressed in the first phase (e.g. DoE (L. Eriksson, 2008)). The global planning (see Figure 4 – Global planning aligned with the V-cycle design process) shows the alignment with the V-cycle

Conclusions

It is the goal of the INTRALOG project to investigate the added PPP-value (People, Planet, Profit) which automated guided trucks (AGT's) can add to logistics operation at distribution centres and inter-terminal/intermodal traffic hubs. This will be done in two steps:

i. To identify the potential with reference to the demand from the logistic environment

ii. To design, realize, test (field trials) and validate (against the PPP-demands of the end-users) feasible strategies for implementing automated guided trucks as part of advanced logistic scenarios.

INTRALOG contributes to the businesses opportunities of the consortium professionals and, at the same time, contributes to the knowledge build-up on autonomous driving for all the associated partners, in the full chain from knowledge providers, suppliers, industry, and end-users.

INTRALOG does focus on the adaptation of vehicle control to the logistic operation, leading to positive effects for all three PPP aspects.

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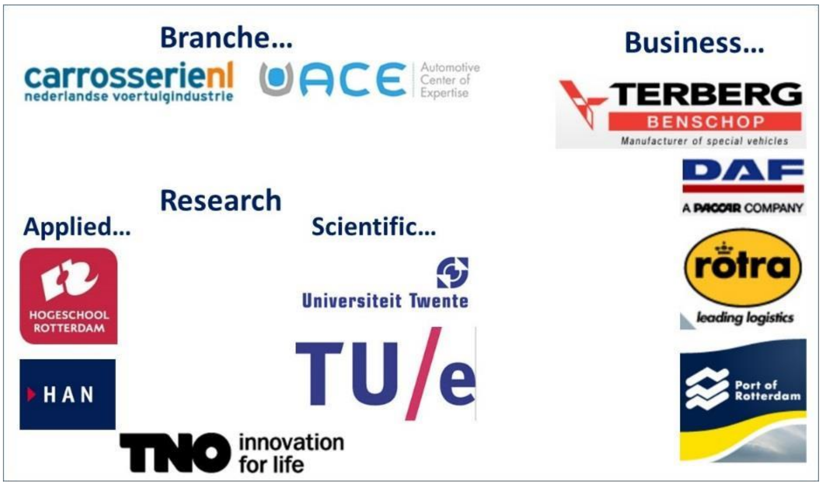

