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FACULTY OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING

Yifei Zuo

MOBILE APPLICATION TO SUPPORT FUEL-EFFICIENT DRIVING THROUGH SITUATION AWARENESS

Master’s Thesis
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ABSTRACT

Situation awareness is usually conceptualized as design and implementation principles for safety critical industries like aviation or military. Finland was one of the first countries in the world to establish an intelligent transport systems (ITS) strategy in 2009. Increasing the situation awareness in traffic is regarded as one of the means to implement the strategy.

In the theoretical part of this thesis, we explore the use of situation awareness and context awareness in intelligent transport systems. Particularly, the thesis focuses on summarizing proper design and evaluation principles to provide situation awareness support for fuel efficient driving. These guidelines were exploited in implementing a mobile application, called Driving Coach Mobile Application in the practical part of the thesis. The purpose of the application is to provide awareness to the drivers about how they can save fuel. Driving Coach Mobile Application's accordance of design and implementation principles to situation awareness support is validated by user study with simulated data focused on usability, usefulness and fuel efficiency awareness support. The results of this thesis can be used in fleet management planning, city planning as well as in personal driving, for example.

Keywords: Situation awareness, Intelligent Transportation System, fuel efficiency

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TIIVISTELMÄ

Turvallisuuskriittisissä teollisuuden osa-alueissa kuten ilmailussa tai sotilaallisessa toiminnassa, eri toimijoiden tilannetietoisuuden parantamiseen tähtäävät suunnittelu- sekä toteutusperiaatteet ovat olleet merkittävässä roolissa jo pitkään. Suomi oli maailman ensimmäisiä maita, jotka julkistivat älykkään liikenteen strategian jo vuonna 2009. Tilannetietoisuuden parantaminen liikenteessä on edelleen eräs tämän strategian toimeenpanomuoto.

Tämän työn teoreettisessa osassa tutkitaan avulla tilannetietoisuuden sekä toimintatilanteesta tietoisuuden soveltamista älyliikenteessä. Erityisesti tarkastellaan suunnittelu- sekä evaluointiperiaatteita polttoainetalouden tehokkuuden lisäämiselle tilannetietoisuuden avulla. Työn käytännön osuudessa sovellettiin näitä periaatteita mobiilisovelluksen toteuttamiseksi. Mobiilisovellus tukee kuljettajien polttoainetehokkaampaa ajamista. Sovellus testattiin käytettävyyden, hyödyllisyyden sekä polttoainetehokkaan ajamisen tuen suhteen. Sovellusta voidaan käyttää esimerkiksi kaupunkisuunnittelussa, autokannan toiminnan tarkkailemisessa tai vaikka henkilökohtaisen ajotavan arvioinnissa.

Avainsanat: tilannetietoisuus, älyliikenne, polttoainetalous

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FOREWORD

This thesis was implemented for Center for Ubiquitous Computing at University of Oulu, Finland.

First, I would like to show my thanks to my supervisor D.Sc. (tech.) Ekaterina Gilman, for all the support and valuable instructions given during the whole project. To do thesis, I would like to thank D.Sc. (tech.), M.Sc. (math.) Susanna Pirttikangas for providing the opportunity and improving advices. In addition, I would like to thank Mikko Pyykkönen for designing the application themes and layout.

Second, I would like to thank my friends who care and concern about me whenever needed. Thanks for my colleagues who support me to learn more and gain more. Thanks for the one who is always standing on my side.

Finally, I would like to thank my grandmother, my aunts and my family for endless support and encouragement during this thesis.

Oulu, 03.05.2017

Yifei Zuo

ABBREVIATIONS

C4i	command, control, communication, computers and intelligence
CA	Context Awareness
DAS	Driving Assistant System
DCMA	Driving Coach Mobile Application
DR	Driving Coach
EDAS	Eco-Driving Assistant system
GUI	Graphical User Interface
ITS	Intelligent Transportation Systems
JSON	JavaScript Object Notation
REST	Representational State Transfer
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SART	Situation Awareness Rating Technique

1. INTRODUCTION

1.1. Situation Awareness

Situation awareness (SA) is concerned about human comprehension of the real situation of the environment [1, 2]. Different definitions of SA exist. For example, Smith and Hancock consider it as the appropriate awareness of situation [3]. Endsley considers “Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and a projection of their status in the near future” [4]. Bedny and Meister illustrate “Situation awareness is the conscious dynamic reflection on the situation by an individual. It provides dynamic orientation to the situation, the opportunity to reflect not only the past, present and future, but the potential features of the situation. The dynamic reflection contains logical-conceptual, imaginative, conscious and unconscious components which enables individuals to develop mental models of external events” [5].

In 1995, Endsley came up with a model of SA, as shown in Figure 1 (redrawn from [6]). In this model, SA consists of 3 levels. The three levels are: “Perception of elements in the environment (Level 1), Comprehension of the current situation (Level 2), Projection of future status (Level 3)” [6]. At level 1, the most relevant elements of surroundings are gathered. At the level 2, situation is comprehended by integration and synthesizing the elements of level 1. Therefore, holistic picture of environment is created. Level 3 is the highest level of SA and it is responsible for projecting the future actions based on level 1 and 2.

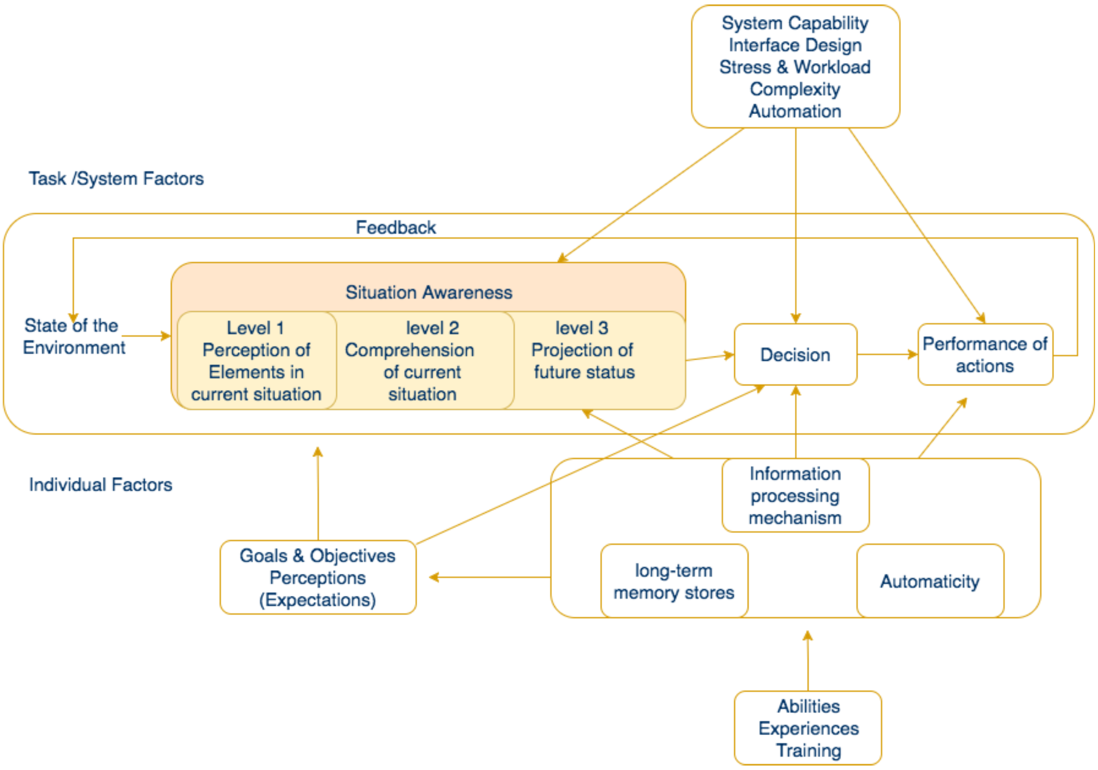


Figure 1. Model of situation awareness and dynamic decision making.

According to this model, SA directly influences people’s decision making. The decision made guides actions to perform. After actions are taken, changes in the environment form the components of a new situation. Driven by goals and objectives, the perceptions or expectations of different situations might be different. However, it's important to separate SA from decision making. As Endsley illustrated [4], if the perception of SA is incomplete or inaccurate, even the pilot with great experience might make a wrong decision, and in turn, a pilot may not be able to take correct action even with accurate understanding of SA. In addition, Endsley reminds one critical aspect of operators involved is that they may be very active and able to control the system to collect certain information through sending out commands instead of passively receiving information only. Besides, working memory, long-term memory, goals and attention influence the individual operators for the accuracy and completeness of SA. Moreover, there is another term defined as Team SA, "the degree to which every team member process the SA needed for his or her job" [6]. In other words, from SA perspective, sharing SA elements is important in the whole team. It is not enough and might cause errors if only one person in a team has the SA [7].

In ubiquitous computing domain, context-awareness term is related to SA. Context is known as "any information that can be used to characterize situation of an entity" [8], where the entity can be a location, a person or an object if they are relevant to a user and application interaction, as well as changes of objects. Context Awareness (CA) defined by Dey and Abowd is "A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task." [9].

Some authors consider SA and CA has the same meaning and use them interchangeably. Kofod and Aamodt [10] came up with a three layered architecture for AmICREEK system comparable to Endsley's model of SA. In this architecture, CA and SA are used synonymously. The second layer aims at exhibiting CA which is considered to be comparable to Comprehension (level 2) in Endsley model and the context relevant goal acquisition highlighted by third layer of this architecture is claimed to be equivalent to Projection (level 3) of Endsley model.

For some specific cases, researchers benefit from the integration of SA with CA. Feng et al. [11] propose to model SA for Context-aware decision support where a system provides an operator with services and information from a group of entities combining with a shared SA model. They prove that for accomplishing situation assessment, utilizing CA can be a good way and the support of context-aware decision helps human operators for achieving cognition of SA.

