UNIVERSITY OF WEST BOHEMIA
FACULTY OF ELECTRICAL ENGINEERING

DEPARTMENT OF TECHNOLOGIES AND MEASUREMENT

DIPLOMA THESIS

Technical-Economic Design of a Telematics Unit for Trucks and Buses

Jan Beseda **2018**

ZÁPADOČESKÁ UNIVERZITA V PLZNI
Fakulta elektrotechnická
Akademický rok: **2017/2018**

ZADÁNÍ DIPLOMOVÉ PRÁCE

(PROJEKTU, UMĚLECKÉHO DÍLA, UMĚLECKÉHO VÝKONU)

Jméno a příjmení:	**Bc. Jan BESEDA**
Osobní číslo:	**E15N0003K**
Studijní program:	**N2644 Aplikovaná elektrotechnika**
Studijní obor:	**Aplikovaná elektrotechnika**
Název tématu:	**Technicko-ekonomický koncept telematické jednotky pro nákladní vozidla a autobusy**
Zadávající katedra:	**Katedra elektroenergetiky a ekologie**

Zásady pro vypracování:

1. Prostudujte problematiku dopravní telematiky a popište používané technologie.
2. Prostudujte a popište základní principy produktového managementu.
3. Zanalyzujte požadavky trhu za účelem návrhu nové telematické jednotky pro nákladní vozidla a autobusy.
4. Navrhněte technicko-ekonomický koncept nové telematické jednotky a sestavte projektový plán. Identifikujte legislativní požadavky pro uvedení výrobku na trh.
5. Kriticky zhodnoťte navržené řešení.

Rozsah grafických prací: **podle doporučení vedoucího**

Rozsah kvalifikační práce: **40 - 60 stran**

Forma zpracování diplomové práce: **tištěná/elektronická**

Seznam odborné literatury:

1. **PŘIBYL, Pavel. Inteligentní dopravní systémy a dopravní telematika. Vyd. 1. Praha: Nakladatelství VUT, 2007, 254 s. ISBN 978-80-01-03648-8.**
2. **Geracie,G., The Guide to the Product Management and Marketing Body of Knowledge, Product Management Educational Institute, 2013. ISBN-13: 9780984518500.**
3. **Crawford, C., M.: New Products Management, Mc-Graw Hill, 2014. ISBN-13: 9780077729097.**

Vedoucí diplomové práce: **Ing. Radek Soukup, Ph.D.**
Katedra technologií a měření

Datum zadání diplomové práce: **10. října 2017**

Termín odevzdání diplomové práce: **24. května 2018**

Doc. Ing. Jiří Hammerbauer, Ph.D.
děkan

L.S.

Doc. Ing. Karel Noháč, Ph.D.
vedoucí katedry

V Plzni dne 10. října 2017

Abstract

The work addresses product management – its development, general description of product manager's tasks, and product lifecycle management. Some of its aspects are demonstrated in the document, which appear in one of its seven phases. It is preparation of materials necessary for starting development of a new product, namely of a new version of existing electronic device – a telematics onboard unit for buses and trucks. The materials include product requirements specification, determination of its main active components, definition of certifications necessary for launching the product on market, outline of project plan, and estimation of total development and manufacturing costs.

Key Words

Bus, costs, development, estimate, management, product, project, telematics, truck

Abstrakt

Práce se zabývá problematikou produktového managementu – jeho vývojem, obecným popisem činností produktového manažera a popisem životního cyklu produkt managementu. V dokumentu jsou demonstrovány některé jeho aspekty, které se objevují v jedné z jeho sedmi fází. Jedná se o přípravu podkladů nutných pro započetí vývoje nového produktu, konkrétně nové verze již existujícího elektronického zařízení – telematické palubní jednotky pro autobusy a nákladní vozidla. Podklady zahrnují specifikaci požadavků na produkt, určení hlavních aktivních prvků, definici potřebných certifikací pro uvedení výrobku na trh, nástin projektového plánu a odhad celkových nákladů na vývoj a sériovou výrobu produktu.

Klíčová slova

Autobus, management, náklady, naklaďák, odhad, produkt, projekt, telematika, vývoj

Declaration

Hereby I declare that I solely wrote this diploma thesis, with the aid of literature and sources referenced in List of References, which is a part of this diploma thesis.

Further I declare that all software used while working on this this diploma thesis is legal.

.....

Signature

In Plzeň on 2018-05-23 Jan Beseda

Acknowledgement

I would like to thank company Openmatics for the experience I gained during my work as a product manager in their service; for the extra flexibility I got when I needed days off for my studies, and for support that my superiors provided me with on the way, namely to Petr Loucký, Kateřina, Samková, and Jakub Trčka.

I would also like to thank Radek Soukup, supervisor of my diploma thesis, who helped me a lot and guided me in processing of this work.

Lastly, I would like to thank my partner Jakub Kolmistr who was really unhappy that I am working on this final thesis but supported me regardless.

Contents

Introduction

Transportation is an important part of human life all around the world. Both passengers and freight are carried by all possible modes every day – in the air, on the water, and on the land. In the European Union (EU), the main mode of transportation of both the passengers [1] and the freight [2] is road transportation. While passengers travel over the land by large majority with cars, travelling by buses or coaches (hereinafter just buses) is still superior to the other means of public long-distance transport. [3] Heavy goods vehicles (HGV), or more generally 'trucks', are the main means of freight road transportation in the EU. [4]

Over the years, there was a steady growth of freight road transportation demand until 2007 in the EU, and since then demand is relatively stable. [5] This growth was a factor that led to a need of more effective use of available road networks, because the networks cannot be continuously extended forever, and the economic recession between 2007 and 2009 forced transportation operators to look for other ways of cost reductions. These were the major factors that helped to a broader spread of telematics use in transportation.

With trucks being the main means of freight transportation, and buses the main means of long-distance public passenger transportation, telematics became an important part of running these vehicle types. Telematics for trucks and buses is a specific set of services or products that are relevant just to these vehicle types and their operators. As any other product it needs to be developed to fulfill the customer needs, to become competitive on the market, and to bring revenue to its manufacturer or reseller. The responsibility of creating such a product is the main task of product management.

The purpose of this work is to familiarize the reader with product management (PDM), a discipline that deals with creation, introduction, and continuous improvement of products; and to demonstrate its application on a design of an electronic telematics device, which enables further services to be delivered to bus- or truck-fleet operators. The depth of electronic design in this work will stop just at the description of the main active parts and functional components; it will not cover individual passive parts, their connections, or the manufacturing process. These subjects are beyond the scope of this work.

English is the language used in this work because I expect to use findings in this work in a company Openmatics where I am currently employed at and the main communication language there is English.

List of Symbols and Abbreviations

Abbreviation	Meaning
ADAS	Advanced Driving Assistance Systems
AIPMM	Association of International Product Marketing & Management
B2B	Business-to-Business
B2C	Business-to-Consumer
BT	Bluetooth®
CCTV	Closed Circuit Television
CE	Conformité Européenne (European Conformity)
CFR	Code of Federal Regulations
COM	Computer on Module
DAB	Digital Audio Broadcasting
DAS	Driving Assistance Systems
DoC	Declaration of Conformity
DR	Dead Reckoning
EEA	European Economic Area
EMC	Electromagnetic Compatibility
eMMC	Embedded Multi-Media Controller
EoL	End-of-Life
ETC	Electronic Toll Collection
EU	European Union
FCC	Federal Communications Commission
FM	Frequency Modulation
FMCG	Fast Moving Consumer Goods
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HGV	Heavy Goods Vehicles
HP	Hewlett-Packard
IATF	International Automotive Task Force
IoT	Internet of Things
IT	Information Technology
ITS	Intelligent Transportation System
LVD	“Low Voltage Directive”

List of Symbols and Abbreviations

Abbreviation	Meaning
MRD	Market Requirements Document
NASA	National Aeronautics and Space Administration
OAD	Opportunity Assessment Document
OBU	Onboard Unit
P&G	Procter & Gamble
PDM	Product Management or Product Manager
PDMM	Product Marketing Management or Product Marketing Manager
PPS	Precise Positioning Service
PRD	Product Requirements Document
R&D	Research and Development
RAM	Random Access Memory
RDS	Radio Data Systems
RED	"Radio Equipment Directive"
RF	Radio Frequency
RoHS	"Restriction of the Use of Certain Hazardous Substances"
SCM	Single Chip Module
SOC	System on Chip
SOM	System on Module
SPS	Standard Positioning Service
TMC	Traffic Message Channel
UNECE	United Nations Economic Commission for Europe
USA	United States of America
V2B	Vehicle-to-Business
V2D	Vehicle-to-Device
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything

List of Symbols and Abbreviations

Abbreviation	Meaning
VDA	German Association of the Automotive Industry
WEEE	Waste Electrical and Electronic Equipment

1 Telematics

This chapter describes what telematics is, it's commonly known usage in daily life, notable specifics of telematics in road transportation, and more detailed view on telematics in trucks and buses.

1.1 Telematics in General

The word "telematics" is a connection of words "telecommunications" and "informatics". [18] Understanding its meaning, the word itself can be used for a simple explanation of the discipline – telematics deals with data processing (informatics) and transfer of the information over long distance (telecommunications). In typical use cases, at the point of their collection, the data are either just gathered or even further processed, before they are sent to the desired location, where additional processing may take place.

Various forms of information technology (IT) and telecommunication technologies became important parts of our lives in the past decades. Informatics, and with it telematics, came along, and nowadays telematics becomes an even more important part, because of the continuous effort to bring more and more activities in our lives into the Internet of Things (IoT).

From notable industries that utilize telematics services can be mentioned healthcare, insurance, and transport. [18] In health care the term "telematics" is not that often used, but rather "eHealth", "telemedicine" or "telemonitoring" are used. Example is the ability to let a nurse watch a patient with a set of tools from office without even having to visit the patient, who actually can be miles away, insurance agency can get all history of manipulation with an object and automatically solve the case without the need to visit the accident point, in transport the cars can communicate with one another or with infrastructure around the road and thus effectively adjust their driving style according to a given situation. In theory all human activities, once automated and connected to information exchange networks, could be related to telematics.

With the possibility to remotely control objects of our interest, we can save enormous amount of time and energy, reduce various risks that would otherwise needed to be mitigated if all the work was supposed to be done by humans, and at the end we can invest the saved resources in more meaningful activities.

It is essential to note that without proper instruments for data gathering, processing, and transmitting, none of the above could work. Electronics is a crucial part of telematics – proper sensors, communication interfaces, computing hardware, and power supplies, are that which constitutes telematics in the physical world. For each industry, each environment, each kind of user, each country – or simply for each specific use case – an appropriate tool must be designed that complies with requirements of the use case.

1.2 Transport Telematics

There can be distinguished four elements that are involved in the act of transport. It is the subjects of transport, mode of transport, means of transport, and transport terminals. A subject of transport can either be a human being or some kind of freight. Means of transport are for example cars, boats, airplanes or rails. The modes of transport are air, road, railway, maritime, inland waterways, or any other type of a way that is able to conduct a physical object. Among terminals belongs for example airport, port, railway station, bus station, or parking lot. [8]

The purpose of transport telematics, also called Intelligent Transport Systems (ITS) specifically for road transport, is among others to increase safety, provide improved security and control (e.g. information on the methods and conditions of travel, monitoring of the vehicle usage, electronic toll collection), increase effectivity and mobility. Higher levels of safety can be achieved through the ability of vehicles to communicate with one another or the surrounding environment, improved security and control abilities can be through the possibility to continuously oversee immediate transport and based on statistics predict future development of the traffic, increased effectivity and mobility can be done through optimal use of available roads and so optimize navigation. At the end telematics in transport helps us increase comfort on the way while saving lives, money, time, and environment. [19]

The focus of this work is on road vehicles, buses and trucks. Therefore telematics systems used in other modes of transport than road won't be discussed here.

1.2.1 Telematics in Public Transport

Public transport encompasses services where passengers pay to actually get transported with unfamiliar people by a public operator. There are several areas where telematics already became an important in the daily life. Telematics brings a lot of new

possibilities especially to big cities, but as well to railways and highway. Each kind of transport system and each vehicle type have their specifics.

Figure 1: Ticket terminal accepting bank cards [21]

1.2.1.1 Ticketing Systems

Terminals provide the passenger with a way to purchase or validate tickets without the need to involve additional staff, which reduces the costs of the operator and as well saves the passenger's time. The terminals can be placed either outdoors, for example at the stop, or inside of the vehicle itself, and nowadays accept various ways of payment, including debit and credit cards.

Figure 2: Bus stop sign [22]

1.2.1.2 Passenger Information Systems

Various information systems can be installed directly in a vehicle – signs that tell the travelling passengers what the next stop is, or what the vehicle line direction or a number is, other screens can just show news or advertisements of the provider and inform or entertain the passengers during the trip – these are usually called "infotainment" systems. Different information systems can be installed as well at bus stops and inform the passengers about incoming arrivals, delays or additional information that can for example be related to current traffic situation, such as accidents.

1.2.1.3 In-Vehicle Systems

As well as for passengers, special systems are inside the vehicle that are of interest just to the drivers and deliver information necessary to fulfill their responsibilities. It can provide them with detailed schedule which is updated from the dispatching center, communicate with dispatchers, or let them control various devices inside the vehicle, including the passenger information systems or ticketing systems. In-vehicle systems also

include closed circuit televisions (CCTVs) that provide the driver with detailed view on the passenger situation inside the vehicle.

1.2.1.4 Dispatching Control Systems

Dispatching centers are invisible to the passenger's eye, but important parts of the transport systems. The dispatchers are those who have the overview of each vehicle's position, traffic in the city and so can completely orchestrate the transport flow of the operator's vehicles. In some cities the dispatching centers have increased privileges and are integrated with traffic control systems and thus can handle difficult traffic situations of which the passengers benefit.

1.2.1.5 Infrastructure Systems

Figure 3: Variable message sign [23]

Infrastructure that is remotely controlled is another type of a telematics system. These systems are not found just in cities, but as well on highways or railways. Example of such a system are variable-message signs through which it is possible to tell passing drivers important information related to immediate traffic situation. For example it is possible to regulate allowed maximum speed on highways close to big cities in rush hour and thus increase safety and smooth flow of the transport.

1.2.2 Advanced Driver-Assistance Systems

Advanced Driver-Assistance systems (further ADAS) are systems that provide a driver with helpful information relevant for the driving itself in a most suitable way for the driver, they also help in critical driving situations and as well during accidents either by informing the driver or taking action themselves. The purpose of these systems is to make driving more comfortable and safe. Example systems are the parking assistant, night-vision, adaptive cruise control, or emergency systems. Those that can nowadays be called a telematics system are for example vehicle navigation, traffic telematics, or eCall. [17]

With new technologies emerging the automotive industry, the driver-assistance systems also develop further. Few implementations of various inter-vehicular communications are such examples – slow steps towards autonomous driving.