Figure 1 - INTRALOG consortium

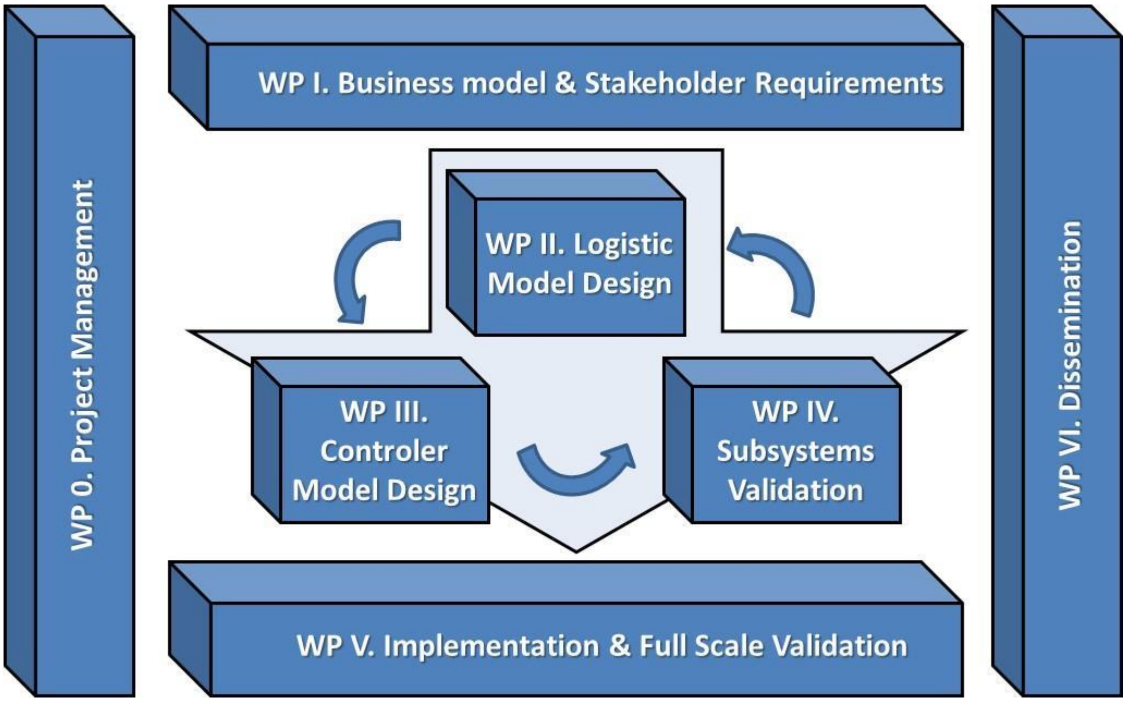

Figure 2 - INTRALOG project set up

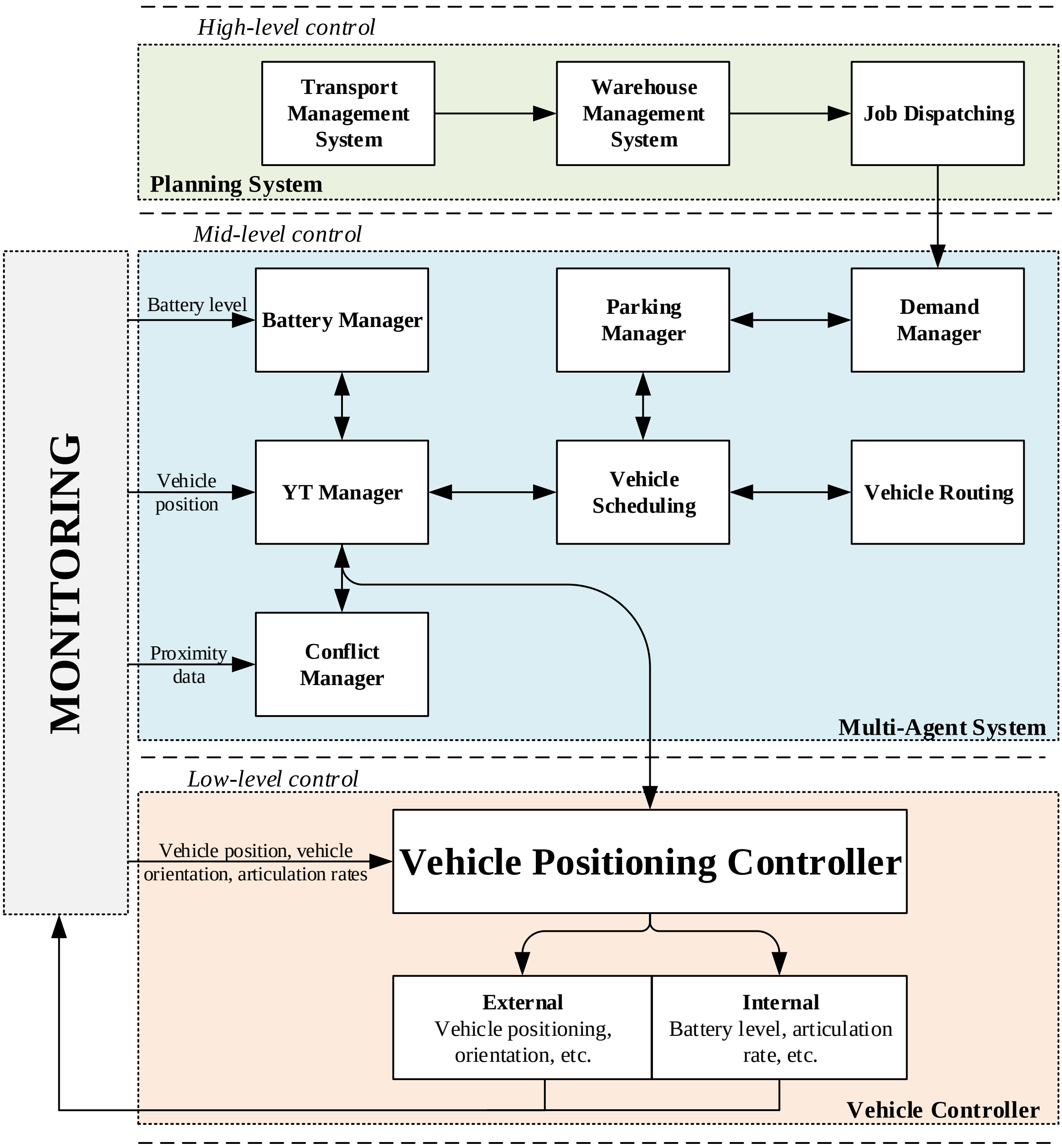

Figure 3 - MAS within the different hierarchal levels of control at a DC

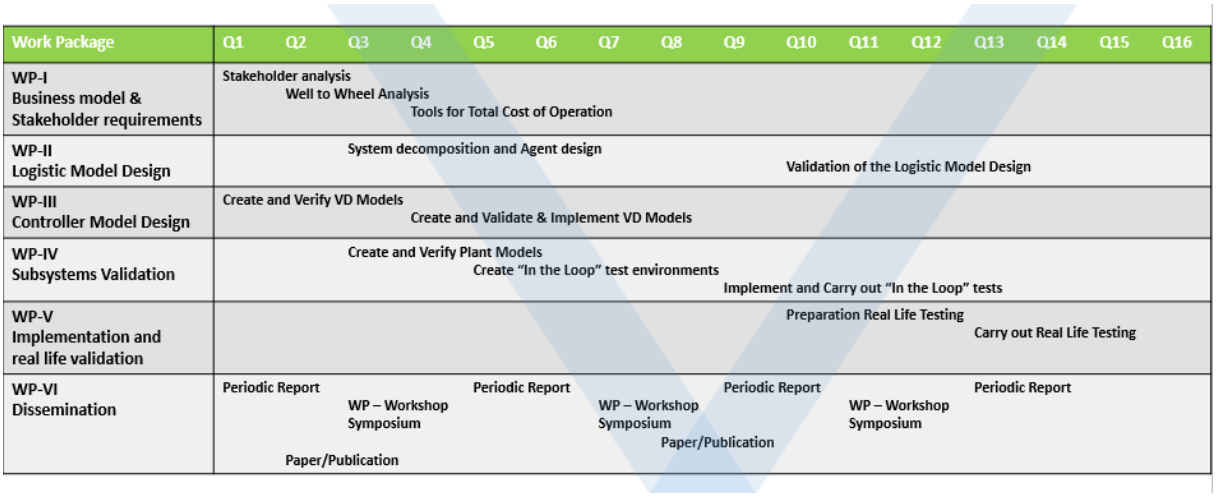

Figure 4 – Global planning aligned with the V-cycle design process

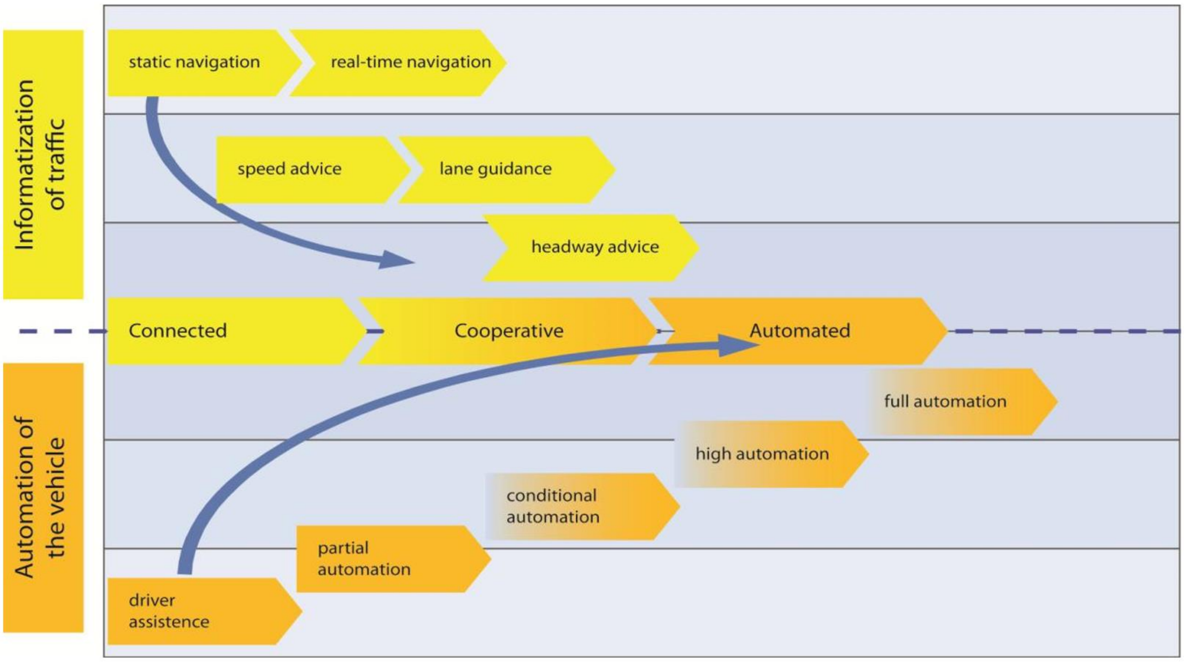

Figure 5 - Mobility will change more in the next twenty years than in the past one hundred years (NL-U, 2016)

Use case	One way distance	Remark
CER - Central Exchange Route MV1-MV2. It will interconnect the deep sea terminals with customs, phytosanitary inspection, empty container depots outside the terminals, and rail and barge terminal (s) for quantities of <10 per destination	Ca 15km	Closed route, owned by PoR
		Difference in degree of automation between MV1 and MV2
		The older terminals are not yet ready for handling autonomous vehicles.
Inter-terminal - deep sea – short sea and vice versa	Ca 40km	Public road
Intermodal and vice versa	5 – 120km	Connection on CER
		Via Public road- Terminals are located further in the midlands
Terminal to DC's and vice versa	10 – 120km	1. Auto Docking is main focus 2. Existing versus new locations

Table 1 Business model – transport requirements