Other researchers differentiate the two concepts. For example, in pervasive computing, Boytsov [8] points out that SA, aiming to interpret real-life situation from context data, is considered to be the highest level of context generalization. Alcaraz and Lopez [12] states that the differentiation of SA and CA exists from the level of abstraction model, representation and granularity of context. That is, context aware system delivers information to low-level representations of physical events via sensor devices to offer an accurate picture of a situation. In contrast, SA stands in a high-level with knowledge state to explain at a certain moment what an application domain experiences. For further understanding of the two concepts, Endsley [13] explains that SA is defined as an operational term which concerns about goals and decisions of a given operator. The operators are people who needs SA for a specific reason. Those who might have SA but not involved in an objective are excluded from the definition of operators. Whereas CA doesn't concern about operators much.

1.2. Intelligent Transportation Systems

Intelligent Transportation Systems (ITS), in general, adapt a variety of innovative technologies and operation methods to help resolve issues like traffic accidents, traffic congestion, transport efficiency and emissions raised by modern transportation environment [14, 15]. In short, ITS aim at utilizing appropriate technologies to create intelligent roads, vehicles and support users [16].

There are three phases of ITS development history: preparation (1930–1980), feasibility study (1980–1995) and product development (1995-present) [17]. At the first period, because of lack of mature technology and reduced attention, ITS progressed slowly. The first ITS is considered to be electric traffic signals installed with only, red and green lights which still need additional bell as color changing reminder [18]. The ITS development boost occurred during feasibility study period by the prompt of government and industry. Several key projects like AHS (Automated Highway System) in United States have already fully automated test vehicles on highway [19], an European project named VITA II [20] adopted 10 cameras and 60 processors helping control the vehicle in the center of a lane, change lanes, keep safe distance and overtake. At the last phase, researchers are facing the challenges of large-scale integration for developed transportation systems and create feasible solutions. Moreover, modern ITS feature big data processing and storage aspects, as well as security and privacy issues [21].

According to Figueiredo et al. [16], ITS can be categorized depending on the purpose as follows:

1. Advanced Traffic Management Systems are systems managing traffic service and reducing traffic delays by controlling traffic signals.
2. Advanced Traveler Information Systems help drivers reach their destinations more efficiently, more environmentally friendly through offering optimized travelling routes.
3. Commercial Vehicle Operation are systems in use by logistics companies which need low cost, fast goods delivery, hospitals or institutes providing people transportation services.
4. Advanced Public Transportation Systems are focusing on managing the schedule of buses and trains, improving massive public transport service and control cost as well.
5. Advanced Vehicle Control Systems with the in-vehicle devices installed could help, for example, with acceleration, breaking, steering and cruise control. As driving environment has become very complicated, for the safety purposes, auxiliary systems are developed like in-vehicle information systems, advanced driver assistance systems and roadside telematics.
6. Advanced Rural Transportation Systems aim at improving transportation of rural place.

1.3. Situation Awareness in Intelligent Transportation Systems

In 2001, Stanton pointed out that SA has gained a lot of attention from researchers and applications of SA have covered the domain of transportation [2]. Therefore, the understanding of SA in transportation domain seems to be necessary.

From the driving view point, Matthews et al. [22] outlined spatial awareness, identity awareness, temporal awareness, goal and system awareness aspects to achieve SA. Spatial awareness means acknowledgements of environment and location features. Identity awareness means perception of salient items. Temporal awareness means awareness of changes over time. Goal awareness includes three levels of goals: navigate to destination, keep speed and direction, and maneuver vehicle in traffic. System awareness means awareness of system information inside a large driving environment.

Basically, a driving trip always starts from choosing a destination and making a driving plan. If driving on frequently used routes, there is not much demanding for driver for route awareness as information is stored in long-term memory. For unfamiliar places, challenges include and not limited by knowledge of road, trip schedule and weather information. Changing lanes, overtaking, giving way and speed management decisions require understanding of current situation and prediction of situation changes. In a lower level, steering wheel control, gear control, acceleration and breaking control also require monitoring information of those actions. Matthews et al. [22] define three levels of SA. SA level 1 is required for drivers to maintain stable control of vehicle and ensure actions are taken appropriately. Level 2 of SA is needed to maneuver vehicle in traffic stream. Level 3 of SA contributes to projection of environment. At the same time, for comprehension of driving situation, both level 1 and level 2 are required. Based on this understanding, Ma and Kaber [23] proposed a driver information processing model in Figure 2 (redrawn from [23]). This model provides an operational definition of SA in driving domain.

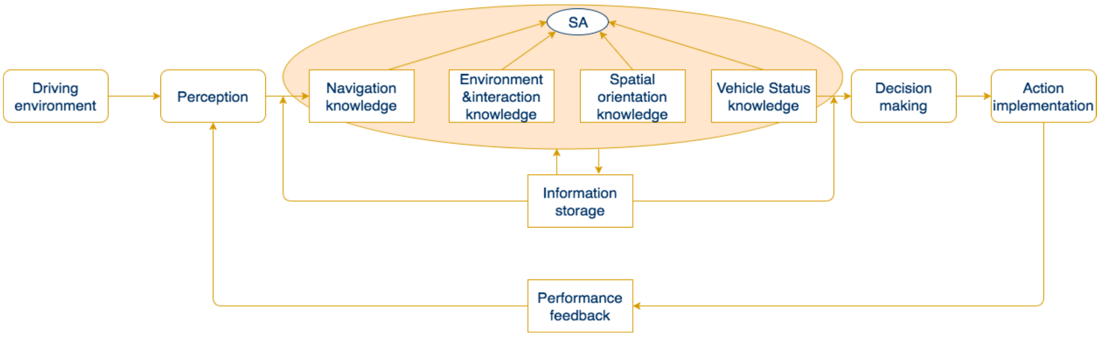


Figure 2. SA in driving information processing model.

The importance of SA for drivers is obvious. With low SA, severe accidents may happen. Endsley [24] mentioned that a loss of SA is the reason of incidents mostly caused by human error. Ding et al. [25] illustrated the relation between situation safety awareness and cognitive failure in Figure 3 (redrawn from [25]) which indicates that a higher cognitive failure lowers the possibility of being safe.

For ITS, it is hard to say in a simple way whether they in general could enhance SA or impair SA. Matthews et al. [22] reviewed some studies which focus on finding out an effective way of navigation. Their studies demonstrated that both providing drivers a verbal direction and giving them a map could benefit driving performance. The reason is that route navigation system, which gathers and delivers more information to drivers, helps improve knowledge of road situation. However, they also pointed out that ITS may decrease SA if drivers' mental workload is too high, for example, when several verbal instructions come at the same time. In 2005, Ma and Kaber [23] developed a 3D virtual reality system with a stereo display, physical steering wheel, physical gas and brake pedal to simulate driving environment and investigated impact of using in-vehicle mobile phone on drivers' SA. The result from this study showed that cell phone conversation may decrease SA due to increased workload and lead to a decrease of driving performance. In 2007, Ma and Kaber [26] found that accurate navigation information is able to enhance drivers' SA and driving performance. Moreover, both mobile phone and laptop were considered useful to show navigation information.

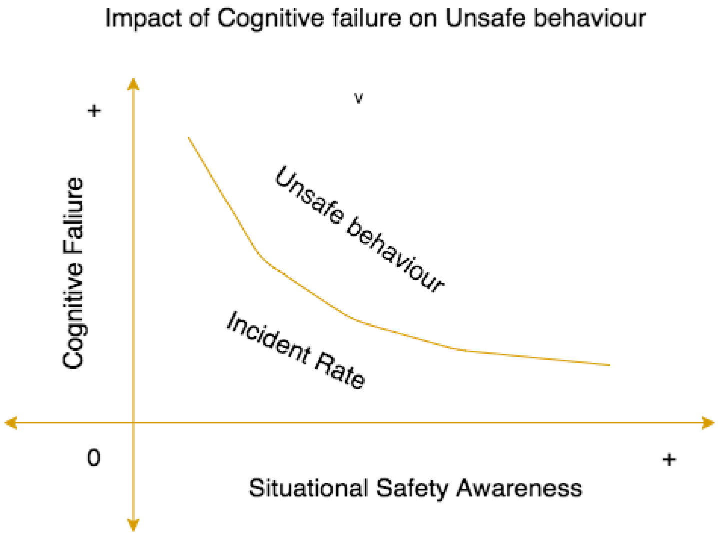


Figure 3. Situation safety awareness and cognitive failure.

Matthews et al. [22] proposed principles to minimize errors for the design of ITS to achieve SA: "

- For warning and alerting systems, maximize the rapid detection of new information (Level 1).
- For information systems, minimize the impact on the driver's existing process of scanning and information acquisition (Level 2).
- Design information content in a format that allows it to be rapidly integrated with other information that is held in SA (Level 2).
- Ensure that the format of the information is consistent with the driver's relevant mental model (Level 2).
- For multiple in-vehicle systems, ensure that visual and auditory warnings and alerts are unambiguous and consistent with the relevant driver's mental model (Level 1 and 2).
- In the absence of specific mental model, avoid in designs information density that exceeds the capacity of working memory. (Level 2 and 3).
- Minimize the requirement for the driver to develop new mental models to process the information to avoid imposing a cognitive load associated with the requirement to juggle mental models (Level 2 and 3).
- Consider any training requirements that may be necessary to facilitate the rapid integration of the new technology into the driver's existing mental models (Level 2 and 3)."

The question of how to follow those principles for a specific system and condition is open. Furthermore, evaluation of specific systems offers challenges.

1.4. Objectives and scope of thesis

The focus of this thesis is to explore how to properly design ITS to support SA for the users. Particularly, it is focused on ITS supporting fuel efficient driving. Moreover, evaluating ITS solutions supporting SA is a challenge. Therefore, this thesis also aims to contribute to this issue.

The objectives of the thesis are as follows:

Objective 1. Study related work about SA, CA, ITS, and SA support with proper ITS design and implementation.
Objective 2. Based on literature review, develop design principles and evaluation guidelines towards ITS supporting SA.
Objective 3. Implement and analyze ITS supporting SA by following identified principles and evaluate it with proposed guidelines.