1.2.2.1 Vehicle Navigation

The use of navigation systems in transport was historically highly related to military use. The first Global Positioning System (GPS) satellite was launched in 1978 on behalf of United States Department of Defense. The system consist nowadays of two levels – one for general public called Standard Positioning Service (SPS), and the other for US and allied government use called Precise Positioning Service (PPS). [24] There are other navigation systems that are as well available globally or in a state of development, in general called global navigation satellite systems (GNSS). These are Russian GLONASS, European Galileo, and Chinese BeiDou.

Various electronic devices are capable of determining the exact location of the user based on available GNSS signals or internal motion sensors, and while utilizing information on available routes to a desired location and special algorithms, these are able to find the best route based on user requirements and guide the user to the desired destination. The requirements can be "the cheapest ride", "the fastest ride", or a way that goes through roads with restricted vehicle weight or height, axle load, or goods type such as explosives. Many of these devices or their transmutations into software are currently highly integrated in modern road transport vehicles.

The navigation systems can be divided into three groups, the first one being offline navigation systems that have map data saved in internal storage and calculate the routes without connecting to any other system. These need to be generally manually updated in order to reflect infrastructure development. Then there are online systems that are constantly connected to the internet and download map data anytime they are used, and as well the computation algorithms are online and only the resulting route is delivered and displayed in the devices. And lastly there is the mixture of the offline and online systems that is capable of doing all the work offline or online.

The benefits of navigation systems in daily use are for example the speed of determining the route based on given requirements, or elimination of the need to have a printed map and constantly check it.

1.2.2.2 Traffic Telematics

Additional value to the navigation systems is brought by services that bring information about current traffic. Example of such service is Traffic Message Channel (TMC) that brings information through Radio Data Systems (RDS). RDS is a system for

embedding small amounts of digital data into FM broadcasting. Similar to TMC, there are Transport Protocol Experts Group (TPEG) services which are available for example via Digital Audio Broadcasting (DAB). However, many modern systems get information about current traffic situation over the internet. [25]

The added value of this information is that it helps determine an alternative route in cases that for example a traffic jam or a traffic accident occurred ahead on the currently determined route which would result in a significant increase of time necessary to get to the destination or an increase in costs if the original route was followed.

1.2.2.3 eCall

eCall is an emergency system in the EU that is mandatorily installed in all cars sold, starting 1 April 2018. [26] The purpose of the system is to automatically call emergency (number 112) in case of a serious accident of the car. The system works autonomously and can as well be triggered by passengers.

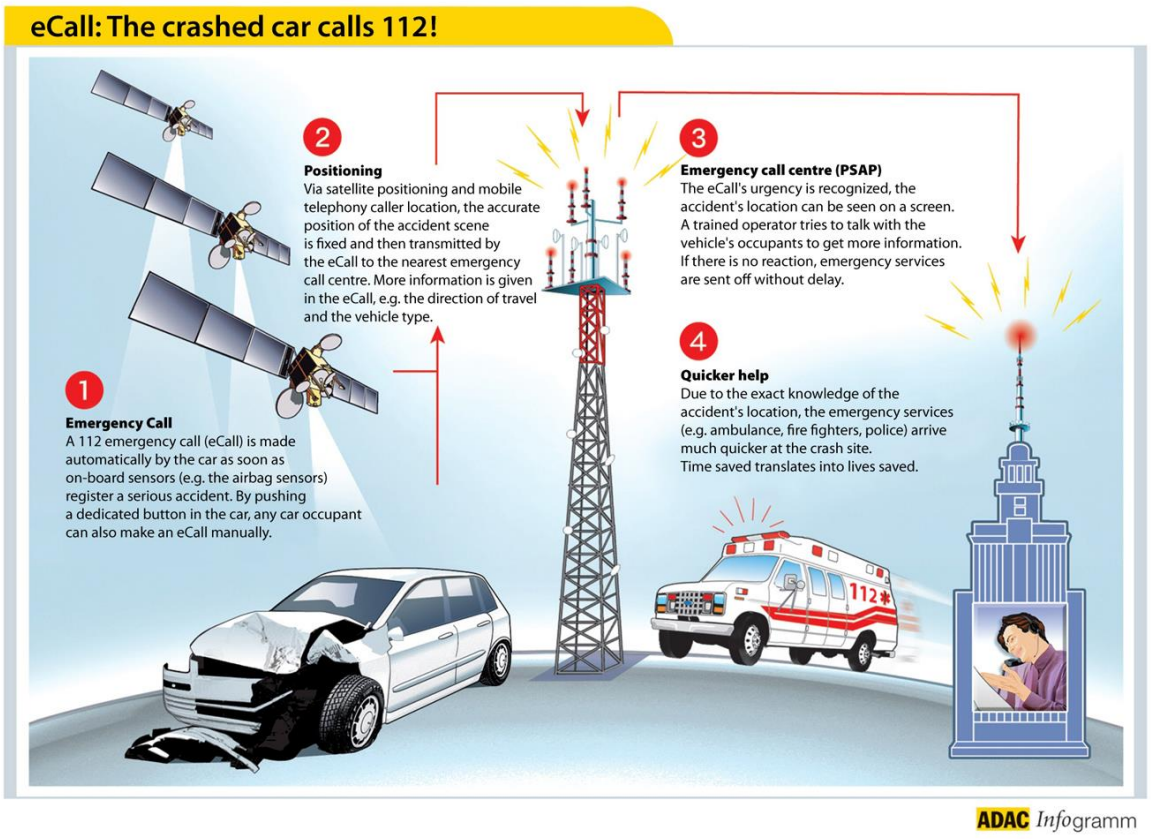


Figure 4: Diagram describing eCall function [27]

1.2.3 Vehicular Communication Systems

V2B (Vehicle-to-Business), V2H (Vehicle-to-Home), V2I (Vehicle-to-Infrastructure), V2V (Vehicle-to-Vehicle), V2N (Vehicle-to-Network), V2P (Vehicle-to-Pedestrian), V2D (Vehicle-to-Device) and V2G (Vehicle-to-Grid), all in all summarized by V2X (Vehicle-to-Everything) are all terms that recently gained a lot of attention in automotive. All these terms describe the ability of a vehicle to communicate with other nodes that participate in the process of road transport, which is very close to telematics. It integrates the vehicle itself and as well through the communication with other nodes to the internet.

1.2.3.1 Wireless Communication

Progress in development of vehicular communication is somewhat already standardized. While there are differences between standards used in the EU and in the USA, both have dedicated the band around 5.9 GHz for this purpose. In the USA it is IEEE 802.11p standard and in the EU it is ETSI EN 302 663. The main connection to the internet however still relies on cellular networks, where it is much related to IoT and use of specific LTE bands.

1.2.3.2 Electronic Toll Collection

Electronic toll collection (ETC) systems are an example of how vehicles communicate with infrastructure. The purpose of ETC is to collect required toll without the need to stop or slow down the vehicle. The passing vehicle is automatically recognized and the toll is directly charged at the operator.

For the use of ETC the vehicle must be equipped with an electronic device that is capable of communication with a toll collection system that is permanently installed along the road. The toll collection system is usually operated by various providers in various countries, or even specific roads. The vehicle must often be equipped by a device of all individual providers.

1.3 Telematics in Trucks and Buses

Considering that the buses and trucks are usually run in larger fleets by a single operating company (from now on operator) and that the operator wants to profit from operating the multitude of vehicles, increase profit or attract more customers, i.e. keep

competitive on the market and profitable at the same time, telematics becomes an interesting tool for helping managing the fleet and achieving business goals of the operator.

It is important to mention how the operators are usually structured – example of the operating company has let's say 40 vehicles in use, 50 drivers employed, 2 dispatchers administering utilization of the vehicles and the drivers and fulfillment of required services by the customer. The dispatchers and the drivers are in most cases just employees and through some hierarchy report to the business owner of the operator.

Fleet telematics consists of devices installed in vehicles that collect various data about vehicles, drivers, goods or passengers, and send it to the central dispatching office where dispatchers can further process it. It can as well arrange communication between the drivers and the dispatchers. Example of a telematics system is on Figure 5.

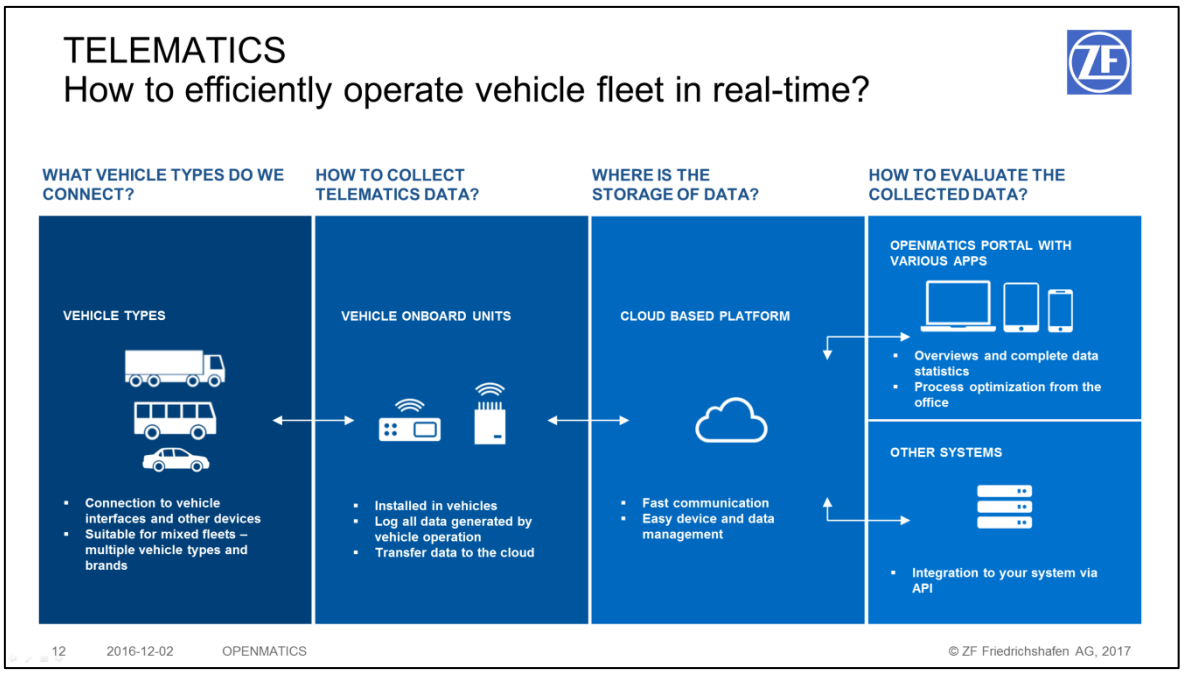


Figure 5: Example telematics system – company Openmatics s.r.o.

Clearly there are big differences between running a fleet of buses and running a fleet of trucks – while buses are transporting passengers, trucks are meant to transport freight or goods. For this reason the following chapters will describe specifics of bus fleets, specifics of truck fleets, and what is common for both – fleet management.

1.3.1 Fleet Management

The important information that is common for both vehicle types can be in my opinion divided into several groups. It is communication between the driver and the dispatcher,

remote diagnostics and predictive maintenance, resource tracking and planning, and legal requirements.

1.3.1.1 Legal Requirements

From the legal requirements, the most notable requirement that telematics can help fulfill in the EU, is the regulation number 561/2006 of the European parliament and the council, which lays down requirements on use of driver's working time and regulates how often the drivers have to take brake or how long they are allowed to drive without taking a break. Overall the regulation is rather complex and out of scope of this work, but it is important to note that by the regulation, there must be installed a specialized device that records the utilizations of the times, which is called a digital tachograph. The drivers register themselves and their times in the device with a special ID card, and the operator must regularly download the data onto another special card and submit the data to the government. By connecting a telematics device to this tachograph, the operator can download the data remotely from the office and does not have to visit each vehicle.

1.3.1.2 Resource Tracking and Planning

It is in the best interest of the operators to know where their vehicles are and how they are used. After all the drivers are usually just employees and in most cases must be controlled how they use entrusted properties – the vehicles, the goods or the passengers, and the fuel. The operator's best interest is for the goods or passengers to be delivered intact and on time, and with the least fuel costs, and as well the least damage on the vehicle caused.

The task of telematics here is to provide the dispatchers with information necessary to control these resources, such as vehicle position on map, start and end of individual journeys in history of the vehicle, rotations per minute of the engine, speed, or driver's allowed driving hours. This information then gives better overview of driver's driving style and can help the company to give appropriate trainings to the drivers in order to improve their driving style, or to predict the delivery or delays or to call it from records in cases when the delivery was not delivered on time and customer claims it.

1.3.1.3 Remote Diagnostics and Predictive Maintenance

Remote diagnostics is the ability to run diagnostics on a vehicle without the need to visit a workshop. In reality the telematics device is connected to vehicle electronics and once a special indicator that normally informs the driver about an error or a warning over the vehicle dashboard, telematics device just forwards the data directly to the dispatchers. The indicators on the dashboard are not often able to clearly state what has happened with the vehicle and this must be found out by trained specialists in the workshop. The telematics device, once provided with detailed information about all states that the vehicle can encounter, is able to give a clear picture to the dispatchers or the driver and repairs can immediately be planned without a delay or the need to interrupt current journey.

Telematics system continuously provides the operator with exact information about the vehicle status. Based on the gathered data and on maintenance plans specified by vehicle manufacturer, the operator can let automated systems plan regular service repairs and workshop visits and just perform necessary tasks when required; this is the part of the predictive maintenance where telematics helps mitigate damage caused by improper maintenance.

1.3.1.4 Communication between the Drivers and the Dispatchers

Fleet telematics also gives operators the ability for dispatchers to communicate with drivers. The telematics device itself has to provide the driver with a user interface, or the interface can be provided by an additional device that the driver uses. This communication channel can be used to either replace voice communication, or transfer text message, order assignments or serve even as an emergency channel.

1.3.2 Truck Specific Requirements

1.3.2.1 Order Management

Order management is simply processes and administration behind driver's tasks of taking-over, loading, transporting, unloading, and handing-over the goods between two parties or destinations. With help of modern communication systems, drivers usually receive the instructions electronically – either in connection to the telematics system or without it; and the take- and hand-over signature is as well stored electronically. Precise time of the transaction is needed for fulfilling contract terms between operators and their

customers. In combination with telematics aid, the dispatchers get precise information what task was completed, where, when, and by whom.

1.3.2.2 Asset Tracking

Modern telematics systems offer various ways to track asset. In the terms of trucks logistics, the asset might be the vehicle itself, its trailer, or as well goods that is loaded on the trailer. The information of value is here identification of the transported cargo, and as well the conditions in which the cargo is transport, e.g. humidity, vibrations, temperature (in cold chain management or controlled temperature chain). With special sensors, this information can as well be handled by a telematics system installed on the vehicle.