1.5. Structure

This thesis consists of 10 chapters, as can be seen from Figure 4. Chapter 1 introduces definitions of several concepts: SA, ITS and how SA is understood in transportation domain. Objectives of thesis are also formulated in Chapter 1. Chapter 2 talks about fuel economy research and what are the factors related to fuel economy. Also, how SA is utilized to support fuel-economy. Chapter 3 collects studies on how to deliver information in efficient and precise manner. Then, there are proposed design principles based on the studies. Chapter 4 overviews measurements of evaluating SA and develops guidelines for evaluating how SA is supported in terms of fuel economy. Chapter 5 shows how the proposed design principles are used in the Driving Coach mobile client application. Then, in Chapter 6, it tells how the mobile application is implemented by demonstrating its protocol, class diagrams and graphical use interface. Chapter 7 evaluates the system following the developed evaluation guidelines and discusses system limitations. Chapter 8 concludes how the thesis objectives are achieved and draws a picture of future work. Chapter 9 lists all the references of studies mentioned in the thesis. And Chapter 10 lists one appendices of how to install the system future work development environment.

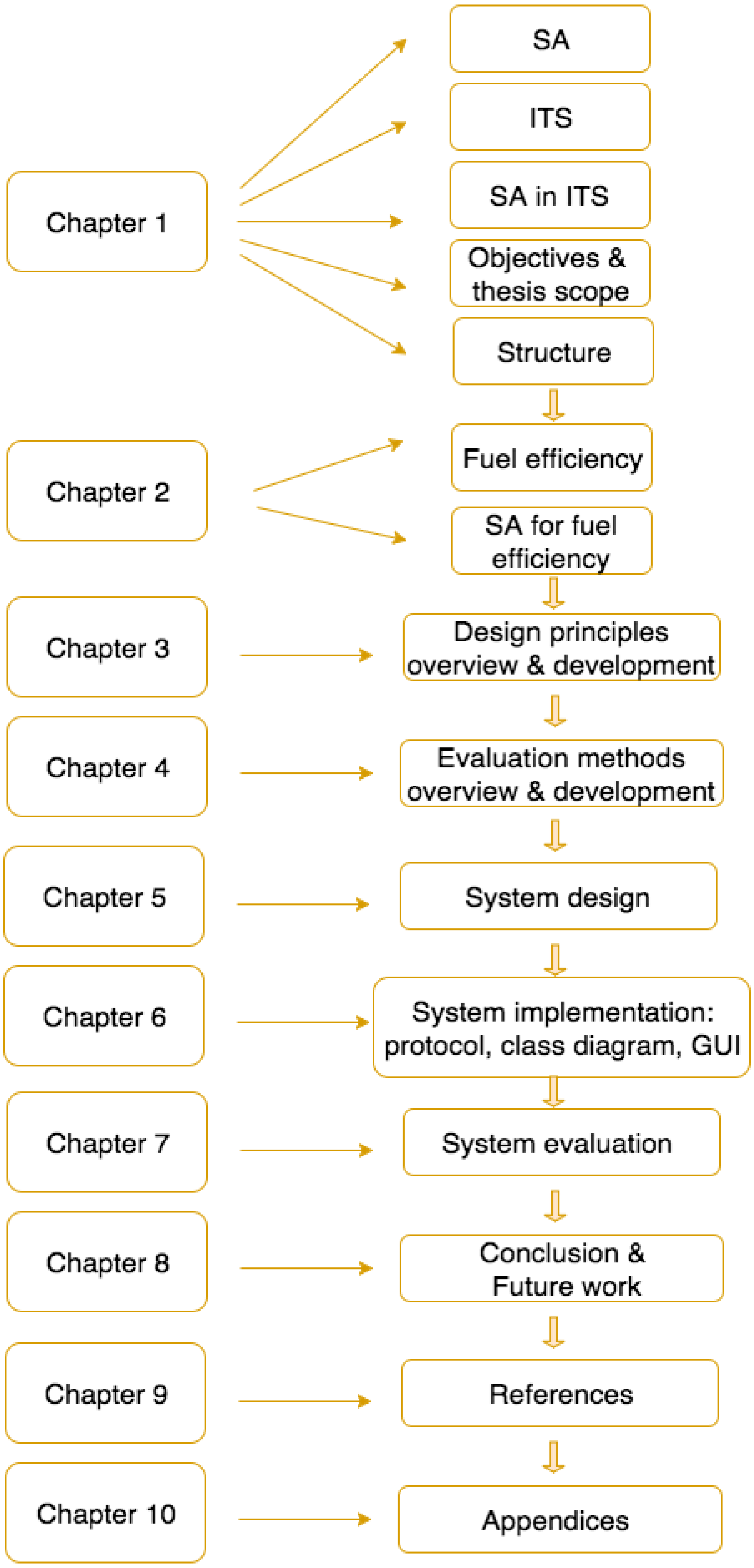


Figure 4. Thesis flow chart.

2. FUEL EFFICIENCY

2.1. Fuel efficiency background

For driving, one core metrics most drivers are willing to pursue is improving driving's fuel economy. Recently, fuel efficiency has been a hot topic for ITS, because of increasing amount of cars, shortcomings of environment pollution and car accidents. Fuel efficiency or Fuel economy is the relationship between the distance of the trip and the fuel consumed for this trip. The aim is to drive the longest possible distance with the given amount of fuel. Many parameters of a vehicle and environment could influence fuel efficiency. For example, it was found that using fuel efficient tires would help to save 5% of fuel usage and a heavy car consumes more than a light one [27].

Generally speaking, there are two ways to improve fuel efficiency: invent new technology for more efficient car engine, aerodynamics etc. and change driving behavior.

Lancefield [28] identified how to improve fuel economy of a diesel engine through variable valve actuation. In 2014, Takaki et al. [29] presented a study of adopting a higher compression ratio and deeper engine downsizing for a turbocharged engine of a cooled exhaust gas recirculation system. Their study has a result of improving fuel efficiency with 5%. Similarly, Li et al. [30] intended to improve gasoline engine fuel efficiency. They discovered that knock problem is severer for high loads by combining downsizing, high boosting and direct injection. Therefore, they applied Miller cycle to realize early or late intake valve closing which improve fuel economy by 6.8% and 7.4% respectively at the low load operation combined with compression ratio.

Behavioral aspect is interesting as well. In 1994, Jensen [31] discovered that travel speed is crucial to vehicle emission level. In 2001, Ericsson [32] studied 62 primary driving patterns with a result of 16 independent driving pattern factors in which 9 factors proved to have important effect on fuel consumption and emissions. These factors are acceleration, stops, speed oscillation, speed 50–70 km/h, late gear changing from 2nd and 3rd gear and engine speed >3500 rpm. In 2011, Sivak and Schoettle [33] reported that a driver can contribute to about 45% of fuel economy. To conclude, the factors affecting fuel consumption are road selection, congestion, cruise control, aggressive driving, high speed, unnecessary stops, gear change delay, inappropriate tire pressure and excessive idling. Beusen et al. [34] used on-board logging device to train drivers about fuel efficient driving. His study showed that after the training, the average fuel consumption of all the 10 drivers fell by 5.8%. Thus, the research provides us evidence that appropriate long-term training may lessen fuel consumption of drivers.

Fuel efficiency is connected with safety. In 1997, Buzeman [35] wrote in the book that large and high mass vehicles consume more fuel than small ones but they have better crashworthy than small vehicles, which means in a crash, heavy vehicles are more safe. He also pointed out that it would have negative effect for safety if mass and size of passenger vehicles will be reduced to ensure lower fuel consumption. However, later in 2001 and even recently in 2012, Haworth and Symmons [36] and Jacobsen [37] explored another aspect of safety and fuel efficiency. From Haworth, a lower fuel consumption and vehicle emission can be benefits of safe driving behaviors. And just like Buzeman mentioned, Jacobsen also noticed a vehicle mass reduction rises the risk of danger for driving. Furthermore, Haworth established a link between safe driving and fuel efficiency and emphasises benefits for the environment and costs.

Haworth and Symmons [36] confirmed and concluded some factors influencing road safety and fuel efficiency, as shown in Table 1 (rewritten from [36]).

Table 1. Selected factors of road safety and fuel efficiency

Vehicle factors	**Safety**	**Fuel economy**
Vehicle mass increase	Improve for occupants Worsen for others	Worsen
Vehicle safety features	Improve	May worsen
Air conditioning	Improve	Worsen
Smooth vehicle profile (e.g. aerodynamics, bullbats)	Improve	Improve
Cruise control	Improve	Improve
Engine power increase (with driving style unchanged)	May worsen	Improve
Road/infrastructure factors		
Traffic calming	Improve	Worsen
Replacement of traffic lights with roundabouts	Improve	Improve
Decreased residential speed limits	Improve	May worsen
Decreased open road speed limits	Improve	Improve
More freeways	Unclear	Improve
Increased public transport infrastructure and/or services (with assumed increase in patronage)	Improve	Improve
Decreased congestions	May reduce total number of crashes but increase average severity	Improve
Rebuild more direct/straighter/ level roads	Improve	Improve
Road user factors		
Eco-Driving training (attitudes and skills)	Improve	Improve
Increased speed limit enforcement	Improve	Improve
Aging of vehicle fleet	Worsen	Worsen
Regular vehicle maintenance	Improve	Improve
Correct tyre pressures	Improve	Improve
Annual roadworthiness inspections	Improve	Improve
Motorcycle usage	Worsen	Improve
Better informed vehicle choice	Improve	Improve
Speed limiting devices	Improve	Improve
Fuel consumption feedback devices	Worsen (if causes distraction)	Improve

‘Improve’ means that factor increases the level of safety/fuel economy
‘Worsen’ means that factor decrease the level of safety/fuel economy
‘May worsen’ means that factor can decrease the level of safety/fuel economy, but probably by a negligible amount.

2.2. Situation awareness for fuel efficiency

As it was discovered, many factors affect fuel efficiency [32, 33]. Therefore, we believe that supporting drivers with appropriate information regarding their driving performance in certain circumstances would help drivers in their decision-making for actions to take during the drive to improve fuel efficiency. Moreover, giving drivers the hints on how they can improve their driving in terms of fuel efficiency would also support their decision making.

In order to achieve the aim of improving fuel efficiency through enhancing drivers' SA, this thesis develops a system following SA design principles and validates what and how the principles can indeed lead to better SA.

In 2015, Gilman et al. [38] proposed a driving assistant system (DAS) named Driving Coach. The system is designed to improve driving behavior and performance by avoiding aggressive driving behavior, planning the trip and driving in a fuel-efficient manner. The system has the feature of capturing and understanding of driver situation, interpreting and analyzing context, predicting fuel consumption and providing corresponding feedback. The prototype assists drivers after the actual trip and does not yet support real-time operation. The system fuses on-board and real-time information from third-party services, identifies personal factors affecting fuel consumption and adapts decision making based on driver's progress and response to recommendations. Its architecture includes client applications at the third layer, RESTful client connector at the second layer and Driving Coach back-end at the first layer. Client applications deliver information to drivers. Driving Coach back-end implements the core of the system. RESTful client connector provides interfaces for client applications.

However, Driving Coach lacked tailored mobile client interface. Thus, in this thesis, we design and implement a tailored mobile application that follows SA principles. The name of the mobile client application is Driving Coach Mobile Application (DCMA).

3. DESIGN PRINCIPLES

This chapter summarises ITS design principles concerning modality, safety and feedback provisioning.

3.1. Modality

With the development of in-vehicle systems, ideas of using visual, auditory, haptic as well as multi-modal feedback have been studied. From Jamson et al. [39], most of previous researches utilize visual modality for eco-driving. Nouveliere et al. [40] for example, presented an EDAS (Eco-Driving Assistant System) where a colored display provides information of driving behavior performance. Their study resulted in saving around 10% of gasoline.

Kim and Kim [41] conducted three simulation tests with virtual driving system and concluded that providing both visual and auditory feedback is better than visual only. Azzi et al. [42] did an experiment trying to figure out the eco-driving performance of drivers with in-car assistance providing feedbacks using visual, haptic or visual and haptic modality. This experiment suggests no significant difference among feedback types. Therefore, the choice of the most appropriate modality approach should be based on purpose of the system and situations the system is supposed to be used.

According to Stephen [43], 70 percent of human sense receptors reside in eyes retina which indicates a close connection between vision and thinking. One advantage mentioned by Stephen is that for information input, visual modality is faster than auditory. Another advantage of using visual modality is that images tell a story better than words. From [42], first, almost every system that adopts visual modality shows it is very helpful and necessary. Second, haptic modality is not suitable for mobile client application because mobile application has its limitation to support different haptic modalities. Third, visual modality consumes less time to deliver complex information compared to auditory modality.

In this thesis, we focus on visual modality. Visual modality should be designed with care. From [34], first, do not show too much information and do not increase complexity. A high density of information with high complexity would overwhelm and confuse people, and it is hard to set an appropriate boundary from complex to simple. Second, don’t alert unnecessary conditions. When things go well, there is no need to draw people’s attention. Third, if an alert is a must, distinguish it from the rest information so that it can be differentiated and attract attention. Next, do not overwhelm eyes. That is, avoid using too many colors and too many bright colors which will result in situation that people are hardly able to look at information. Then, try not to distract attention from key parts. People tend to be easily distracted if there is unnecessary content. Finally, delivered information should be complemented by context. If there is no comparison, no axes, no units, the numbers are meaningless and not very helpful. Thus, based on above discussions, there are the basic design principles we concluded for visual modality:

1. Use clear and simple images, graphs to show information effectively.
2. Use two to three contrast colors to draw attention for key information.
3. Use graphs with axes, scales and labels.
4. Deliver information with context.
5. Use simple and separate displays to focus on different aspects.

6. Adopt familiar visual metaphors to enhance common understanding.
7. Group information to emphasize implicit relations.
8. Be consistent.

3.2. Safety

As discussed before, safety and fuel economy affect each other. A key problem influencing safety is distraction while driving. Klauer et al. [44] found when drivers are distracted visually, manually by complex tasks, they are having three-times higher risk of crash than without being distracted. Environmental conditions like intersections, wet roadways and heavy traffic increase the danger for drivers engaged in secondary tasks. And it is pointed out that inattention is a major contributor to 65% of near-crashes and 78% of crashes and 23% of population attributable crash risk happened due to inserting and retrieving CD. Young et al. [45] categorized distraction into four different types: visual, auditory, biomechanical or physical and cognitive distraction. Different in-vehicle devices have different demand on drivers. Visual distraction is the condition when drivers focus on another target for a while instead of looking on the road. Similarly, auditory distraction is the condition when the driver concentrates more on auditory signals instead of on the road environment. Biomechanical or physical distraction is the condition when drivers manipulate an object by one or both hands instead of keeping the steering wheel. Cognitive distraction considers any thoughts that attract the driver's attention from safe navigation and drive. In another project, Rouzikhah et al. [46] examined how an eco-driving message affects driver distraction. Several scenarios were compared: baseline scenario (without distracting activities), eco-driving scenario, navigation scenario and CD changing scenario. During these scenarios, drivers need to take actions of lane changing, overtaking, roundabout braking, intersection braking and drive straight. At the same time eco-driving measurements were recorded. The results show that navigation and CD changing tasks increase divers' workload significantly more than the rest two scenarios. However, eco-driving scenario makes drivers' mental workload slightly higher than drive without distraction. The authors concluded that while driving and taking crucial actions even simple distractions, like checking a short message, could potentially lead to missing an important event, therefore authors recommended to not deliver eco-driving text messages while vehicle is moving. Therefore, when designing ITS, distractions should be considered and minimized. This condition does not apply to ITS delivering information after the trip.

To achieve safety, it is important to use diverse data sources. Fusing the different data sources contributes to collection of information directly viewed and heard from the environment [12]. Kühn and Hannawald [47] said that data like vehicle movement data (acceleration, speed, direction, vehicle status, etc.), driver body movement data (eye, head, hand movements and pedal operation), traffic data and weather information provide the interaction information between driver, vehicle, road, traffic and weather. These are also critical to understand accidents.

In conclusion, two important principles need to be considered for ITS design from safety perspective:

1. Minimize distractions.
2. Fuse diverse data to help analyze factors influencing safety and fuel economy.

3.3. Feedback

Feedback is the most important aspect and if given clearly and accurately it can lead to fuel saving [48]. Tulusan et al. [49] reviewed several types of feedback. First, feedback on momentary driving behavior delivers real-time information to drivers mostly through ambient displays which unobtrusively change colors. Despite its advantage theoretically, drivers usually ignore this kind of system due to heavy mental workload which may take more effort and make drivers frustrated to achieve goals of less fuel consumption. Second, accumulated feedback aggregates information over time (from minutes to hours to days or driving cycles) and delivers overall information of driving behavior. This feedback received positive comments from drivers. Third, offline feedback monitors and analyzes overall driving behavior regarding fuel consumption, acceleration, breaking, emission and gear shifting to deliver a detailed information. As it provides offline feedback and does not distract driver, it is recommended to connect this feedback with social network to help prompt drivers' participation. Also, this feedback can be used as a training and education tool. However, it's weakness is that drivers have to spend extra time to read the feedback. Fourth, prior to giving feedbacks of driving advice, providing suggestions before a trip start can avoid undesired behavior. Usually, several trip plans are suggested concerning traffic, road work, destination, distance, time and fuel consumption, so that drivers could follow one of those.

Moreover, researchers notice that relatively simple feedback of fuel consumption is not enough. Often drivers are hardly able to identify what exact action should be taken to improve fuel efficiency [28]. Thus, not only a clear picture of current fuel consumption but also effective guidance of action type and scale like acceleration, speed control and braking behavior are required.

In short, ITS design principles from feedback perspective are:

1. Select suitable feedback type for system requirements.
2. Identify clear guidance and scale in terms of feedback.

4. EVALUATION GUIDELINES

4.1. Measurements of Situation Awareness

Various measurement methods of SA have been developed. In 1995, Endsley reviewed current evaluation techniques and came up with her own ideas of how to measure SA in a better way [50]. In Endsley's opinion, each proposed method has its advantages and disadvantages, and she grouped the measures into four basic categories and each category may have different sub measures:

- Physiological techniques
- Performance measures
    - Global measures
    - External task measures
    - Imbedded task measures
- Subjective Techniques
    - Self-rating
    - Observer-rating
- Questionnaires
    - Post-test
    - On-line
    - Freeze techniques

Electroencephalographic and eye-tracking devices are two examples of Physiological techniques. Electroencephalographic measures are good at registering information objectively but hard to determine whether information is registered correctly. Eye-tracking devices are not good at measure SA.

Performance-based techniques measure the level of SA, it is inferred from the level of performance. Generally speaking, performance measures are objective and nonintrusive as the performance data can be collected automatically. Global measures evaluate the overall performance of a system. These measures have a problem with diagnosticity and sensitivity as the overall performance of a system is the only criterion and it doesn't provide much information about reason of poor performance. External task measures add or remove certain information from display to measure the time spend by operators. These measures have a high possibility of providing misleading results. Imbedded task measures record performance of sub-tasks from operators. These measures have to depend on systems, that is, for some system, this kind of measures is easy to evaluate but for others it might be difficult.

Subjective Techniques are also named as Rating techniques. These measures either rate the subjects, or have observers of the subjects to rate SA for a number of scaled dimensions. Self-rating measures limit operators in estimating SA due to lack of knowledge of what is happening in reality if trial is conducted with simulator. For observer-rating measures, an observer has more knowledge of current situation and what is going on, but may lack the operator's view.

Questionnaires are more direct ways to assess SA. Post-test questionnaires means that people will be asked to fill in a detailed questionnaire after the test. However, in reality, people are not good at describing details. On-line measures ask questions during the test but this may lead to distraction. Freeze techniques pause system at a time during test and ask questions about the situation.

As can be seen, many measures for SA exist.