1.3.3 Bus Specific Requirements

Additionally to services and/or products described in chapter 1.2.1, there are various other ways how telematics systems help in terms of passenger transport in buses.

1.3.3.1 Infotainment

Infotainment means information and entertainment. It is the way of informing or entertaining passengers on the way. Various channels can be installed in the vehicle that provide passenger for example with information related to weather or connection in the final destination, or entertainment over wireless network to private devices or to installed screens, or access to the internet. Though it is not a telematics service in the full sense, the telematics system can be used to control what information or entertainment is provided, or it can control the internet access.

1.3.3.2 Passenger Counting

Valuable information for operators is how many passengers are actively being transported in the vehicle. With sensors connected to the telematics system, it is possible to deliver this information.

2 Product Management

In my opinion, Product Management is the art of accepting with one hand company goals, market situation, customer's needs, and available technology; and with the other hand delivering a product that is competitive on the market, brings added value to the customer and profit to the company.

"Stated simply, product management is the process of conceiving, planning, developing, testing, launching, delivering, and withdrawing products in the market. It is the organizational function within a company dealing with the thoughtful and proactive management of a product or group of products throughout all stages of the product lifecycle." [9]

2.1 Brief History of Product Management

Product Management (PDM) is addressed to be first described by Neil H. McElroy who worked for Procter & Gamble (P&G) back in 1931. McElroy described so called "Brand Man" who was responsible for closely analyzing customer needs, initially going from door to door and observing customers in their home environment, and based on collected information helped design the product. McElroy was successful with the idea of a single person being responsible for the product, learning the exact requirements and needs of the customer that several brands (a brand is a product line or a group of products with similar characteristics) were newly created at P&G. Besides his successful career at P&G, McElroy helped with founding National Aeronautics and Space Administration (NASA) and counseled at Stanford where he influenced Bill Hewlett and David Packard, founders of Hewlett-Packard (HP). [9][28]

Taiichi Ohno and Eiji Toyoda focused on implementation of just-in-time manufacturing at Toyota – *kaizen*: "improving the business continuously while always driving for innovation and evolution", and *genchi genbutsu*: "going to the source to find the facts to make correct decisions principles" were tools that had a big influence on what product management is today. In the West the HP Company was one of the first which implemented just-in-time manufacturing. And so through former employees of HP, who often were those starting business in Silicon Valley, PDM found its way from P&G, a company that focuses on fast moving consumer goods (FMCG), to hardware and software businesses to almost all industries nowadays. [28][29]

With the spread of internet and software industries in the past decades, product management became an important function even in this field, or more precisely, especially in this field. In software engineering, where product is not of a material origin, it is much easier to make changes of its design and further improve its features. What in terms of electronics engineering takes weeks or months in the matter of design, implementation and testing; in terms of software engineering the similar takes days or weeks. This allows for the engineering to work much faster. "Agile" are called the methods that are used in software engineering these days, among others it is for example Scrum or Kanban. Software engineering is currently probably the most significant industry that further improves PDM as a discipline – perhaps every software developer knows Manifesto for Agile Software Development which is available in tens of languages:

"We are uncovering better ways of developing software by doing it and helping others do it.
Through this work we have come to value:
***Individuals and interactions** over processes and tools*
***Working software** over comprehensive documentation*
***Customer collaboration** over contract negotiation*
***Responding to change** over following a plan*
That is, while there is value in the items on the right, we value the items on the left more."[31]

Nowadays, PDM is getting more and more recognized as an important business function, which neither belongs to the marketing nor engineering functions, and rather overlaps or connects them. Especially in software development companies, PDM already often holds a chair in the management team. [28][29]

2.2 Product

Product, project, program, portfolio, and brand – these are a few terms that are often understood as the same thing in minds of the uninitiated. But there are quite some differences between these terms in the mind of an expert. A **product** is goods or services that the company delivers to a larger amount of customers, and often anonymously in case of business-to-consumer operation. A **project** is a set of tasks that are meant to be completed on time and in a frame of a defined budget. A product can be a result of a project, and a product development process may consist of several projects. But in the business point of view the difference between a project-oriented business and a product-oriented business is that the project-oriented company delivers various projects to various

customers, and each project is unique to each of the customers, which can have a specific time for warranty or maintenance set or none, while a company that delivers products always makes the product available to many customers, and usually keeps improving them and developing over time. A **program** is a set of projects. A **portfolio** is a set of products, programs, projects, and operations that are invested in in order to achieve strategic objectives. And lastly, a **brand** is a sum of perceived psychological and emotional factors in a relationship between a company and its customers – a product is the tangible part of the service or goods that brings what a brand promises to deliver. [9][14]

2.3 Product Management in a Company

PDM as an internal company function emerged quite recently. In classical organization a product could be perceived as a responsibility of marketing function, because a product is one of the components of general marketing mix – product, price, place, and promotion. On the other hand, a product is a thing that is developed and delivered by engineers and thus is rather a technical topic, therefore a responsibility of the engineering team. In such organizational structure the product would be generally drafted by the marketing team and "thrown" over the wall to the engineering team for processing. The marketing team waited for the outcome, and once the final product was ready, it was usually something else than the marketing team initially had in mind. [28]

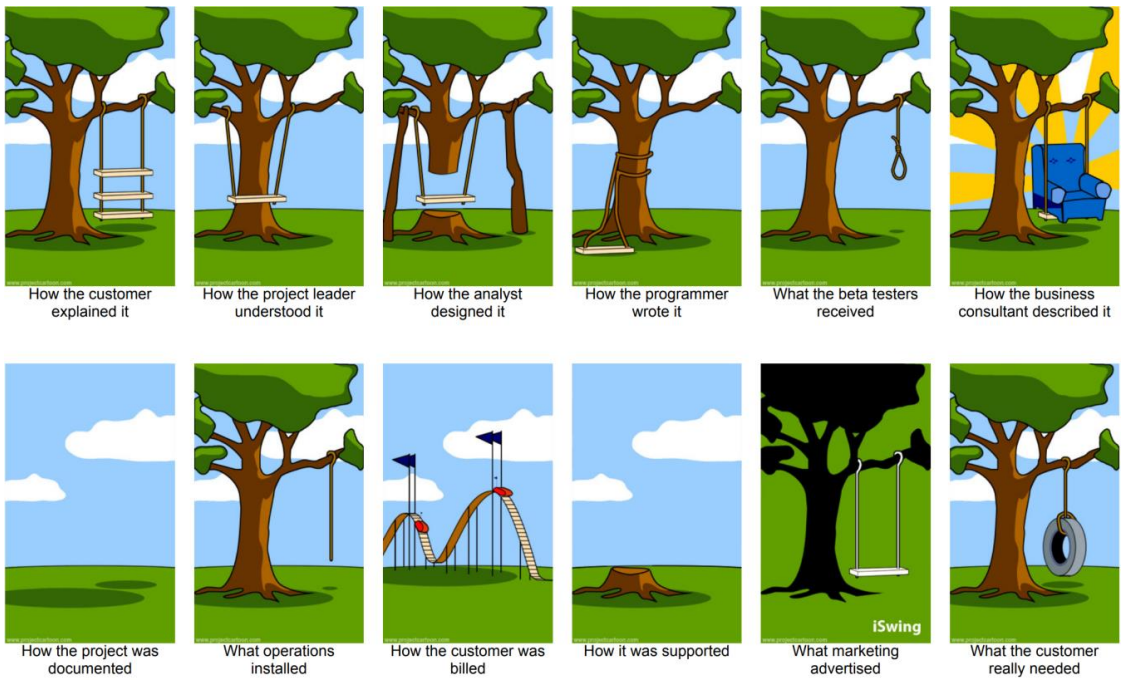


Figure 6: Different conceptions of a product [32]

Product management overlaps the marketing and engineering teams. Assuming the marketing team has background in economics, and the engineering team has technical background, product management team is there to connect the expertise of both and achieve the ultimate goal – together design, develop, and deliver a product that really makes sense – a product that is valuable, profitable and competitive on the market.

Depending on maturity and size of the company, and as well on the industry, the parties involved do not necessarily need to be just from engineering, marketing, or product management teams, but as well other contributors that help create a successful product might be involved. Following chapters describe a few groups of people involved on a creation and improvement of a product. [9]

Figure 7: Aspects involved in product development

2.3.1 Internal Aspects

The product must go in alignment with company strategy and vision, and so in companies that recognized the importance of product management, the PDM function is often directly reporting to the **general management**, or directly to the CEO, for example in Google, Microsoft or in Facebook. [9]

The product manager is responsible for orchestrating the teams to create and adopt a successful product and does so based on various inputs. Besides general management, the other sources of information that contribute to the product development inside the company are for example **sales, customer support and operations** – parties that are in direct contact with the customer. These are the people who are responsible for explaining,

selling, setting up and servicing the delivered product and are as well the connecting point between the customer and other internal departments of company. They must be involved in the process of creation of the process because at the end they are the ones representing the product to the customer on a daily basis.

Another very important partner of the PDM is the **marketing team**. This team provides a PDM with results of various market researches and as well is responsible for marketing the products on the market, depending on company size and number of products, there can even be a single person responsible for marketing the product/s – a product marketing manager (PDMM). Besides marketing the product and performing market researches, the marketing team can as well be dictating the visual side of the product in case the company has a single corporate identity which is defined by a set of rules.

The actual teams that create the product are at the end **product management** and **engineering** (or research and development departments (R&D) – based on the company conventions). These teams may be further consisting of various specialists that are responsible for individual tasks in the process – e.g. a developer, a tester, a system architect, or a user experience (UX) designer.

Based on the product character (goods, software, service) and company standing, there might be various 3rd parties considered as internal players – e.g. in case the company will be **manufacturing** the goods and does not have its own production line, or in case the product needs to be tested against various regulations and the company does not have its own **laboratory** to perform the compliance tests. The above can also apply to any of the teams described above – any services the described teams provide might as well be outsourced.

2.3.2 External Aspects

Among external factors that influence the product creation and development belongs the most important one – the **customers**. PDM must provide the customers with such a product that delivers value added, which the customers wants to pay for – to achieve this goal, the product manager must know what the customer's needs and current options to fulfill these needs really are and how these can be met.

Integral role in the process plays as well the **competition** – knowledge of the market, its maturity, its size and the knowledge of other players' capabilities are crucial to product success on the market.

All products, be it goods, services or software, are created by using specific **technologies**. General knowledge or availability of specific technologies or other products used in the new product development process are highly dependent on current technical progress. The product can either be constructed from available technologies, or a new technology is developed during the product creation itself.

With regard to competition and market, **legal** aspects of new product creation must as well be adhered. Special attention must be paid to intellectual property rights – e.g. trademarks, patents and copyrights – the product management should take care that rights of any other party delivering similar products to the market, or whose products were used during the new product creation, are not infringed, and as well that the product complies with governmental regulations restricting the market. Finally intellectual property rights on the newly developed product should as well be taken care of and the product should be registered where desired.

2.4 Product Management Lifecycle

Regardless of the product status – whether the developed product is a completely new thing, or it is just an innovation of an existing product – there are various steps that are usually taken in the development process. In some cultures, companies and industries, the product development has to strictly follow a prescribed line and certain steps must be taken at a concrete moment of time with a specific way of documentation. In other environments, the development process might be completely unorganized. For comparison many automotive manufacturers employ a norm 16949 of International Automotive Task Force (IATF) that describes in high detail various techniques and methods that should be used in product and process development, whereas a private restaurant owner can wake up in the morning and decide on the daily menu without ever planning it or documenting it.

There are many approaches to the product development process such as phase-gate product development, integrated product development, lean product development, or agile product development. [14] In this work, I used the product management process according to Association of International Product Marketing & Management (AIPMM), because in my opinion the format in which it is described is universally applicable and covers the

different phases of product development process with reasonable detail. The process is divided into seven phases – Conceive, Plan, Develop, Qualify, Launch, Maximize or Deliver, and Retire. [9][30]

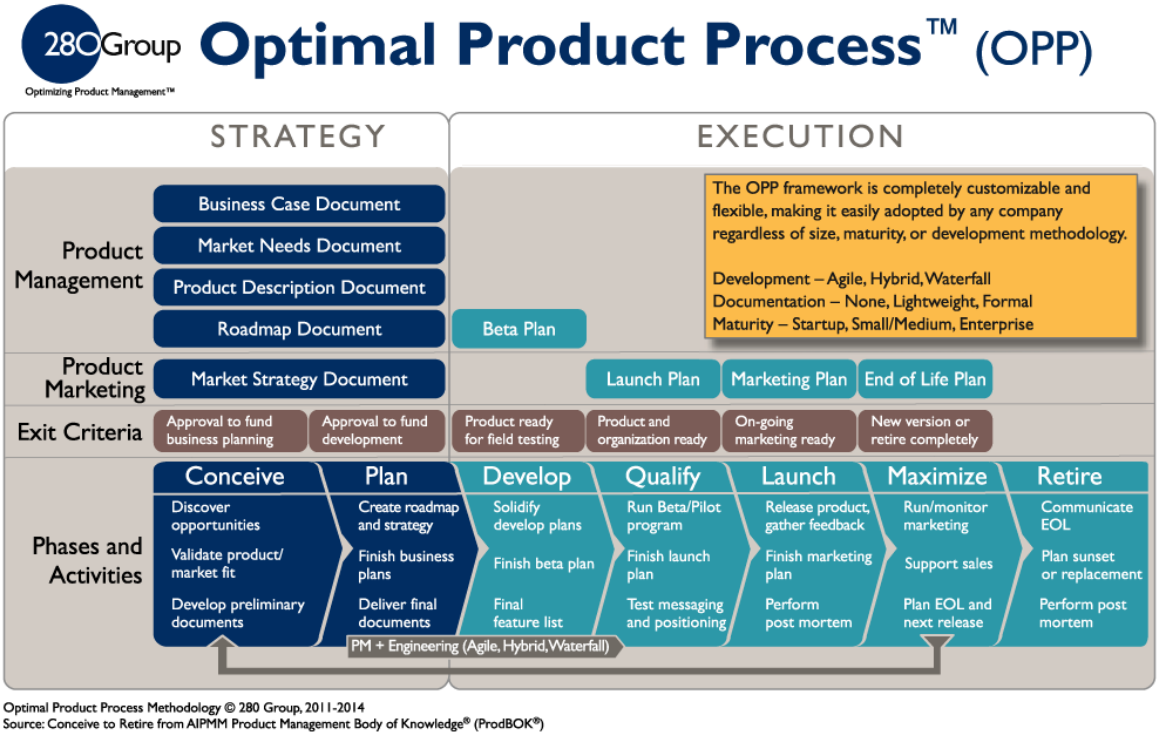


Figure 8: Optimal Product Process according to AIPMM [30]

2.4.1 Conceive Phase

Conceive phase is probably the most complex phase of the product management lifecycle. In established companies it is either performed on purpose with a defined beginning and end or, more often, going on continuously and inadvertently; and it might be the same starting phase for development of more than one product. This phase is mainly focused on research and analysis and its ultimate result is identified market opportunities and a product concept that is meant to seize them.