4.2. SAGAT evaluation guidelines

Salmon et al. [51] conducted a review of 17 SA evaluation methods of the applicability for C4i (command, control, communication, computers and intelligence) environments. Among these, Situation Awareness Rating Technique (SART), and Situation Awareness Global Assessment Technique (SAGAT) are the most popular ones with more than 10 validation studies, whereas the rest have less than 4. Based on Salmon's comparison, both SAGAT and SART require low training time. SART is a self-rating technique with advantages of low cost, easy conduction, wide applicability in different domains. Disadvantages of SART are issues in technique sensitivity and problems of collecting SA data post-trial. SAGAT is a direct approach with advantage of removing problems related to SA data post-trial collection and disadvantage of requiring expensive simulators and inability to operate in real-time. From [52], SAGAT measures how much a driver is aware of and understand the elements in the environment and SART measures how a driver perceives himself without referring to environment elements. And it is pointed out that SAGAT is more reliable of measuring SA.

Based on literature review, SAGAT is recommended to evaluate SA as it has a lot of validation studies, more reliable and is able to measure understanding of how a system works and the performance of its operator. SAGAT [53] is an objective approach which uses simulated situation and randomly freezes a scenario with queries to operator to assess understanding of current situation. While operators are answering questions, simulator display is blanked until answers have been delivered. Each answer is graded according to what was happening in a certain situation in reality. Therefore, it can be evaluated that a system increases operators' SA or not. A good query of SAGAT covers all three levels of SA. However, for each domain or even each case, the query should be customized.

Factors affecting fuel efficiency in Table 2 help develop evaluation guidelines to assess SA for fuel-efficient driving [54].

Not only the above factors provide ideas of evaluating SA, Beukel and Voort [55] stated that for measuring overall SA, they designed a questionnaire based on three critical situations involving accident avoidance: Emergency brake, Merge out and Cut in. Drivers can be asked to give self-assessments about (a) information gained (b) the quality of information understood and (c) how much familiar are they with the situation. For example, measuring drivers' understanding of what kind of attentions are needed in the situation of approaching the end of motorway and a failure of noticing road lines. Then, in their questionnaire, they asked drivers: "what caused the system's request for extra attention?" Therefore, one point of guidelines could be: designing questionnaire based on the purpose of measurement.

Gugerty [56] measure SA by two means: recall measure and performance measure. The recall measure compared the real location of cars and the end location of cars recalled by participants. The performance measure focuses on awareness of participants' knowledge of cars nearby in situations of (a) how much they detect hazard situation in the drivers' lane and (b) how aware they are when blocking car detection to their immediate right or left.

Table 2. Fuel-efficiency factors to achieve SA

	Level 1	**Level 2**	**Level 3**
Factors	**Perception**	**Understanding**	**Projection**
Vehicle data	Vehicle mass On-board devices Motor type Tire friction	Effect on fuel consumption	Actions to improve fuel consumption, e.g. remove unused things from vehicle
Driving behavior	Speed Acceleration/deceleration Gear Location Cruise control Engine power increase Air conditioning Fuel consumption	Flaws from driving attention focus	Actions to perform to improve driving behavior, e.g. decrease the acceleration
Traffic	Traffic situation Car distance	Effect from traffic situation to fuel consumption	Actions to take, e.g. plan the route to avoid traffic jam
Route	Pedestrians Traffic signs	Effect from route selection to fuel consumption	Actions to plan the route, e.g. to minimize the number of traffic lights
Weather	Temperature Friction Visibility	Effect from weather condition to driving	Actions to improve driving in severe weather condition, e.g. heavy snow

5. SYSTEM DESIGN

This chapter presents the design of DCMA for Driving Coach system [38]. We have followed the gathered design principles in order to achieve better SA for drivers to improve their driving behavior. Figure 5 shows the high-level architecture for the whole system. Driving Coach gathers driving behavior information from on-board diagnostic device, weather information and traffic situation information. Moreover, Driving Coach fuses this information with geospatial information from local region. Such fusion allows to retrieve all the information about the route driven, like crossings, traffic lights, etc. Moreover, certain driving behavior patterns could be observed, like over speeding in certain circumstances. Mobile client application designed in this thesis will communicate with Driving Coach system via RESTful interface to deliver information to the driver.

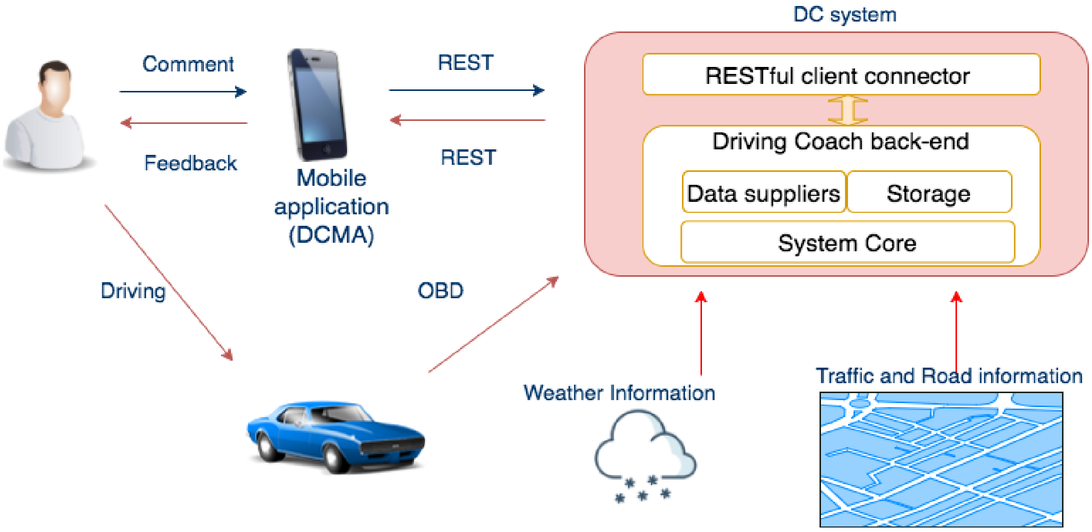


Figure 5. System big picture.

Driving Coach [38] provides the following functionality:

- Fuel economy driving evaluation
- Aggressive driving evaluation
- Route selection evaluation
- Fuel consumption prediction
- Providing hints on improving driving
- Adopting evaluation based on driver’s responses to recommendations and progress.

Based on functionalities that DCMA needs to provide, the system layout design of the DCMA is shown in Figure 6.

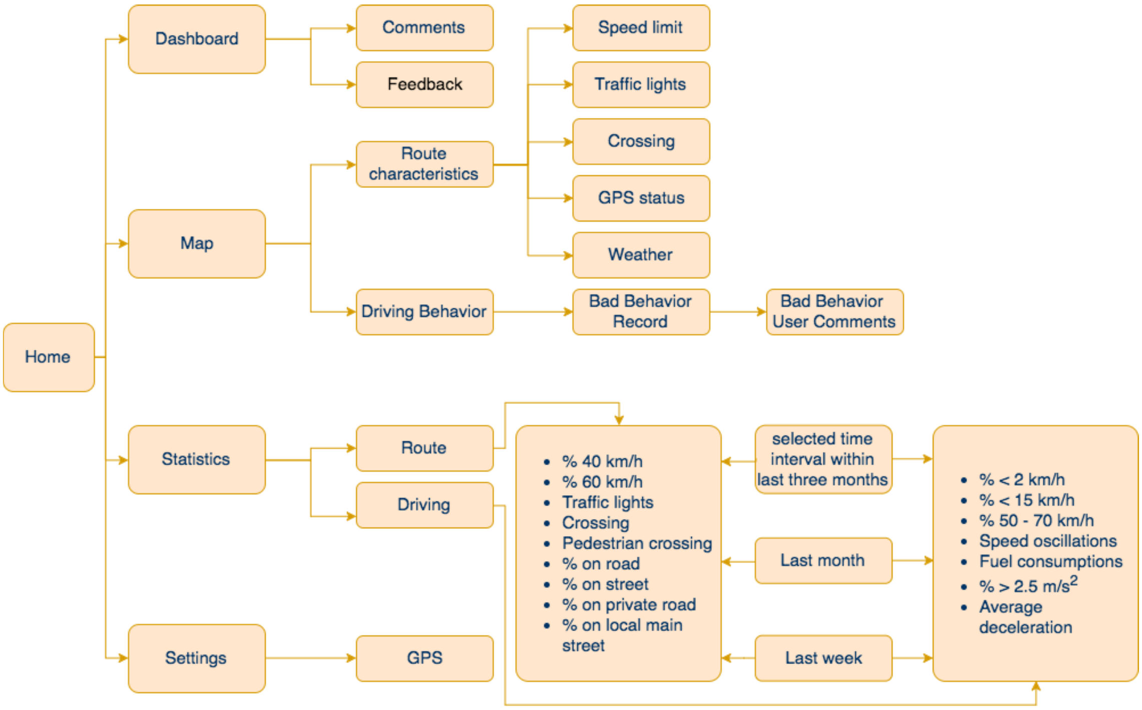


Figure 6. System layout design.

The mobile client application layout consists of four main views.

- Dashboard view is for comments and feedback for drivers.
- Map view shows the information about the route driven. This view has 2 functionally different sub-views: Route characteristics and Driving behavior. Route characteristics view shows the route related information like trip route, weather information, traffic lights and pedestrian crossings. Driving behavior view shows bad behavior occurrences of the trip. Also, each bad behavior occurrence contains detailed information of what kind of bad driving behavior it is and it allows drivers to provide their comments on bad behavior cases.
- Statistics view has 2 functionally different sub-views: Route characteristics and Driving behavior views where each sub-view shows graphs for route characteristics or driving behavior. The plots show details about time period drivers drive with certain speed, how many pedestrian crossings there are, what's the fuel consumption, how much does a driver accelerate and decelerate.
- Settings view currently is for enabling and disabling GPS tracking. We keep this for future usage.

Therefore, we follow the proposed design principles from Chapter 3. Table 3 lists how developed design principles are fulfilled in the DCMA design.

We have self-designed images and graphs to show information effectively. These images and signs are based on common metaphors. In order to contrast information, two colors and a theme background color gradients between the two colors are used. All the graphs used in the system have axes, title, and scale to deliver clear information. What's more, all information delivered is context-based. Four displays are used and each display groups information to make sure it is clear. Theme and each display are consistent in terms of color and style. Visual modality is adopted. Considering the achieved functionality, data relates to driving characteristics are used. Finally, feedback combines text and numbers to identify clear guidance and scale.

Table 3. Fulfillment of design principles

Design principles	**Fulfillment**
Use clear and simple images, graphs to show information effectively.	Self-designed images and graphs are used.
Use two to three contrast colors to draw attention for key information.	Two colors and a theme background color gradients between the two colors are used.
Use graphs with axes, scales and labels.	Each graph has axes, title, and scale.
Deliver information with context.	Information delivered is context-based.
Use simple and separate displays to focus on different aspects.	Four displays are used.
Adopt familiar visual metaphors to enhance common understanding.	Self-designed images and signs are based on common metaphors.
Group information to emphasize implicit relations.	Each display groups information
Be consistent.	Theme and each display are consistent.
Minimize distractions.	Visual modality is adopted.
Fuse diverse data to help analyze factors influencing safety and fuel economy.	Data relates to driving characteristics are used.
Select suitable feedback type for system requirements.	Feedback with text is used.
Identify clear guidance and scale in terms of feedback.	Feedback uses numbers.

6. SYSTEM IMPLEMENTATION

6.1. System Protocol

For working environment, we choose to use Android Studio as the target platform of mobile phone is Android. We also need to consider Android version in order to keep the application working on as many mobile phones as possible. As map is one of key parts of the interface, Google Map with available API, would be best suit for this project. Furthermore, the services provided by this framework, such as GPS enabling, location tracking, drawing makers and polygons are vitally important. The GraphView library was selected to draw plots for the mobile client.

Mobile client application communicates with the server, based on representational state transfer (REST) approach. Here, for clarify we call Driving Coach RESTful client connector (see Figure 6) as a server. Payload is encoded in JavaScript Object Notation (JSON) format. REST is a set of constraints and design principles which is widely used in web services. It is usually based on Hypertext Transfer Protocol (HTTP), Uniform Resource Identifier (URI) and eXtensible Markup Language (XML). JSON data uses human-readable text to convey object which has attribute-value pairs.

For example, the request to get the list of trips for time period is:
http://server address/client/trips/period/{userID}/{fromDateTime}/{toDateTime}
The time format for *fromDateTime* and *toDateTime* should be YYYYMMDDHHMM.

There are three return code for the request to get list of trips, as Table 4 shows.

Table 4. Payload example for trips request

HTTP status code	**Payload example**
200	[{"tripID":"2144495","tripStartTime":"2014-11-23 10:15:58","segmentStartTime":"4680"},{"tripID":"2144866","tripStartTime":"2014-11-23 14:50:46","segmentStartTime":"766"},{"tripID":"2165454","tripStartTime":"2014-11-30 10:23:46","segmentStartTime":"9009"}] Can be also empty list []
400	DateTime in wrong format or From and To dates should be different and in right order or Time interval is too long
404	User with id userID does not exist

6.2. System Class Diagram

Two class diagrams describe how DCMA is implemented.

Figure 7 shows the core classes of DCMA system excluding some development-level fields and methods for better clarity. These classes can be divided into three groups: activity classes, utility classes, abstraction classes.

Abstraction classes contain system-wide concepts of data saved for past trips (savedTrips class) and bad behavior (badBehavior class) which both are mainly used in map activity. Saved trip differentiates rendering history trips into two groups: week and month. Bad behavior supplies an icon for marking a bad behavior on map based on retrieved data from server.

Utility classes include communication handler (commHandler class), view pager (NonSwipeableViewPager class), timespan (timespan class), driving behavior (drivingBehavior class). Communication handler defines interface for carrier communication between DCMA and the driving coach server. View pager customizes pager tabs with disabled horizontal swipe feature, in order to avoid swipe feature conflict against charting library. Timespan is used in map activity and it focuses on providing time selection feature like last week, last month, and custom date interval from calendar. Driving behavior is in charge of handling bad behavior information from server and providing methods to activities for querying bad behavior's type, time, and content, as well as collecting such behavior's corresponding comment.

Activity classes, implement DCMA functionality with 4 tabs (see Figure 6) where each tab is represented as an activity: dashboard activity (dashboardActivity class), map activity (mapActivity class), statistics activity (statisticsActivity class), setting activity (setUpActivity class). Also, there is the main entrance to tabs: main activity (mainActivity class). They are described in details as follows.

Main activity provides entrance to the tabs rendered in our system GUI. The Android lifecycle for DCMA system is managed here.

Dashboard activity is the default tab which is displayed when DCMA is first launched. It is responsible for retrieving and rendering fuel economy evaluation content of the latest driven trip. Hints on how to improve driving behavior are fetched from the server.

Map activity is responsible to display the driven trip on the map. In addition, it retrieves bad behavior (abstracted as badBehavior class) data from server and marks them on map. Besides, various kinds of weather information with predefined thresholds are drawn, consisting of slipperiness, rain, snow, grain, sun. All drawn data are bound and refreshed based on selected trip or last trip by default. Also the state of GPS is visualized.

Statistics activity handles the charts for different driving evaluation criteria defined in our system (more details are given in statisticsActivitySwipe charting package section). The charts are visualized with customized view pagers defined in view pager utility class.

Settings activity manages enabling and disabling of GPS for DCMA.

Figure 8 shows the structure of statistics activity (statisticsActivitySwipe package) for data visualization. The charts are divided into two container categories: driving adapter (ViewPagerAdapterDriving class) takes care of charts about driving behavior and route adapter (ViewPagerAdapterRoute class) takes care about route characteristics for the driven trip. Both adapters count their total view pagers and enable swiping feature between charts.

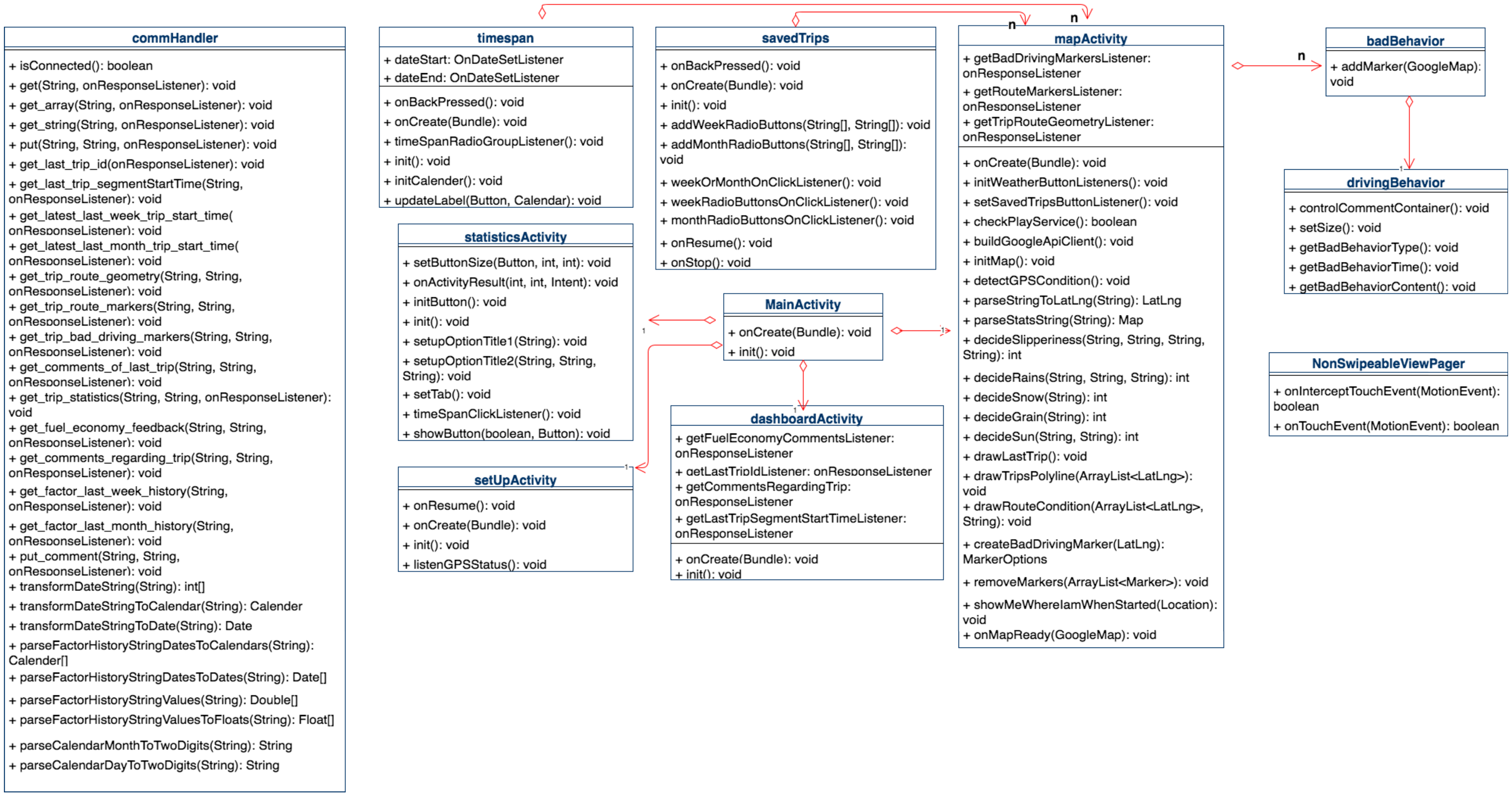


Figure 7. Class Diagram Part 1— Main functions overview.