2.4.1.1 Opportunity Assessment Document

The market opportunities are identified based on thorough market research, competition analysis, customer monitoring, and threats and opportunities identification. Results of the analyses are summarized in opportunity assessment document (OAD). The product concept is a very rough description of a product that would help a company to seize the opportunities.

2.4.1.2 Market and Product Requirements Documents

Once the concept is meaningful enough for the company management, a small project team is formed and the process continues in deeper investigation. The target market is more closely identified and buyer and user personas are illustrated. Buyer persona is a role of a person whose needs will be seized and who will pay for the product, whilst the user persona is the actual user who will be using the product. Problems and needs of these personas are cleared out and another competition analysis is performed, which identifies competition capable of solving these personas problems. Findings of these steps are recorded in a market requirements document (MRD), sometimes called "market needs document". Requirements are further processed and prioritized based on the expected outcome value and performed feasibility study and summarized in product requirements document (PRD), sometimes called "product description". PRD is the base draft document of the product. It can contain various illustrations and diagrams describing the product, as well as sketches of the user interface. MRD and PRD are then consulted, evaluated and updated with customers, internally inside the company and possibly externally with specialized professionals.

2.4.1.3 Other Documents in Conceive Phase

Once the documents are considered mature enough, product vision and strategy, a draft project plan, and business case are prepared – these are the foundation for the management to decide, whether or not to advance further to the next phase.

2.4.2 Plan Phase

As the name says, the purpose of this phase is simply planning. The outcome of this phase is product description, product roadmap, development plan, marketing plan, and updated business case.

2.4.2.1 Product Description

The product description must be detailed and clear enough to start the development. There are various techniques the product can be described with. It can for example be done in a form of user stories, which describe individual features in natural language and often in singular first person, e.g. "*As a driver, when I am not on the way and receive an order to*

go to a specific location and to pick up goods, I need a message to pop up on my tablet screen and tell me when and where I am supposed to be and give me the option to directly start the navigation so that I do not waste time unlocking the tablet and setting up the navigation myself'. Or the requirements can be described in a form of what system must do, should do or can do based on the importance of the requirements and priority of the integration. Additionally, drawings, or mock-ups or even complete functionality of user interfaces can be included in the description.

2.4.2.2 Product Roadmap

Product roadmap is a living document; it is a connecting point between the product vision and strategy and individual development plans or projects. It provides rough information in case of incremental development, which is useful in fast-paced environments like software or electronics development. There can be an internal and external roadmap – the internal one, more detailed for use inside of the company, and the external one used for communication with customers.

2.4.2.3 Development Plan

The purpose of the development plan is to provide more detailed and more precise estimation of delivery milestones and required resources necessary for the engineering of the product compared to the estimation in Conceive phase. It is now possible to be done because of the detailed product specification. Additional plans can be drafted that involve other individual departments and their involvement in adoption of the new product, such as manufacturing plan, support plan or logistics plan.

2.4.2.4 Marketing Plan

Having more detailed product description and development plan allows the company to prepare launch strategy and update product and marketing strategy. Additional research is done on definition of target market and value proposition and pricing is updated. Launch strategy takes care of deploying the product to market, describes what, how and when will be communicated about the product before and after announcement of its launch to the market. The purpose of the launch strategy is to attract the right customers at the right time once the product is about to be released. Lastly the business case is as well updated,

covering the improved insight and decision is made whether the development will start or not.

2.4.3 Development Phase

The descriptions are further analyzed by technical specialists in this phase and based on the results of these analyses, the plans and specifications are further refined.

2.4.3.1 Product Description Updates

Once analysis of the product description is done by experienced technical experts, the described features might be completely rewritten to reflect complexity of the tasks necessary to develop them. The product description is usually divided into two types in this stage, the first one being the "business" description, which describes the value added of the product, how it solves the customers' needs, and at most how it roughly will be used by the users; and the "technical" documentation which describes what technology will be used to develop and/or manufacture the product, of what technical parts will the product consist, and how it will be tested and measured.

2.4.3.2 Development Plan Updates

Individual chunks of work packages can be created based on the updated descriptions and depending on complexity of such detailed description of product features, the features can be prioritized and developed according to the priority list. A few prototypes might be released that each includes a few new features added compared to the previous prototype. There are specific approaches to prototyping in software, in goods, and in services development. Prototyping is used to verify the functionality of the product and to further improve it. Sometimes selected customers are involved in testing of the prototypes to provide their feedback on the functionality and usability of the product so that it is further improved before it is finally released.

2.4.3.3 Software Prototyping

If the product is developed in iterations, which is the case usually in software development, the individual features might be delivered in several versions, which are often called "alfa", "beta", or "release candidate" versions. Additionally the features can be

gradually added into individual versions. The versioning is usually done by three numbers, e.g. 2.10.15 – the first number describing versions which are not compatible with one another, the second number describing additions of new features, and the third number describing versions which fix various bugs in the software.

2.4.3.4 Goods Prototyping

In other industries prototyping takes place, for example in electronics development, "evaluation boards" can be used which only allow the developers to investigate an individual active part in detail and test the software necessary to operate it, then a "functional prototype" is created which already connects few main active components and provides foundation for development of software for the complete final product, then "development prototype" is released which is soldered by hand but on the final PCB layout, and already used in verification of the software and as well in various mechanical and electrical tests. The development prototype is then followed by "pre-production assembly", which are a few units already soldered by machines and used for product compliance tests, and if this assembly passes all test, the "production" assembly is released which is in fact the final version of the product that will be assembled in the manufacturing process.

2.4.3.5 Launch Plan

As a part of the marketing plan, launch plan is created. The launch plan describes concrete steps that will be taken in order to introduce the product in the market. The individual steps may be advertising in various media, participating in exhibitions, or other events, and it includes as well proposal on how individual customers will be informed.

2.4.3.6 Internal Release Plans

Other plans inside the company include the manufacturing plan, operations plan, distribution plan, training plan or support plan. Each plan describes steps necessary to introduce the product in the respective departments of the company, but as well to other 3rd parties – trainings and documents necessary for the adoption of the newly developed product. The documents include product datasheet, end user documentation such as manual, pricing plan and policy, support guidelines, installation manuals, quality checklists.

2.4.4 Qualify Phase

In this phase the product gets approvals – from the market and from inside the company – confirmations that it is capable of fulfilling the originally presented requirements, brings the promised added value to the customers, and revenue to the company, i.e. that it complies with internal company requirements and with the market requirements.

2.4.4.1 Market Acceptance

There are two topics that need to be considered in this phase before the product launch. The first one is the acceptance of the product features by the customer and the other one is compliance with legislative requirements.

2.4.4.1.1 Pilot Testing

The market acceptance in this phase and prototyping in the previous phase slightly overlap. However, in the previous phase the product was provided only to a short amount of customers to get their opinion about the product in general, which was then taken in account for additional development; in this phase the product is considered ready for the launch, but to make the final release, it is once more shared with some selected customers for preliminary testing, usually called "pilot testing". Customer and more specifically user feedback is the key component in the decision – the product should in the best case be accepted without flaws.

2.4.4.1.2 Qualification

The product must demonstrate that it complies with various standards and laws that regulate the market and are laid by various regulatory authorities. This is highly dependent on the target market in terms of geographical location of the market. For example in most of the European countries, the products must demonstrate their compliance with many regulations and this is confirmed by placing so called "CE" – Conformité Européenne (European Conformity) – mark on the product or its packaging. There are many organizations that regulate the market in the USA; one of them is FCC (Federal Communications Commission) which for example puts together requirements on telecommunication products.

2.4.4.1.3 Intellectual Property Rights

In terms of legal requirements additional to the qualification, the product must demonstrate that it does not violate patents, trademarks, copyrights of other makers or that it does not interfere with software licenses of software used in the development. These topics were already addressed in Plan phase, and as well during the development, but now is the time to proof it in a form of documents. Besides that, the company might as well want to patent their product, and defend their copyrights. This is the time as well to have the final confirmation in written form from the authorities involved in such processes.

2.4.4.2 Internal Acceptance

The internal release plans were created in the previous phase and in this phase the plans need to be executed and the actual readiness of individual departments confirmed at the end of this phase. The assumptions at the end are that the launch plan is verified and all steps prior to the official release are made, the sales department is educated about the new product and able to sell it, the customer support is ready to actually support the customers, the manufacturing lines are ready for the mass production, or that operations and distribution are ready to handle the product. The product documentation must as well be ready and reflect the final state of the product.

2.4.4.3 Launch Decision

If product passes all the acceptance criteria and readiness checks, the final decision about the release is made as “yes”. The business plan is once again reviewed and financial indicators taken in account. Pricing policy might be updated to reflect the final state of the development and then the product might be released.

2.4.5 Launch Phase

Launch is the first phase of product lifecycle according to the definition of classic marketing, not to be confused with product management lifecycle. There are different approaches to the product launch based on the market company is targeting at. If it is well known or re-segmented market, then it is much easier to predict the necessary steps to do in comparison with a completely new market. These steps were already thought of in Plan phase and then defined in the development phase and approved of in Qualify phase. Now it

is the time execute. This phase is one of the most important phases. That said many companies are not able to properly handle this phase nowadays. [9][30] Failure in this phase leads to a huge wasted effort of the company activities.

The activities that take place in this phase are mainly of marketing character – ads, tradeshows, workshops, direct mails, social media marketing, website updates, or press updates. Launch phase may be going on for some time with ad hoc updates. At the end of the phase, outcome of the individual activities is evaluated and the result serves for definition and plan of further marketing activities, as well as for project growth prediction and draft for sales activities.

2.4.6 Deliver Phase

Deliver, "market" or "maximize" is the phase that corresponds with the growth, maturity and decline stages of the classic product lifecycle. This phase includes ongoing marketing and sales activities. The marketing continues with propagation of the product through new channels and approaches, the sales does what it is meant to do – to sell the product – and as well provides feedback to the marketing, which then helps with new approaches to further market the product and help sales generate revenue.

Furthermore, product management continuously collects feedback on the product from the market, monitors the product environment and evolution of technologies relevant to the product, and evaluates these inputs. These activities are very similar to those in Conceive and Plan phases and if need be, further development of the product might be initiated, if the product management function states so. The length of product on the market is highly dependent on its demand and consumption. If these get low, regardless to marketing activities, or if the company changes its strategy, the product management can decide about ending the product lifecycle and its withdrawal from the market.

2.4.7 Retire Phase

This is the final phase of the product management lifecycle. Though it is the last, it not so much less important than the other phases. The product management spends usually most of their work time performing activities in all other phases of the lifecycle. Retire phase comes at the end, which for some products might be in many years after their initial launch. Depending on the product character and its status on the market, various factors need to be taken in account and individual tasks performed that lead to a successful end of

the product on the market. For example in case of some consumer goods, such as colored pencils, it might involve just selling off the shelf supplies, but in case of software products, careful approach e.g. to business contracts must be undergone. These activities are summarized in so-called "End-of-Life" (EoL) plan. The plan might as well include definition of alternative products or support of the product after its withdrawal.

3 Requirements on Telematics Unit for Commercial Road Vehicles

This section is a product description in its form at the end of Conceive phase of product management lifecycle. The level of detail in this description is influenced by my previous experience with a device of similar functionality and complexity. The product described is the next generation of current telematics onboard unit called Bach, which is a product of company Openmatics. Its datasheet is in Appendix A.

The reasons for developing a new onboard unit can be divided into two groups. The first group were requirements discovered during Deliver phase of Bach product management lifecycle, which the device was not able to fulfill on hardware or software level; and the second group were facts that individual components slowly get obsolete and unavailable on the market – search for substitutions and their integration in the manufacturing process becomes rather costly and the company needs to have a suitable replacement ready before the Retirement phase of Bach product management lifecycle.

The first section of this chapter describes general purpose of the device, the second one describes functional requirements – these are rather technical characteristics of the device – and the last section describes non-functional requirements – these are rather business characteristics the device must comply with.

Language used to describe the requirements uses modal verbs must and should. Must is used to describe "hard" requirements – requirements that under no circumstances may change – and "should" is used to describe requirements that might change during Develop Phase.

3.1 Onboard Unit

Onboard unit (OBU) or telematics unit is a device that is installed on board of a vehicle and connects it into a telematics system.

3.1.1 Purpose of the Device

Main function of the device is to collect, process, store, and transmit data that are either generated by the device itself or obtained from other devices to which it is connected. Data from the OBU help dispatchers to plan and monitor individual vehicles and drivers' work. Additionally the onboard unit serves as a channel for communication between the vehicle driver and the dispatchers.

3.1.2 Environment Setting

The device is intended to be installed in commercial vehicles – buses and trucks. It needs to comply with regulations that limit use of electromagnetic radiators in vehicles and be durable enough to withstand temperatures and other electrical and mechanical factors that occur in the place of installation in the vehicle.

The onboard unit will be connected or will provide internet connectivity to other devices inside the vehicle and so must provide interfaces necessary to establish connection with such devices. The processing power and memory capabilities must be sufficient enough to store and process gathered data.

Lastly the device must provide internet connectivity that is able to transmit data with minimal latency between the onboard unit and target servers. The target servers are either servers of company Openmatics or servers of the customer. Data can be transmitted to either one or more servers at a time.

3.1.3 Use Cases

Many of the use cases the device was involved in have already been described in chapter 1 of this work in detail. Here is just a short list to remind the reader about some of them:

- Vehicle location, travel direction
- Arrival and departures from specified areas, and infotainment
- Current and average vehicle speed
- Rotation per minute of the engine
- Fuel level in fuel tank
- Preventive maintenance planning and remote diagnostics
- Digital tachographs readouts

3.2 Functional Requirements

3.2.1 Mechanics

Table 1: Requirements on mechanical aspects of the design

Requirement	Description
Mounting	It must possible to mount the device to a wall with screws
Weight	The weight of the device should be less than 500 grams
Dimensions	The dimensions of the device should be as following without wall mounting brackets: Height: < 40 mm Length: < 140 mm Width: < 120 mm
Degree of Protection	The ingress protection must be at least IP65 according to ISO 20653:2013
Thermal Design	The device must be designed for external housing temperatures of +85 °C maximal and -40 °C minimal and verified according to IEC 60068-2-1:2007 and IEC 60068-2-2:2007
Thermal Discharge	The cooling must be performed without use of any mechanical fans or liquids
Installation Location	The device is designated for use in commercial vehicles – installation location is the pilot cabin – light amounts of dust and low humidity are assumed

3.2.2 Interfaces

3.2.2.1 Interfaces Arrangement

All user interfaces should be accessible on one side of the device. Lock of any connector must be easily accessible.