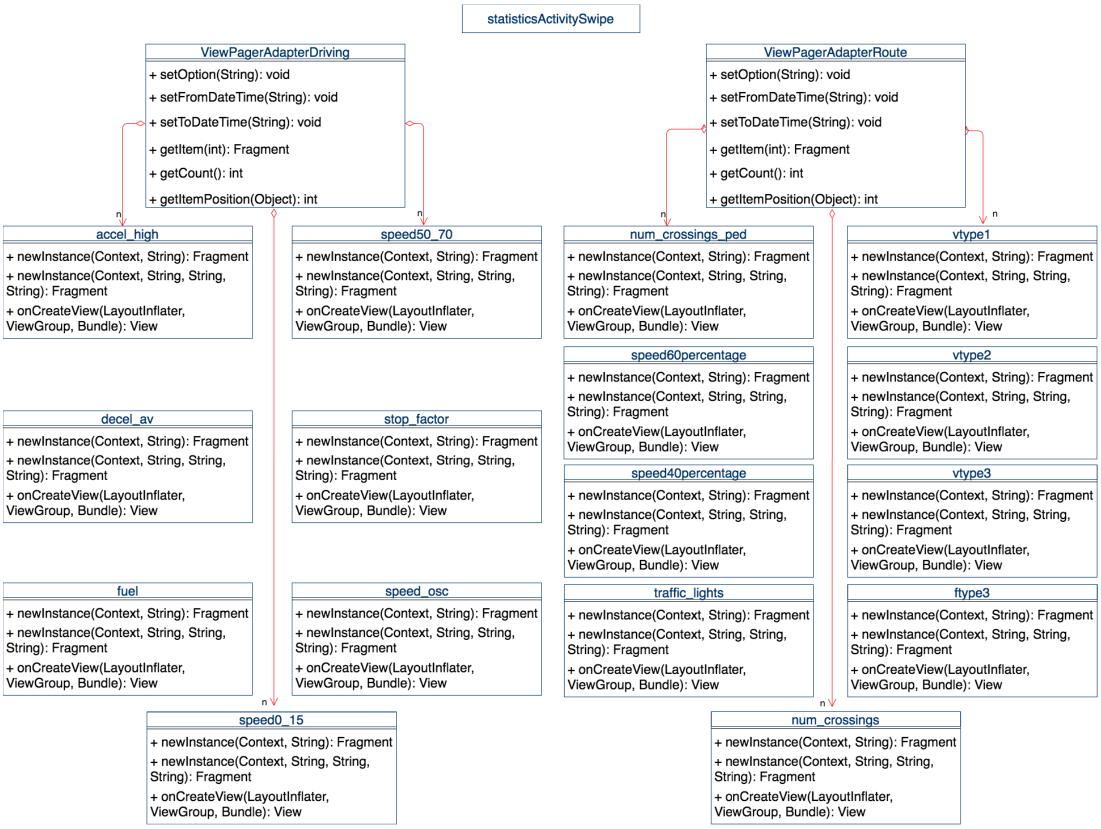


Figure 8. Class Diagram Part 2 – Statistics.

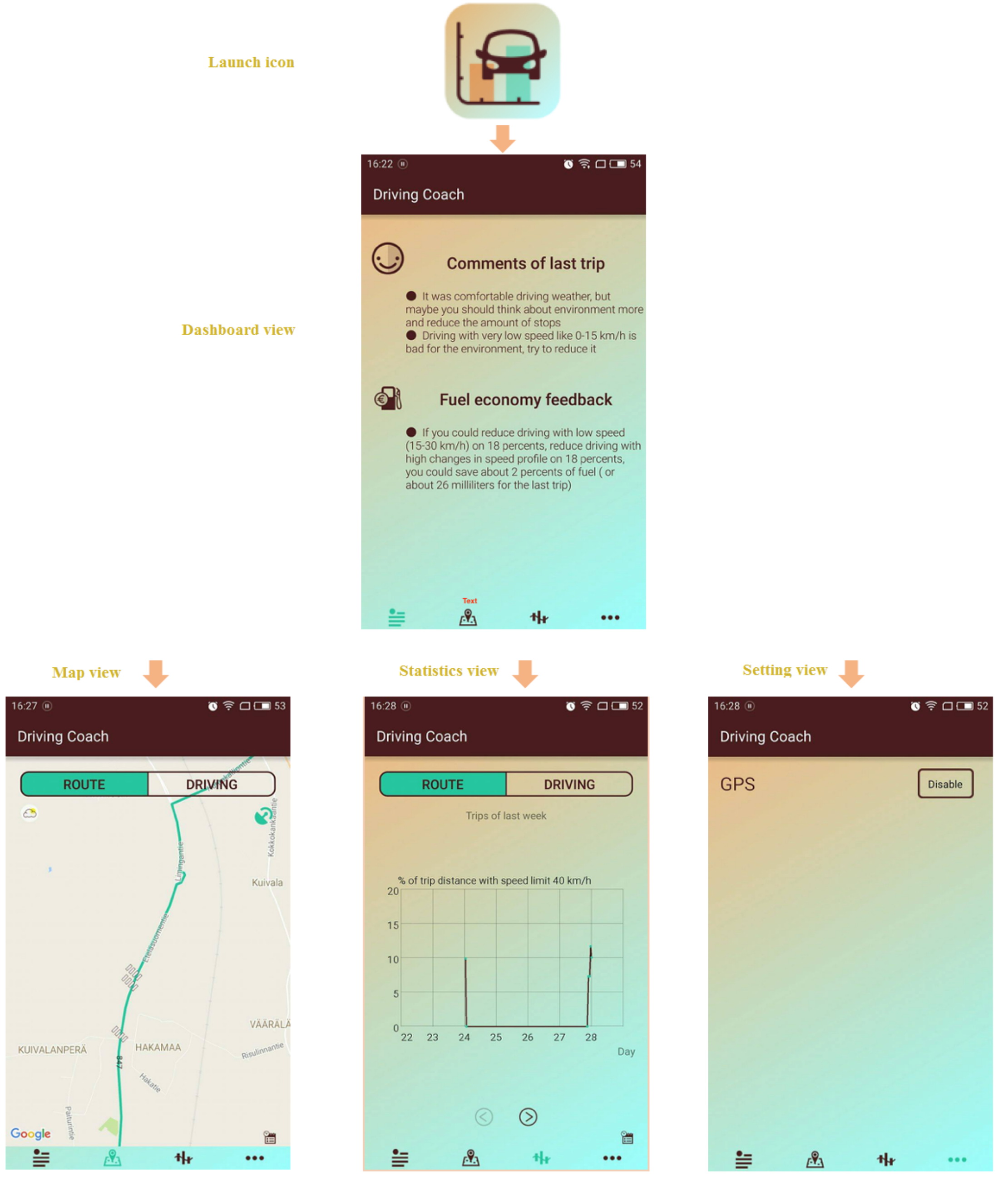
For driving behavior statistics, seven charts are rendered: high acceleration (accel_high class), average deceleration (decel_av class), fuel consumption (fuel class), percent of time with speed 50-70 km/h (speed50_70 class), percent of time with speed < 2 km/h (stop_factor class), speed oscillations per driven meter (speed_osc class), percent of time with speed 0-15 km/h (speed0_15 class).

For charts route characteristics statistics, nine charts are rendered: number of pedestrian crossings per meter (num_crossings_ped class), percent of trip distance with speed limit 60 km/h (speed60percentage class), percent of trip distance with speed limit 40 km/h (speed40percentage class), number of traffic lights per meter (traffic_lights class), number of crossings per meter (num_crossings class), percent of trip driven on road (vtype1 class), percent of trip driven on street (vtype2 class), percent of trip driven on private road (vtype3 class), percent of trip driven on local main street (ftype3 class).

Note that one of the crucial implementation issue resolved here is enabling both to swipe charts by using arrow keys and by using touch swipe input, this explains the reason for customized view pager class (NonSwipeableViewPager class) discussed previously. The 16 classes listed above follow unified structure so that chart library (GraphView) is applied with actual data retrieved from the server. All statistics charts can be drawn based on selected timespan which comes from timespan (timespan) and map activity (mapActivity) class.

6.3. System Graphical User Interface

GUI was designed by following design principles, outlined in Chapter 3. Figure 9 demonstrates system graphical user interface. This GUI implements DCMA layout flow mentioned in Figure 6.



Comments of last trip

- It was comfortable driving weather, but maybe you should think about environment more and reduce the amount of stops
- Driving with very low speed like 0-15 km/h is bad for the environment, try to reduce it