3.2.2.2 Interfaces Overview

Table 2: Interfaces overview

Description	Quantity	Mandatory	Optional	Remarks	Front Panel Designation
Mechanical External Interfaces					
GNSS antenna	1	X			GPS
WLAN antenna	1	X			WLAN
Bluetooth	1	X			BT
Cellular antenna	1	X			GSM
Main Connector	1	X		Might be realized as multiple connectors	PWR/DATA

Description	Quantity	Mandatory	Optional	Remarks	Front Panel Designation
Mechanical Internal Interfaces					
2FF SIM	1	X			None
MFF2 SIM	1		X		None
Internal Visual Outputs					
LED	2	X		Status signalization	LED1, LED2
Wireless Interfaces					
GNSS	1	X		With Automotive Dead-Reckoning	None
Cellular	1	X			None
WLAN	1	X		802.11 b/g/n/ac	None
Bluetooth	1	X		v4.1 and newer	None

3.2.3 Hardware

3.2.3.1 Wireless Interfaces

Table 3: Wireless interfaces

Requirement	Description
GNSS	The device should support Galileo The device must support GPS and GLONASS Dead Reckoning (DR) must be supported
Cellular	2G/3G must be available with possibility to extend the capability to include 4G without the necessity to redesign the PCB The modem needs to be soldered on the main PCB Family of modems with same pinning for use in regions described in paragraph 3.3.1 must be used 1 2FF SIM card slot (mini SIM) must be included and accessible only after opening the device housing 1 MFF2 (embedded SIM) should be included
WLAN	WLAN 802.11 b/g/n/ac protocols must be supported WLAN 2.4 and 5 GHz must be available The device should be capable to run either in Access Point or Client mode or both at the same time
Bluetooth®	Bluetooth® (BT) v4.1 with BLE support must be available The BT interface must be dedicated – not combined with the WLAN interface

3.2.3.2 Wired Interfaces

Table 4: Wired interfaces

Requirement	Description
Ethernet	One 10/100/1000 Mbit Ethernet interface must be available The interface must be included in the main connector
CAN Bus	CAN bus version CAN2.0 Part A (11 bit), CAN 2.0 Part B (29 bit) and CAN FD 1.0 according to ISO 11898-1:2015, ISO 11898-2:2015, and ISO 11898-3:2015 must be available SAE J1939 protocol must be supported 2 CAN interfaces must be available Baud rate on all interfaces must be at least 1 Mbps An alternative configuration of the CAN interface with a terminating resistor (i.e., as the final element) must be possible via a cable bridge between CANFx-T and CANFx-L inside the attached cabling, this means that additional pin for CAN-L and CAN-H (with attached 120 Ω resistor) pins are available on the connector
K-Line	One uni-directional K-Line diagnostics interface according to ISO 14230-1:2012 and ISO 14230-2:2016 must be available
RS232	Single RS232 interface must be available RX and TX must be supported The interface should be included in the main connector along with other interfaces
Control Interfaces	Two programmable RGB status LEDs must be available on the same side of the device as connectors Each LED should be clearly readable while all connectors are plugged in

3.2.3.3 Sensors

Table 5: Sensors

Requirement	Description
Accelerometer	One accelerometer must be available
Gyroscope	One 3D gyroscope must be available

3.2.3.4 Power Management

3.2.3.4.1 Power Supply

Nominal voltage 12/24 V according to ISO 16750-2:2012 must be supported

The device must be powered from vehicle power supply

RTC power for period of at least 2 weeks must be available

Description of power terminals as defined by DIN 72552-2:2014-07 must be used

3.2.3.4.2 Operation Modes

It must be possible to switch the device between standby and normal modes

Table 6: Power consumption requirements

Operation Mode	Power Consumption	Monitored Signals
Standby	< 1 mA @ 24 V	KL15, KL30
Normal	No specific requirement on consumption	As in standby plus: All other interfaces OS is running

3.2.3.5 Computing System

Table 7: Computing system

Requirement	Description
Computing Power	CPU with frequency of at least 1 GHz must be used The power consumption of chipset and CPU module shall not exceed a limit of 5 W. The maximal typical power consumption shall be about 3 up to 5 W.
Memory	1 GB memory for random access memory (RAM) must be available 2 GB memory for bootloader, file system, and data storage must be available PCB layout must be ready to accommodate additional Embedded Multi-Media Controller (eMMC) memory The eMMC capacity must be at least 1 GB
Software	The system is designed for Linux operating system A Linux driver must be provided for each component

3.3 Non-Functional Requirements

3.3.1 Scalability and Variability

The system must be so designed that it will be is possible to replace or completely remove some parts depending on vehicle type and region of use

Variants of the device with all influenced components adjusted for desired regions as described in Table 8 must be available

It must be possible to change storage memory capacity

Table 8: Scalability and variability

Requirement	Description
Vehicle Types of Use	Trucks Coaches Charging stations Electric buses Diagnostics
Regions of Use	European Economic Area (EEA) United States of America (USA)
Environment of Use	The device must be so designed to be immune and to environments described in chapter 3.1.2, and not to interfere with them

3.3.2 Reliability

The device must be designed for durability of at least 5 years, a life cycle of 18.000 h, with maximum failure rate of 2000 ppm

Table 9: Typical temperature profile

Temperature [°C]	- 40	- 20	0	30	50	50 – 65
Duration [h]	180	540	1980	11700	2700	900

3.3.3 Testability

Table 10: Testability

Requirement	Description
Manufacturing Test Coverage	Final tests at the end of production line must cover 100% of external interfaces and 100% of onboard components Logs must be available that document the performed testing
Compliance	The device must be compliant to all standards that are legally required for its use in vehicle types and regions described in chapter 3.3.1 The compliance must be verified with testing and documented with test reports, certificates published by respected authorities must be delivered

3.3.4 Usability

Table 11: Usability

Requirement	Description
Accessibility	The command line of the running software system shall be accessible through one of the external interfaces, e.g. RS232
Packaging	Each unit must be packed individually Maximum weight of package containing multiple packs must not exceed 20 kg

3.3.5 Other Non-Functional Requirements

Table 12: Other non-functional requirements

Requirement	Description
Availability	Components used in the design must be available on the market at least for another 5 years
Delivery Plan	5000 units should be produced in 2
Unit Costs	The total material costs should not exceed 350 EUR per unit

4 Design of a Telematics Device for Buses and Trucks

The requirements specification finalized in the previous chapter serves as a founding document for more detailed product specification. It is in Plan phase when the product is being further specified in detail. This chapter shows how simple requirements recorded in the requirements specification transform into a description of real components or functionalities of the final product.

Rough plan of the development activities is created as well at this stage and so is compliance testing plan. Finally costs estimation summarizes necessary funding to complete the development; it is a supplement document to the business case.

4.1 Specific Product Components Selection

Only following parts will be looked for at this stage of product lifecycle – GNSS receiver, cellular network modem, WLAN transceiver, Bluetooth® transceiver, microcontrollers and modules for running the operating system. Detailed bill of materials and PCB layouts are created during Development phase. The described parts were selected, because they are the main active components and because they contributed to over 60 % of the total unit material costs in the design of the previously developed telematics unit Bach at Openmatics. It is in total 4 parts out of 162 unique parts from the complete bill of material of Bach, which is less than 2.5 % of the total number of unique parts.

I selected the individual parts based on my experience and knowledge of manufacturers that are capable of delivering required functionality. This is a general task of a product manager in Conceive phase – in order to be able to design a product utilizing the latest innovations the product manager must continuously educate oneself about available technologies which are specific to the product manager's specialization and market of focus.

4.1.1 GNSS

Out of three pre-selected GNSS modules, u-blox module was selected as the final component. One of u-blox' modules were used in the design of Bach. Sierra Wireless module does not support DR. Telit and Sierra Wireless modules module do not follow automotive standards in production, or at least the information was not available online. U-blox module was the final winner. However, information about the price of u-blox module was not available. [33][34][35][36][37]

Table 13: GNSS modules

Manufacturer	**Sierra Wireless**	**Telit**	**u-blox**
Model	AirPrime® XA1110	Jupiter SL869-ADR	NEO-M8L-03A
GPS	Yes	Yes	Yes
GLONASS	Yes	Yes	Yes
Galileo	Yes	Yes	Yes
Dead Reckoning	No	Yes	Yes
Automotive	N/A	N/A	AEC‑Q100 ISO/TS 16949

Manufacturer	**Sierra Wireless**	**Telit**	**u-blox**
Accuracy [m]	< 3.0	1.3	2.5
Temperature Range [°C]	-40 – +85	-40 – +85	-40 – +85
Unit Price [EUR]	11.03	19.02	N/A

4.1.2 Cellular Network Modem

Three manufacturers, specialized in connectivity for automotive industry, were pre-selected, modules of these three companies were already used in Bach design. From their best offerings, only modem from u-blox had LTE capabilities. However, the price was quite high for a unit price. This is typical approach when only one unit is being ordered. The same supplier also listed price from 10 and more units and it was 70.15 EUR. [38][39][40][41][42]

Table 14: Cellular network modules

Manufacturer	**HUAWEI**	**Sierra Wireless**	**u-blox**
Model	MU709-s**x**	AR855**x**	TOBY-L2
EEA	Yes	Yes	Yes
USA	Yes	Yes	Yes
Connectivity	HSPA+, UMTS, EDGE, GPRS, GSM	HSPA, EDGE, GPRS, GSM	LTE, UMTS, EDGE, GPRS, GSM
Peak Uplink Rate	5.76 Mbps	5.76 Mbps	150 Mbps
Automotive	N/A	ISO/TS 16949	ISO 16750
Temperature Range [°C]	-40 – +85	-40 – +85	-40 – +85
Unit Price [EUR]	31.65	N/A	194.42

4.1.3 WLAN and Bluetooth®

There is quite a long list of manufacturers that offer dedicated Wi-Fi and Bluetooth® modules. However, most of the dedicated modules are outdated and the trend is nowadays to combine the two technologies into a single module. In the original device, the combined module was used. The experience of selling and running the Bach device showed that BT performance drops significantly while using Wi-Fi at the same time. That lead to an assumption that dedicated modules might perform better individually. Additionally, the manufacturer's support regarding the software integration was quite unsatisfying. Looking at well-known manufacturers supplying the automotive industry – Intel, LSR (Laird), Sierra Wireless, ST Microelectronics, and u-blox – only ST is offering dedicated Wi-Fi and BT in broader selection range, but their Wi-Fi modules do not support 802.11ac protocol. Because of these facts, I have decided to select just between u-blox and LSR modules of both which combine the technologies, regardless the risk that the Bluetooth®

support might be lacking. LSR is the manufacturer whose module was integrated in Bach. [37][43][44]

Table 15: WLAN and BT modules

Manufacturer	**LSR**	**u-blox**
Model	Sterling-LWB5	JODY-W167
EEA	Yes	Yes
USA	Yes	Yes
Dedicated Antennas	No	Yes
BT Version	4.2	4.2
Automotive	N/A	ISO/TS 16949 ISO 16750-4
Temperature Range [°C]	-40 – +85	-40 – +85
Unit Price [EUR]	20.98	N/A

Once again, u-blox module was selected as the preferred component for the requirement. Even though it combines the two technologies in a single chip, it offers a possibility to have dedicated antennas for each of them, moreover, 2x2 MIMO is supported as well.

4.1.4 Computing System

Table 16: Embedded systems

Manufacturer	**Microchip**	**NXP**	**PHYTEC**	**VIA**
Model	ATSAMA5D27-SOM1	SCM-i.MX 6	phyCORE®-i.MX 6	SOM-6X50
EEA	Yes	Yes	Yes	Yes
USA	Yes	Yes	Yes	Yes
Max CPU Frequency [GHz]	0.5	0.8	1.2	0.8
Max CPU Cores	1	4	4	1
Max RAM Capacity [MB]	128	4096	2048	512
Max Ethernet Speed [Mbps]	100	1000	1000	100
Max CAN Bus	2	2	2	0
Memory Interfaces	SD, MMC, eMMC, SDIO	SD, eMMC	MMC/SD/SDIO	SDIO
Automotive	ISO/TS 16949	N/A	N/A	N/A
Temperature Range [°C]	-40 – +85	-40 – +85	-40 – +85	0 – +60
Unit Price [EUR]	39.96	86.30	N/A	N/A

System on Module (SOM), single chip module (SCM), computer on module (COM), or system on chip (SOC) is term used to describe an embedded system that integrates basic components of a computer and additional electronic devices in a single circuit. [50] The

main benefit of using an embedded system in electronics development is that the initial integration is already done and the design can be reused with various combinations of additional interfaces and peripherals, which saves a lot of effort in terms of time and money for the company. Those are the reasons why an embedded system was chosen as the core computing system of the device.

4 manufacturers delivering embedded systems were selected and their products evaluated. VIA and Microchip unfortunately do not provide much scalability, especially the possibility to increase used memory size and the core processing unit. PHYTEC and NXP modules were the winners, but because PHYTEC does not publish unit price of the module, NXP came out as the winner. [37][46][47][48][49]

4.2 Compliance

An important part of product development is securing its compliance with effective regulations. The set of regulations that needs to be observed depends on target market, product type, and use cases the product is designed for.

This section describes regulations that apply to the discussed product as per the requirements specification in the previous chapter; and estimates necessary time and costs that need to be invested in order for product to be certified as compliant with these regulations.

4.2.1 Regional Specifics

The target markets defined in section 3.3.1 are EEA and USA. The product is an electronic device intended to be used in commercial road vehicles and it uses various wireless technologies for its operation, therefore it can be called an intended radiator. The wireless technologies used are Bluetooth®, Wi-Fi, cellular network, and GNSS. With such description of the product use it is possible to proceed with the definition of compliance that needs to be secured. Prices that are listed at individual certification types are based on my knowledge and serve only for rough estimation of the total compliance costs.

4.2.1.1 European Economic Area

In EEA, the general compliance of a product with effective regulations is confirmed by affixing “CE marking” onto the product.

"By affixing the CE marking to a product, a manufacturer declares that the product meets all the legal requirements for CE marking and can be sold throughout the EEA. This also applies to products made in other countries that are sold in the EEA." [51]

There exists a comprehensive document which helps with identification of the applicable regulations and thus with individual steps that need to be taken in order to make the product "compliant". This document is called "Blue Guide" and is available online. However, the guide does not cover all regulations that are currently effective, out of which some are related to the discussed product. [52] Regulations that are not covered by the Blue Guide were identified during my work at company Openmatics in cooperation with companies UL (formerly Underwriters Laboratories), DEKRA, Intertek, and EZÚ (Elektrotechnický zkušební ústav), which are companies specialized in securing product certifications.

Table 17 lists regulations along with information about what standards are followed during the testing (if any), and estimated costs necessary for completion of the process in the EEA.

Table 17: EEA compliance overview

Regulation	Standards	Costs [EUR]
2014/30/EU	EN 301 489-1 V1.9.2 EN 301 489-17 V3.2.0 EN 55024:2010 EN 55024:2010/A1:2016 EN 55032:2012 EN 301 489-19 V2.1.0 EN 301 489-52 V1.1.0	11,000
2014/35/EU	EN 60950-1:2006 EN 60950-1:2006/A1:2010 EN 60950-1:2006/A11:2009 EN 60950-1:2006/A12:2011 EN 60950-1:2006/A2:2013 EN 60950-1:2006/AC:2011 EN 62479:2010 EN 62311:2008	2,600
2014/53/EU	EN 300 328 V2.1.1 EN 303 413 V1.1.1 EN 301 511 V9.0.2 EN 301 893 V2.1.1 EN 301 908-1 V11.1.1	15,600
2011/65/EU	EN 50581:2012	350
UN ECE R10.05	UN ECE R10.05:2014 ISO 7637-1:2015 ISO 7637-2:2015	1,000
Total		30,500

Regulations, which are controlled by the European Commission and which are not covered in the Blue Guide, are RoHS and WEEE directives. Additionally, regulation number 10 of the United Nations Economic Commission for Europe (UNECE) applies to the product.

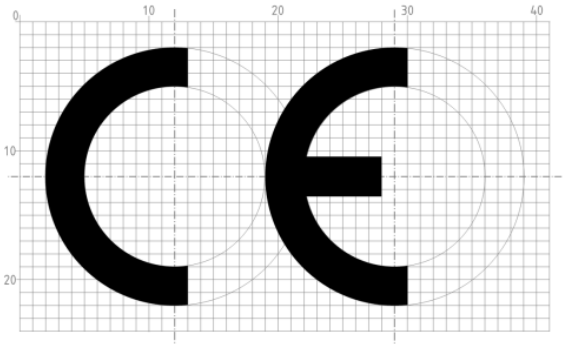


Figure 9: "CE mark" [51]

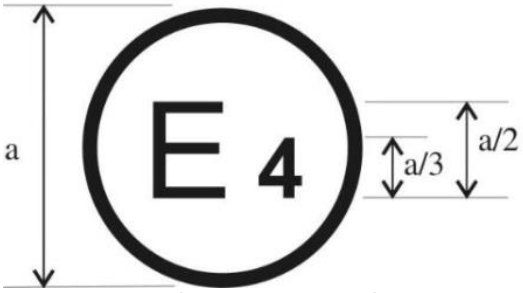


Figure 11: "E-mark"

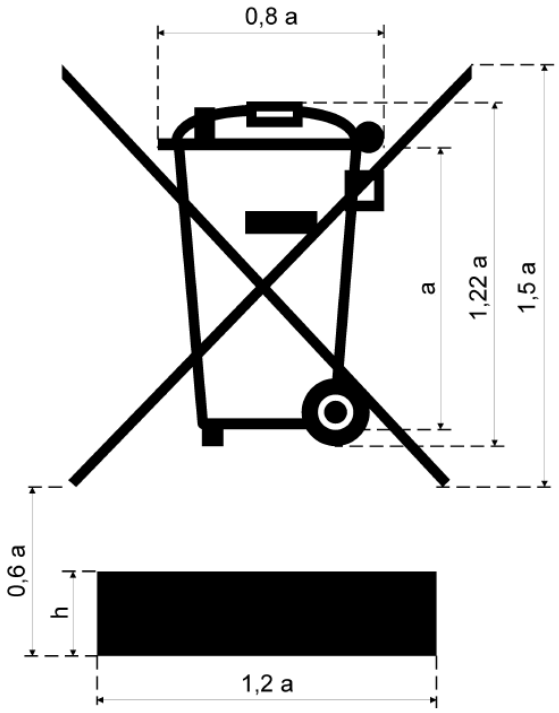


Figure 10: "WEEE mark" (EN 50419:2006)

To demonstrate its compliance with the regulations, a product must bear certain marking on its housing and/or packaging. Products that passed the UNECE R10 regulation must bear so called "E-mark" as evidence of the compliance. The E-mark consists of capital letter E and a number representing the country where the product was certified. CE and WEEE marks declare that the product complies with the regulation of the European Commission. Besides the markings, a declaration of conformity (DoC) must be attached to the product, either as a separate document, or as a link to a web page with its complete text. DoC provides statement of the manufacturer that the product complies with the regulations.

Table 18: List of applicable regulations in EEA

Regulation	Regulation Name	Abbreviation	Proof
2014/30/EU	Electromagnetic compatibility	EMC	CE, DoC
2014/35/EU	Making available on the market of electrical equipment designed for use within certain voltage limits	LVD	
2014/53/EU	Making available on the market of radio equipment	RED	
2011/65/EU	Restriction of the use of certain hazardous	RoHS	

	substances in electrical and electronic equipment		
2012/19/EU	Waste electrical and electronic equipment	WEEE	WEEE
UN ECE R10.05	Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility	UNECER10	"E-Mark"

4.2.1.2 United States of America

There are different approaches to certification in the USA. While in Europe the regulations are created as directives of governmental organizations, in the USA, only some areas are covered by the government – most of the standards are created by professional associations or by other private or non-governmental entities. The ratio of governmental to non-governmental regulations is much smaller in B2B area compared to B2C area.

Regarding the discussed product, the only governmental regulation is the title 47 (Telecommunications) of the Code of Federal Regulations (CFR), maintained by the Federal Communications Commission (FCC). [54]

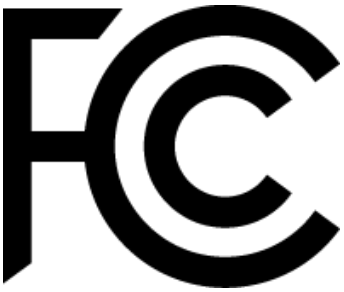


Figure 12: FCC logo [57]

Approach of the FCC to certification of the final product differs also in that if the final product consists only of radio frequency (RF) components that already are certified with the FCC, then the certification process of the final product is a lot different than in case when the final product contains some previously uncertified RF components. Once the final product is certified, it is assigned an "FCC ID", and all test reports, manuals, block diagrams and other documents are registered in a database managed by the FCC under the assigned FCC ID. Any user or buyer can verify the compliance with the requirements online at any time. [55] The final product must as well bear marking, labelling, and declaration of conformity depending on the certification process selected. [56]

In order to operate the device in cellular networks owned by US providers, it is necessary to certificate the device either directly with each individual operator, or with

PTCRB, where some of the local providers are associated. PTCRB has as well as FCC an online database where it is possible to verify, whether the product complies with the certificates or not. No labelling is involved in this process. [58]

Table 19 lists regulations along with information about what standards are followed during the testing (if any), and estimated costs necessary for completion of the process in the USA.

Table 19: USA compliance overview

Regulation	Standards	Costs [EUR]
FCC 47 CFR	OET KDB 447498 D01 Part 15B Part 15C Part 15.247 Part 24	5,000
PTCRB	-	17,500
Total		22,500

4.2.2 Development Process Standards

Besides regional specific compliance requirements, it is important to note that there are various standards that are not legally mandatory, but which are recommended to follow during the development process of a telematics device. Some deal with mechanical, electrical, or electronic design of the product, while other, such as IATF 16949:2016 and ISO 26262:2011, deal with the design or the development process.

IATF 16949:2016, "Automotive Quality Management System Standard", formerly known as ISO/TS 16949, is a standard based on ISO 9001 and derives as well from quality management system developed by VDA (German Verband der Automobilindustrie). VDA stands for Automobile Industry Association.

ISO 26262:2011, "Road Vehicles – Functional Safety" is an international standard for functional safety of electrical and/or electronic systems in automobile production.

4.3 Development Plan

It was noted already in chapter 2 that different companies have different approaches to product design and development. It is highly dependent on the industry and on the use case of the product. Example can be my experience at Openmatics – Openmatics is a young company that was founded in 2010. It is a subsidiary of ZF Friedrichshafen, which is an expert in driveline and chassis technology in automotive industry. Over a hundred years of its existence, ZF has created its universal product development process. It includes some

important aspects of VDA and ISO/TS 16949 standards. The process is very detailed and does not forget even the safety-relevant components that should be developed according to ISO 26262:2011. Openmatics however does not develop safety-relevant products – telematics is only installed in the vehicle as an aftermarket option – and the product as well does not participate in the driving process inside the vehicle – it only monitors the vehicle. Therefore, it was decided that development at Openmatics won't follow the complicated process, and that the company will rather create its own process. This stage-gate process that I practiced at Openmatics during development of various electronic devices is described in this section. Purpose of the section is to provide the reader with the idea of what needs to be done and how long it can take in order to develop the new telematics device. Assumed duration is based on my experience with development of Bach – a telematics device similar in complexity with the product discussed in this work.

4.3.1 Evaluation

Right after the approval of funding the project, evaluation of the components selected in Plan phase starts. The selected modules are ordered in the form of evaluation kits or evaluation boards – those are usually available from their manufacturers.

The components are thoroughly analyzed on hardware and software level. Design of individual circuits that will connect the components in a single product is started. Bill of material is being put together. Software compatibility is verified and in cases when any driver or library is missing for running the device under the final operating system is acquired directly in cooperation with the manufacturer, or is planned to be developed in the later stages of the development. In case any incompatibility is found, it is still possible to change to a different part at this stage.

Once the bill of material is complete and once it is confirmed that the necessary software is or will be available, the prototyping can start. Duration of this stage is expected to be 1 – 3 months for the discussed product.

4.3.2 Prototyping

Prototyping involves creation of a device that will include all the final components. A lot of tuning and debugging of both the electrical circuits and as well of software is involved in this stage. Various prototypes can be created in iterations, each improving the previous one. At the end of the stage, the final PCB should be specified.

The most of the software development takes place in this stage. It should be possible to run the components together on the software level, although not fully operationally, at the end of this stage. Prototyping is expected to take 3 – 5 months.

4.3.3 First Samples

With the "final" design of the PCB it is possible to create the product in its "final" form. "Final" with quotation marks, because in case some issues are encountered at this stage, when most of the climate, mechanical, electrical, and electromagnetic compatibility verification tests take place, the PCB might still need to be modified and a new iteration of the product created. The PCB at this stage is created using the "final" bill of material, but still soldered by hand in a laboratory.

This is probably the longest development stage, because of the demanding testing, but as well because of extensive development of the software. At the end of this stage, the software and the PCB should really be final. Length of this period is about 5 – 8 months.

4.3.4 Pre-Production

At this stage, the software should already be released in its first version that is fully capable of operating all parts of the device. The PCB is in its definitely final version as well.

This stage involves setting up of the manufacturing hall for mass production and certification of the device to demonstrate compliance with required regulations. A couple of units are produced with the final setting of the line and these are tested according to the standards. No errors should be encountered, because the device was already "pre-tested" against the standards in the previous stage. The mass production will start once the product is certified and the manufacturing hall set up. It takes about 1 – 3 months to complete this stage

4.3.5 Production

Once the product is certified and the production line perfectly set up, the production can start. It is usually done a couple of days or weeks before the final and official product launch, however the product can already be officially announced to market prior to the production start – already during the Pre-Production or First Samples stages.

4.3.6 Development Duration Summary

With the description of individual development stages, it is now possible to summarize the overall duration of the development project in case of this device.

Table 20: Development duration summary

Stage	Evaluation	Prototyping	First Samples	Pre-Production	Total Duration [months]
Shortest estimated duration [months]	1	3	5	1	**10**
Longest estimated duration [months]	3	5	8	3	**19**

4.4 Costs

Costs play an important role in Plan phase of product lifecycle management. A product manager should be able to estimate the necessary costs for development and unit production costs of the final product with rather high precision. That is possible under assumptions that the product manager has several years of experience and worked on development of products with similar complexity; and also that an experienced team which provides high quality of various inputs for the calculations is available to the product manager. The output of the estimation should be divided into the one-time costs that are necessary to create the product, and to the costs that will be recurring and depending on produced volume of units. Information about both of these costs types is crucial when the development project approval is taking place.[59][60]

4.4.1 One-Time Costs

These are all the costs necessary to take the product from Plan phase through Development, Qualify and Launch phases of the product management lifecycle.

4.4.1.1 Development Costs

As “development costs” I understand all costs that are involved in engineering of the new product – sourcing of necessary technical material that is consumed during the development process and all labor – any creative human effort – that leads to the finally functional product.

Development costs are very hard to estimate or calculate in advance, especially when a completely new product is supposed to be developed. It is a lot easier in case the company

already developed a product of similar complexity for similar use cases. That is the case of development of the device described in this work.

There are differences in calculation and accounting of the development costs in case the necessary expertise is available inside of the company, i.e. the company employs experienced engineers with all required skills; and in case the expertise must be sourced through external parties. I work in a company which employs skilled software engineers, but does not employ any electronics engineer. With regard to my employment, knowledge and experience, and to the purpose of this work, I will only state that the development costs for engineering of the electronic part of the product vary from 20,000 to 100,000 EUR. The costs for software development will be assumed as not covered by this development project.

4.4.1.2 Qualification Costs

These are the actual costs of tests necessary to be performed in order to verify durability of the product. The costs can be divided into two groups – the first one are the tests necessary to verify compliance with legal requirements; and the second one are various climatic, mechanical, electrical, and electromagnetic tests that are not legally mandatory but may be required by customers or company's regulations. The second group includes for example vibration, temperature, or humidity resistance tests, or resistance to electric discharge and electromagnetic interference. Costs of this verification can climb up to 150,000, depending on complexity of the testing. The first group includes certification that was described in chapter 4.1. It varies highly based on the target market. In case of the telematics unit with functionality described in this work, it ranges from 1,000 up to 20,000, based on the target market country. In either case, companies developing electronic devices usually source the testing in specialized laboratories, even if they have some testing chambers in their facilities, they are not usually able to cover all the tests and for all the target markets.

For purpose of this work, only costs for qualification of the device in the USA and the EEA were estimated in chapter 4.1. In total it is 53,000 EUR – 30,500 EUR for the EEA part, and 22,500 EUR for the USA part.

4.4.1.3 Other One-Time Costs

Besides the development and qualification costs, other one-time costs may be incurred in the Development, Qualify, and Launch phases. It highly depends on company size and processes how these are accounted. For purpose of this work, these costs are not covered.

It can be any operational costs that are incurred in order to introduce the product inside the company, such as trainings and workshops for employees, processes alterations, or business trips costs. Other than that it includes all marketing materials and costs for launching the product on the market, and as well costs for buying a production line, or altering the existing one.

4.4.1.4 Total One-Time Costs

In order to calculate the total one-time costs of the project, all the eventualities would have needed to be known. It is of course not possible to predict future, but it is possible to estimate the costs based on experience, statistics or with thorough investigation. For the final calculation, all the possible costs stated in the previous sections are summarized.

The costs of up to 150,000 for the environmental testing can be added on top of it.

Table 21: Total one-time costs

Type	Development	Qualification EEA	Qualification USA	Total
Minimal costs [EUR]	20,000	30,500	22,500	73,000
Maximal costs [EUR]	100,000	30,500	22,500	153,000

4.4.2 Manufacturing Costs

Manufacturing costs are the costs of producing individual pieces of the device. These costs need to be estimated in order to predict profitability of the product. This goes hand in hand with proposed selling price. The precision of the estimation is highly dependent on the bill of material of the product, and amount of expected units to be produced per year. Other factors that influence the final costs are overhead costs, material waste, and administration costs.

For purpose of this work, the costs will be calculated based on the components described in chapter 4.1. These are assumed to contribute to 60 % of the total bill of material costs. On top of that, overhead, material waste, and administration costs are considered as 10 % of the bill of material costs.

Because the costs of selected WLAN/BT and GNSS modules were unknown and because the costs for the modem were almost 5 times higher than the alternative costs, their costs will be assumed as 120 % of the most expensive alternative component in the selected group. Reasoning for this assumption is that u-blox is the leading manufacturer for automotive components in the selected groups and often slightly more expensive than its competition.

- GNSS: 19.02 x 1.2 = 22.82 EUR
- WLAN/BT: 20.98 x 1.2 = 25.18 EUR
- Modem: 36.65 x 1.2 = 43.98 EUR
- System: 96.30 EUR
- Total: 188.28 EUR

Table 22: Total unit costs

Item	60 % of BoM	BoM	10 % of BoM	Total Unit
Costs [EUR]	188.28	313.8	31.38	345.18

For comparison, the total unit costs of Bach were 343.69 EUR.

5 Discussion

The scope covered in this work is set to Plan phase of the product lifecycle management. The setting puts various limitations on the outcome of the work. These limitations are discussed in this section, as well as possible approaches to verify their extent.

5.1 Requirements

The requirements are written in a detail that reflects company's expertise in the industry.

In case the object of development was something completely new to the company – either the market or the product type – the spectrum of requirements would probably be narrower. This can however only be verified when two companies, two product types or two markets are compared in their approach to solving the problem.

The level of detail of each requirement description is adjusted to the common understanding inside the company. In case the company would need to involve other parties that are not on the same experience level, the specification would have needed to be reformulated into a sufficient level for the other party to understand it as well.

Software requirements are completely omitted in this work, because the intended recipients of this requirements specification are hardware development engineers and software development starts only once the hardware components are defined and available. The single software requirement which limits the possible hardware to be selected is summarized in chapter 3.2.3.5. The software requirements will need to be further specified in Development phase.

Requirements were collected in Conceive phase of the product which in this case is Deliver phase of the previous iteration of the product. There are several uncertainties that the product management must be aware of – all required features may not be known at the end of Plan phase and might be discovered at later stages. Such requirements can naturally not be covered in the specification.

5.2 Components Selection

Components to be looked for and compared during creation of the product specification were only 4. These were selected, because they were less than 2.5 % of the number of unique components in bill of material of the previous iteration of the product, but contributed to 60 % of the total material costs. It must be noted that some functionalities of the previous iteration of the product are removed in the new iteration and so the percentage of the contribution to total costs will increase along with the ration of unique components these parts contribute to. This is highly dependent on the final composition of the bill of material and as well the final costs of the individual parts.

The selection of individual parts that were pre-selected for comparison and finally selected for development, as well as attributes that were compared, were all chosen based on my experience, knowledge of the market and customer and company requirements. It is possible that there are more suitable components to fulfill the requirements and attributes to be examined that I am not aware of. It is possible that my final selection might not be the best fit.

Information about the parts available online is dependent on marketing strategy of the manufacturer. This is typical in business-to-business markets, that the information must be requested so that the communication channel once opened by requestor might be used as a sales channel by the manufacturer. For example, automotive standards applied in the manufacturing process of individual parts were chosen as one attribute for comparison. It is possible that also the parts that do not have the information available online might be

developed and produced following the standards. That can only be verified by direct communication with the manufacturers.

5.3 Compliance

Regulations and applicable standards necessary for the product to demonstrate its compliance with mandatory legal requirements, their costs and duration, were identified in cooperation with companies described in chapter 4.2.1.1. The scope is considered complete because the companies that helped in process of their identification are specialized in certifications and communication with them was held separately. I believe it is highly improbable that all three would have forgotten the same thing. It is still of course possible.

All environmental (climate, mechanical, electrical, and electromagnetic) testing and qualification that is not legally mandatory is left out in this work. Specific testing can be done based on company or customer requirements and it can span to hundreds of different test to be performed. The only information that is considered in this work is again coming from my experience with development of the previous iteration of the product, where the costs went up to 150,000 EUR and duration to finish the complete test set was estimated to 3 – 6 months.

There are 2 target markets that are considered for the product to be launched at – EEA and USA. In case any other country would be added to the list, based on my experience, additional costs of 1,000 – 20,000 EUR and duration of 1 – 3 months per market can be expected. It is highly dependent on target market, completion of product documentation and functionality, and capacity of testing laboratories. In some countries, it is sufficient to demonstrate compliance with standards of another country, while in others complete testing must take place directly in the country. In some countries the testing is legally required and standards are defined by the government, in others the market is free to implement its own standards. The contrast is visible between EEA and USA.

5.4 Development Plan

The development process selected is a stage-gate process that is derived from an internal directive of ZF Friedrichshafen and is enforced at company Openmatics. Because there is no binding public standardized process on how to develop an electronics device, besides the legal requirements the product must be compliant to, the processes are usually developed by companies themselves or adopted in cooperation with other companies, e.g.

in alliances, such as VDA. The selected process might not be the most suitable one, but in my experience it proved to be fulfilling company requirements. Research on possible development processes is however not in scope of this work.

Duration of individual phases and activities done in those phases are based on my own experience with development of the previous iteration of the product. The activities described in the process are related to hardware development, though other activities in product management lifecycle also take place in parallel.

5.5 Costs

The costs were divided into two groups to differentiate costs necessary to complete the development process and costs that are necessary to manufacture the product.

The one-time costs include costs necessary for development of the electronic part of the device and for its qualification. Other costs are not covered. The costs are estimated based on development of the previous iteration of the product. These however do not cover any effort related to software development, because the software is developed by employees of the company and company does not account the employment on individual projects. In my opinion whatever effort necessary to take the product from Plan to Deliver phases can be accounted. However, what should be covered in the final development costs is a decision of the company.

There are many limitations in the calculation of manufacturing costs of the product. It is estimated based on costs of the previous iteration of the product, and that only from knowledge of costs of parts that contributed to 60 % of the total material costs. Considering that some functionality was removed in the new iteration, the unit material costs of the final product will decrease. That is assumed in case the bill of material will remain the same and that other parts will contribute to the total costs in the same ratio as they did in the previous iteration of the product.

Costs of some parts with unknown price or with price sticking out were assumed as 120 % of the costs of the most expensive alternative component in the group. The material costs estimation counts with unit price that is stated for purchase of a single part. The part manufacturers usually provide discounts based on amount of ordered units. For more precise calculation the costs would need to be quoted at the manufacturer to get realistic prices.

Conclusion

The purpose of this work was description and demonstration of activities that a product manager needs to take care of in order to start development of a new product, particularly a new iteration of an existing product – an onboard telematics device for commercial road vehicles.

The setting in the product management lifecycle is right after completion of Conceive phase – in Plan phase – where rough product designing and project planning take place. Detailed design and project plan is not done in this phase, but rather in Development phase. Conceive phase is considered as complete, because the discussed product is the next iteration of an existing product.

Product requirements are written with the aim to cover all possible topics related to development of electronics part of the product, and its manufacturing; and to record them in detail necessary for internal understanding in the company, yet in detail comprehensible by electronics engineers.

Parts selection, project plan and costs estimation are labored highly thanks to my professional experience with the development of previous product iteration, and in order to deliver information based on which the decision whether development of the new product should start or not. There are various limitations in the resulting work – a lot of places where the estimations could be specified more precisely – but sufficient for the company needs and purpose of the work.

At the end I would like to note that product management lifecycle is a process that might take a few years, and in some cases even decades, from its start to its complete end. There are a lot of activities in all its phases that product management must take care of and it is an ongoing learning process. This work covers just a few of them in Plan phase; and from relatively high perspective. To demonstrate all activities in the complete lifecycle on more than one genuine example would in my opinion be work for as long as lifecycles of such products. Other phases from the lifecycle than the one described in this work, as well as other levels of detail could be covered in another work.

List of References

[1] Passenger transport statistics. *Statistics Explained* [online]. Luxembourg: Eurostat, 2018, 20 March 2018 [Accessed 2018-04-15]. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Passenger_transport_statistics

[2] Freight transport statistics. *Statistics Explained* [online]. Luxembourg: Eurostat, 2018, 20 March 2018 [Accessed 2018-04-15]. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Freight_transport_statistics

[3] Passenger transport demand: Is passenger transport demand being decoupled from economic growth?. *European Environment Agency* [online]. Copenhagen: European Environment Agency, 2018, 18 Oct 2017 [Accessed 2018-04-15]. Available at: https://www.eea.europa.eu/data-and-maps/indicators/passenger-transport-demand-version-2/assessment-9

[4] Road freight transport by vehicle characteristics. *Statistics Explained* [online]. Luxembourg: Eurostat, 2018 [Accessed 2018-04-15]. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Road_freight_transport_by_vehicle_characteristics

[5] Freight transport demand: Is freight transport demand being decoupled from economic growth?. *European Environment Agency* [online]. Copenhagen: European Environment Agency, 2018, 18 Oct 2017 [Accessed 2018-04-15]. Available at: https://www.eea.europa.eu/data-and-maps/indicators/freight-transport-demand-version-2/assessment-7

[6] PŘIBYL, Pavel. *Inteligentní dopravní systémy a dopravní telematika*. Praha: Nakladatelství ČVUT, 2005. ISBN 9788001031223.

[7] PŘIBYL, Pavel. *Inteligentní dopravní systémy a dopravní telematika II*. Praha: Nakladatelství ČVUT, 2007. ISBN 9788001036488.

[8] KŘIVDA, Vladislav, Ivana OLIVKOVÁ a Jindřich FRIČ. *Dopravní telematika*. Ostrava: VŠB – Technická univerzita, 2005. ISBN 9788024807676.

[9] GERACIE, Greg a Steven D. EPPINGER. *The Guide to the Product Management and Marketing Body of Knowledge: ProdBOK*. Carson City, Nevada: Product Management Educational Institute, 2013. ISBN 978-0-9845185-0-0.

[10] CRAWFORD, Merle and Anthony DI BENEDETTO. *New Products Management*. Eleventh edition. New York, NY: McGraw-Hill Education, 2015. ISBN 978-0-07-802904-2.

[11] CAGAN, Marty. *Inspired: How to Create Products Customers Love*. San Francisco, CA: SVPG Press, 2008. ISBN 978-0-9816904-0-7.

[12] CAGAN, Marty. *INSPIRED: How to Create Tech Products Customers Love*. Second Edition. Hoboken, New Jersey: John Wiley, 2017. ISBN 978-1-119-38750-3.

[13] LAWLEY, Brian. *The Phenomenal Product Manager: The Product Manager's Guide to Success, Job Satisfaction and Career Acceleration*. Silicon Valley, California, USA: Happy About, 2009. ISBN 978-1-60005-134-0.

[14] ANDERSON, Allan M. *Product Development and Management Body of Knowledge: A Guidebook for Training and Certification*. North Charleston, SC: CreateSpace Independent Publishing Platform, 2017. ISBN 978-1-5448-9338-9.

[15] MIRONOV, Rich. *The Art of Product Management: Lessons from a Silicon Valley Innovator*. Mountain View, CA: Enthiosys, 2008. ISBN 1-4392-1606-1.

[16] *Technical Papers on the Development of Embedded Electronics*. Stuttgart: Vector Informatik, 2016.

[17] REIF, Konrad and Karl-Heinz DIETSCHE. *Automotive Handbook*. 9th Edition revised and extended. Karlsruhe: Robert Bosch, 2014. ISBN 978-1-119-03294-6.

[18] JANOTA, Aleš, Mária FRANEKOVÁ, Peter HOLEČKO, et al. *Aplikovaná telematika*. Žilina: Žilinská univerzita v Žiline, 2015. ISBN 978-80-554-1037-1.

[19] PŘIBYL, Pavel a Miroslav SVÍTEK. *Inteligentní dopravní systémy*. Praha: BEN - technická literatura, 2001. ISBN 80-7300-029-6.

[20] GOEL, Asvin. *Fleet Telematics: Real-time management and planning of commercial vehicle operations*. 1. New York: Springer Science+Business Media, 2008. ISBN 978-0-387-75104-7.

[21] Zahájení pilotního provozu odbavení pomocí bezkontaktní bankovní karty. *Plzeňské městské dopravní podniky, a.s.* [online]. Plzeň: Plzeňské městské dopravní podniky, 2015, 29. 4. 2015 [Accessed 2018-04-19]. Available at: http://www.pmdp.cz/o-nas/aktualne/doc/zahajeni-pilotniho-provozu-odbaveni-pomoci-bezkontaktni-bankovni-karty-1574/newsitem.htm

[22] BS 153 Intelligent bus stop. *BUSE s.r.o.* [online]. Blansko: BUSE, 2017 [Accessed 2018-04-19]. Available at: http://www.buse.cz/en/intelligent-bus-stops/bs-153-intelligent-bus-stop

[23] TRAFFIC LOGIX® SAFEPACE® 600 VARIABLE MESSAGING SIGN. *Fortran Traffic Systems Limited* [online]. Fortran Traffic Systems Limited, 2018 [Accessed 2018-04-19]. Available at: http://www.fortrantraffic.com/shop/detection/traffic-logix-safepace-550-variable-speed-limit-sign-copy/

[24] Global Positioning System History. *NASA* [online]. Washington, DC: NASA, 2017, Aug. 7, 2017 [Accessed 2018-04-24]. Available at: https://www.nasa.gov/directorates/heo/scan/communications/policy/GPS_History.html

[25] The Traffic Message Channel (TMC). *TISA: Traveller Information Services Association* [online]. Brussels: TISA, 2018 [Accessed 2018-04-24]. Available at: http://tisa.org/technologies/tmc/

[26] ECall in all new cars from April 2018. *Digital Single Market* [online]. Brussels: European Commission, 2018, 28 April 2015 [Accessed 2018-04-24]. Available at: https://ec.europa.eu/digital-single-market/en/news/ecall-all-new-cars-april-2018

[27] Od roku 2015 budou nová auta v EU vybavena štěnicí. *Diit.cz: DEEP IN IT* [online]. Praha: CDR server, 2018, 2. 7. 2012 [Accessed 2018-04-24]. Available at: https://diit.cz/clanek/ecall-povinna-stenice-v-autech-od-roku-2015

[28] ERIKSSON, Martin. The History and Evolution of Product Management. *Mind the Product* [online]. London: Mind the Product, 2017, OCTOBER 28, 2015 [Accessed 2018-05-05]. Available at: https://www.mindtheproduct.com/2015/10/history-evolution-product-management/

[29] ERIKSSON, Martin, Richard BANFIELD a Nate WALKINGSHAW. The evolving role of product management: What product management is and why it's so relevant today. *O'Reilly Media* [online]. Sebastopol, California: O'Reilly Media, 2018, June 22, 2017 [Accessed 2018-05-05]. Available at: https://www.oreilly.com/ideas/the-evolving-role-of-product-management

[30] OPTIMAL PRODUCT PROCESS™: A Flexible Framework for Highly-Effective Product Management and Product Marketing across the Entire Product Lifecycle [online]. Second Edition. Campbell, California, USA: 280 GROUP PRESS, 2014 [Accessed 2018-05-05]. ISBN 09-850-3120-4. Available at: https://280group.com/products/books/optimal-product-process/

[31] *Manifesto for Agile Software Development* [online]. Snowbird Utah: Agile Alliance, 2001 [Accessed 2018-05-05]. Available at: http://agilemanifesto.org/

[32] *The Project Cartoon* [online]. The Project Cartoon, 2006 [Accessed 2018-05-05]. Available at: http://www.projectcartoon.com/

[33] *Future Electronics* [online]. Quebec, Canada: Future Electronics, 2018 [Accessed 2018-05-19]. Available at: http://www.futureelectronics.com

[34] NEO-M8L series. *U-blox* [online]. Thalwil, Switzerland: u-blox, 2018 [Accessed 2018-05-19]. Available at: https://www.u-blox.com/en/product/neo-m8l-series

[35] Dead Reckoning - SL869-ADR. *Telit* [online]. London, UK: Telit, 2018 [Accessed 2018-05-19]. Available at: https://www.telit.com/m2m-iot-products/positioning-timing-modules/dead-reckoning-sl869-adr/

[36] AirPrime® XA1110 Multi-GNSS Module with Patch Antenna. *Sierra Wireless* [online]. Richmond, Canada: Sierra Wireless, 2018 [Accessed 2018-05-19]. Available at: https://www.sierrawireless.com/products-and-solutions/embedded-solutions/products/xa1110/

[37] *DigiKey* [online]. Thief River Falls, Minnesota, USA: DigiKey, 2018 [Accessed 2018-05-19]. Available at: https://www.digikey.cz

[38] Automotive-Grade Modules for Connecting Next-Gen Smart Cars. *Sierra Wireless* [online].

Richmond, Canada: Sierra Wireless, 2018 [Accessed 2018-05-19]. Available at: https://www.sierrawireless.com/products-and-solutions/embedded-solutions/automotive-modules/

[39] MU709s-2. *Huawei Official Site* [online]. Shenzhen, China: Huawei Technologies Co., 2018 [Accessed 2018-05-19]. Available at: http://consumer.huawei.com/solutions/m2m-solutions/en/products/tech-specs/mu709s-2-en.htm

[40] *Paoli.cz* [online]. Praha: PAOLI trade, 2018 [Accessed 2018-05-19]. Available at: https://www.paoli.cz

[41] TOBY-L2 series. *U-blox* [online]. Thalwil, Switzerland: u-blox, 2018 [Accessed 2018-05-19]. Available at: https://www.u-blox.com/en/product/toby-l2-series

[42] *TME Czech Republic s.r.o.* [online]. Ostrava: TME Czech Republic, 2018 [Accessed 2018-05-19]. Available at: https://www.tme.eu

[43] JODY-W1 series. *U-blox* [online]. Thalwil, Switzerland: u-blox, 2018 [Accessed 2018-05-20]. Available at: https://www.u-blox.com/en/product/jody-w1-series

[44] Sterling-LWB5: Dual-Band 802.11ac Wi-Fi + Bluetooth v4.2 Combo Module. *LSR* [online]. Cedarburg, USA: LSR, 2018 [Accessed 2018-05-20]. Available at: https://www.lsr.com/embedded-wireless-modules/wifi-plus-bluetooth-module/sterling-lwb5

[45] ATSAMA5D27-SOM1. *Microchip Technology* [online]. Chandler, USA: Microchip Technology, 2018 [Accessed 2018-05-20]. Available at: http://www.microchip.com/wwwproducts/en/atsama5d27-som1

[46] SCM-i.MX6D: Single Chip Module-i.MX 6D. *NXP Semiconductors* [online]. Eindhoven, Netherlands: NXP Semiconductors, 2018 [Accessed 2018-05-20]. Available at: https://www.nxp.com/products/single-chip-modules/single-chip-module-i.mx-6d:SCM-i.MX6D

[47] PhyCORE®-i.MX 6. PHYTEC [online]. Mainz, Germany: PHYTEC, 2018 [Accessed 2018-05-20]. Available at: http://www.phytec.eu/product/system-on-modules/phycore-imx-6/

[48] SOM-6X50. *VIA Technologies, Inc.* [online]. New Taipei City, Taiwan: VIA Technologies, 2018 [Accessed 2018-05-20]. Available at: https://www.viatech.com/en/boards/modules/som-6x50/

[49] *Arrow Electronics, Inc.* [online]. Centennial, USA: Arrow Electronics, 2018 [Accessed 2018-05-20]. Available at: https://www.arrow.com/

[50] HEATH, Steve. *Embedded systems design*. 2nd ed. Boston: Newnes, 2003. ISBN 978-0750655460.

[51] CE marking. *Growth: Internal Market, Industry, Entrepreneurship and SMEs* [online]. Brussels, Belgium: European Commission, 2018, 2018-05-21 [Accessed 2018-05-21]. Available at: https://ec.europa.eu/growth/single-market/ce-marking_en

[52] The 'Blue Guide' on the implementation of EU product rules 2016. *Growth: Internal Market, Industry, Entrepreneurship and SMEs* [online]. Brussels, Belgium: European Commission, 2018, 2016-07-26 [Accessed 2018-05-21]. Available at: http://ec.europa.eu/DocsRoom/documents/18027/

[53] Agreement Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions: Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility. In: Geneva, Switzerland: United Nations Economic Commission for Europe, 2014, Revision 5, Addendum 9: Regulation No. 10. Available also at: https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2015/R010r5e.pdf

[54] *Electronic Code of Federal Regulations* [online]. Washington, DC: Federal Register, 2018 [Accessed 2018-05-21]. Available at: https://www.ecfr.gov/

[55] FCC ID Search. Federal Communications Commission [online]. Washington, DC: Federal Communications Commission, 2018 [Accessed 2018-05-21]. Available at: https://www.fcc.gov/oet/ea/fccid

[56] 784748: Labeling and user information. *Federal Communications Commission* [online]. Washington, DC: Federal Communications Commission, 2018 [Accessed 2018-05-21]. Available at: https://apps.fcc.gov/oetcf/kdb/forms/FTSSearchResultPage.cfm?switch=P&id=27980

[57] Logos of the FCC. *Federal Communications Commission* [online]. Washington, DC: Federal Communications Commission, 2018 [Accessed 2018-05-21]. Available at: https://www.fcc.gov/general/logos-fcc

[58] *PTCRB* [online]. Washington, DC: CTIA Certification, 2018 [Accessed 2018-05-21]. Available at: https://www.ptcrb.com/

[59] OSTWALD, Phillip F. a Timothy S. MCLAREN. *Cost Analysis and Estimating for Engineering and Management*. 4th ed. New York, USA: Pearson, 2003. ISBN 978-0-13-142127-1.

[60] ISON, Stephen. *Economics*. 4. ed. Upper Saddle River, New Jersey: Financial Times Prentice Hall, 2007. ISBN 9780273681076.

Appendix A:

OPENMATICS

Intelligent Connectivity Solutions

TELEMATICS SOLUTION

Bach Onboard Unit Datasheet

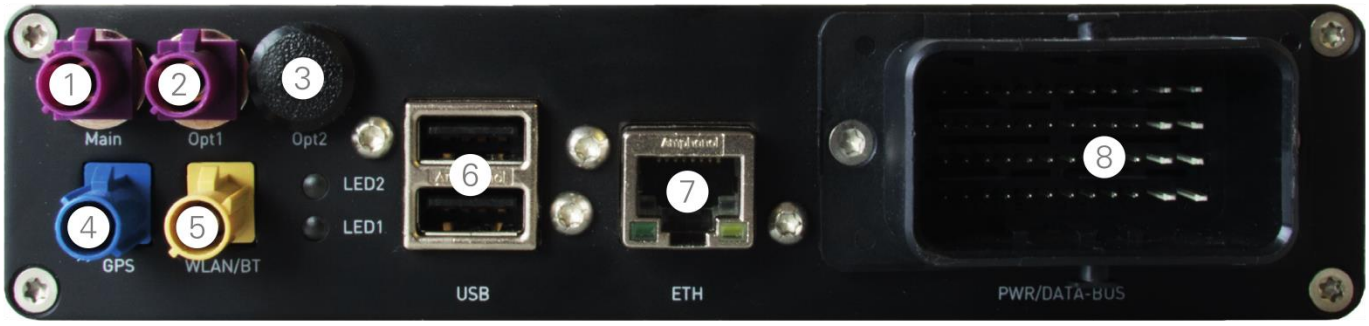
Openmatics s. r. o.
Podebradova 2842/1
301 00 Pilsen
Czech Republic

Phone: +420 371 150 000
Fax: +420 371 150 001
E-mail: info.openmatics@zf.com
Web: www.openmatics.com

OPENMATICS is a brand of ZF

Bach Onboard Unit

1. Cellular Antenna Connector (Main)
2. Optional Connector 1 (e. g. Cellular or WLAN AP)
3. Optional Connector 2
4. GPS Antenna Connector
5. WLAN/Bluetooth Antenna Connector
6. 2x USB Connector (Type-A)
7. Ethernet Connector (RJ45)
8. 48-pin Molex Connector (Power Supply, CAN, GPIO)



SYSTEM

CPU	ARM® 1 GHz
RAM	1 GB
System Memory	1 GB (Flash), 1 GB (MicroSD) – expandable
Sensors	GPS 3D Gyroscope Altimeter 3D Accelerometer 3D Magnetometer (Compass)
Operating System	Linux Based

CONNECTION

WLAN	802.11 a/b/g/n (2.4 / 5 GHz)
Bluetooth	Bluetooth 4.0
Communication	GSM/UMTS/LTE (2G/3G/4G)

CONNECTORS

Automotive Connector MOLEX (48 pins)	6x Digital Input 4x Digital Output 4x CAN 2x K-Line 1x J1708 2x RS232 1x 1-Wire 1x VOut 5 V/1 A
LAN	10/100 Mbit Ethernet
USB	2x USB 2.0
FAKRA Antenna Connectors	2x 2G/3G/4G Antenna 1x GPS 1x WLAN/Bluetooth 1x Optional (e.g. for WLAN AP or Powerless Switch)

DIMENSIONS (l × w × h)	165 x 105 x 38 mm
VOLUME	0.78 l
WEIGHT	510 g
POWER CONSUMPTION (working mode)	< 150 mA @ 24 V
POWER CONSUMPTION (standby mode)	< 1 mA @ 24 V
POWER SUPPLY	12/24 V DC
OPERATING RANGE	-40 °C to +85 °C

Bach Onboard Unit

COMMUNICATION AND INTERFACES

2 Embedded SIM cards and 1 Mini SIM Card

Modem with diversity, 2G/3G/4G

1x Ethernet 10/100 Mbit

1x WLAN 802.11 a/b/g/n

1x Bluetooth 4.0

2x USB 2.0

4x CAN

2x RS232

1x RS485 (J1708)

1x Bi-Directional K-Line

1x Uni-Directional K-Line

6x Digital Input

4x Digital Output

1x 1-Wire

3 PROCESSOR UNITS

Device Management Unit (DMU)

Signal Management Unit (SMU)

Application Management Unit (AMU) based on ARM Microprocessor

SENSOR NETWORK

GPS

3D Gyroscope

Altimeter

3D Accelerometer

3D Magnetometer (Compass)

POWER SUPPLY

Nominal Voltage: 12/24 V

Working: < 150 mA @ 24 V

Standby: < 1 mA @ 24 V

MEMORY

1 GB DDR3 RAM

1 GB NAND Flash

1 GB microSD Memory Card

SYSTEM

Openmatics Linux Distribution

OSGi Framework

MECHANICAL

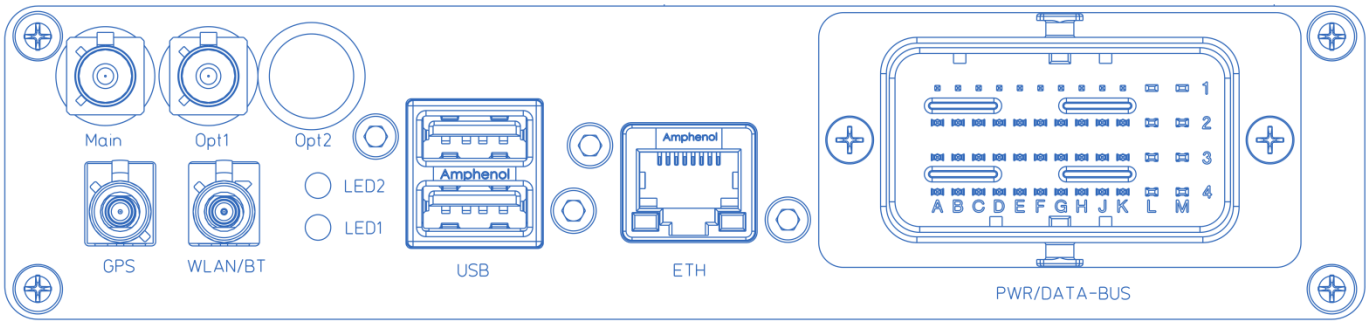
Aluminum housing

Operating temperature from-40°C to +85°C

Compact size: 165 x 125 x 38 mm (including connectors)

Weight: 510 g

Volume: 0,78 l



Bach Onboard Unit – different versions

ZF PART NO.	DESCRIPTION
0501.221.222	On-Board Unit Bach with 3G modem and 1-GB MicroSD Card for European market; 1st generation
0501.221.506	On-Board Unit Bach with 3G modem and 1-GB MicroSD Card for European market; 2nd generation
0501.222.328	On-Board Unit Bach with 4G modem and 1-GB MicroSD Card for European market; 3rd generation
0501.222.329	On-Board Unit Bach with 4G modem and 4-GB MicroSD Card for European market; 3rd generation
6075.010.003	On-Board Unit Bach with 4G modem and 1-GB MicroSD Card for American market; 1st generation
0501.223.311	On-Board Unit Bach with 4G modem and 1-GB MicroSD Card for American market; 3rd generation