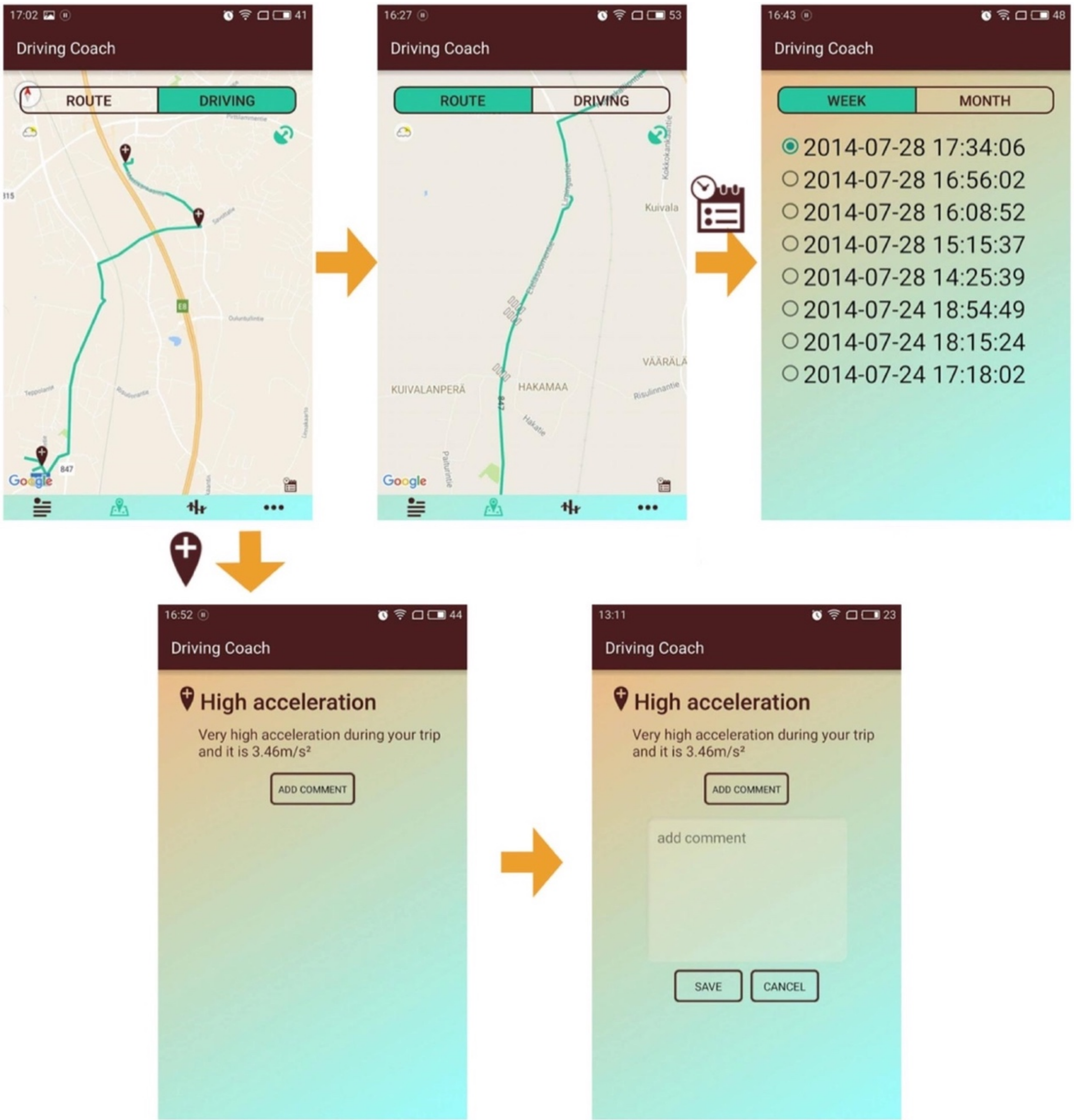
Fuel economy feedback

- If you could reduce driving with low speed (15-30 km/h) on 18 percents, reduce driving with high changes in speed profile on 18 percents, you could save about 2 percents of fuel (or about 26 milliliters for the last trip)

Figure 9. System interface flow.

Based on the first design goal, a colourful and symbolic icon is easy to be distinguished. Dashboard, Map, Statistics and Setting are four views. The default view opened is Dashboard. Dashboard view has two sections: Comments of last trip and Fuel economy feedback (see Figure 9). As an example, comments like “*It was comfortable driving weather, but maybe you should think about environment more and* *reduce the amount of stops*" and "*Driving with very low speed like 0-15 km/h is bad for environment, try to reduce it*" conclude the most important behavior improvement suggestion to driver. Fuel economy feedback like "*If you could reduce driving with low speed (15-30 km/h) on 18 percent, reduce driving with high changes in speed profile on 18 percent, you could save about 2 percent of fuel (or about 26 millilitres for the last trip)*" tells what could be improved to save fuel. Map view provides driving behavior route information and Statistics view shows graphs about route characteristics and they will be explained in more detail later. Settings view for now is only used for GPS control as it is designed for future extension.

Map view has several components in which Google Map is the base for Route and Driving buttons, weather button, GPS button and calendar button navigating to corresponding sub-views (see Figure 10).



● 2014-07-28 17:34:06
○ 2014-07-28 16:56:02
○ 2014-07-28 16:08:52
○ 2014-07-28 15:15:37
○ 2014-07-28 14:25:39
○ 2014-07-24 18:54:49
○ 2014-07-24 18:15:24
○ 2014-07-24 17:18:02

High acceleration

Very high acceleration during your trip and it is 3.46m/s²

High acceleration

Very high acceleration during your trip and it is 3.46m/s²

Figure 10. System interface flow—Map.

Route button shows route characteristics and Driving button shows driving behavior performance. By default, system will show the route, weather information, traffic lights and pedestrian crossing symbols of the last trip. Clicking the weather button shows the weather information of a selected trip. GPS control button enables and disables GPS. Calendar button at the bottom of Map view selects trip to visualize. For example, Figure 10 shows the trips of last week. The Month button shows all the trips of last month. If there is the need to check a specific trip, tap selection button to choose it. Then, system will jump back to Map view and show the selected trip route, weather information, traffic lights and pedestrian crossings.

Driving button on Map view shows locations of bad behavior occurrences, like stops and too much aggressive acceleration. Markers can be clicked for more detailed information. Figure 10 shows an example of bad behavior occurrence "*Very high acceleration during your trip and it is 3,46m/s^2*". User may comment the case in comment box.

Statistics view has Driving and Route categories as well and displays graphs about driving behavior or route characteristics correspondingly, as Figure 11 shows.

Statistics views show the graphs about trips of last week, last month or selected time interval. Due to default data limit, the interval for now is set to be three months.

For route characteristics, the mobile client provides information about:

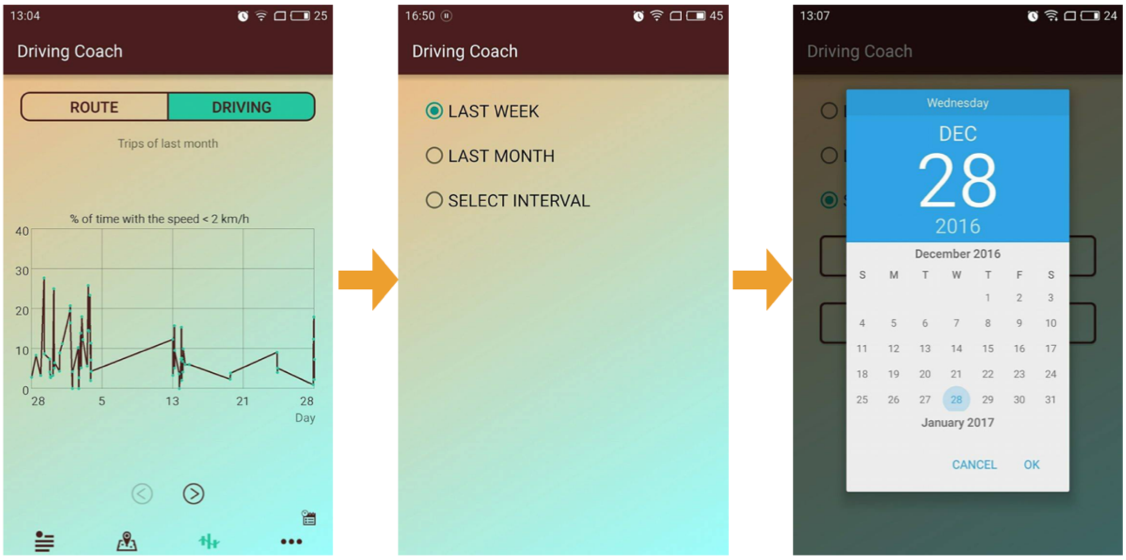
- Percentage of trip distance with speed limit 40km/h
- Percentage of trip distance with speed limit 60km/h
- Number of traffic lights
- Number of crossing
- Number of pedestrian crossing
- Percentage of trip driven on road
- Percentage of trip driven on street
- Percentage of trip driven on private road
- Percentage of trip driven on local main street

For driving behavior, the mobile client provides information about:

- Percentage of time with speed < 2km/h
- Percentage of time with speed < 15km/h
- Percentage of time with speed 50- 70km/h
- Speed oscillations per driven meter
- Fuel consumption
- Percentage when the acceleration > 2.5m/s^2
- Average deceleration

Besides, the graphs are all able to zoom in and zoom out for more details.

Settings tab, which is designed for extension and future developments, for the moment is for setting GPS.



● LAST WEEK
○ LAST MONTH
○ SELECT INTERVAL

Figure 11. System interface flow—Statistics.

7. SYSTEM EVALUATION

DCMA was evaluated with user study which used simulated data for feedback provisioning. This chapter presents DCMA evaluation.

7.1. Study procedure

Each participant installed the application on their phone. Since not every participant is fluent with English, the words used in the application are translated to Chinese to make sure participant wouldn't have understanding barriers. After installation, each participant was introduced the functionalities of the application. And they were given 10 minutes to explore the application themselves and 30 minutes to drive. After driving, each participant was required to answer a web questionnaire (see Table 4, Table 5 and Table 6) through checking the application functionalities to help answer correspondent questions. Answers are then analyzed.

7.2. Questionnaire design

Following the evaluation guidelines, we designed a questionnaire which covers three aspects:

1. Usability. It means the degree of ease of use of a software to achieve effectiveness and efficiency [57].
2. Usefulness.
3. Bad behavior awareness and fuel economy.

For the first aspect, the aim is to explore the usability and user experience of the designed system user interface and what is the performance of following the proposed design principles through interacting with system user interface. For the second aspect, the focus is to evaluate how would the application help user to plan a trip, improve driving behavior and fuel-efficiency. For the last aspect, it is used to understand the participants' awareness of their bad behavior and what can be done to save fuel.

For the questions design of usefulness and bad behavior awareness and fuel economy, factors to achieve SA mentioned in Table 2 in Chapter 4 are embedded in order to explore how SA is supported.

7.3. Study participants

7 Chinese participants (6 males, 1 female) aged from 18 to 30 years old joined the study. They are students, operator, sales and developers from Information Technology, Import and Export Trading, Real Estate development, Fast Moving Consumer Goods and university. Every participant has a valid driving license with driving experience varied from 1 year to 5 years. All test participants are Android phone users. The participants are volunteers recruited on-site without compensation.

7.4. Results

Tables 5, 6, and 7 show the result of each question for the three evaluated aspects of the application. For each question, we use 1 to represent "Strongly disagree", 2 to represent “Disagree”, 3 to represent “Not agree and not disagree”, 4 to represent “Agree” and 5 to represent “Strongly Agree”. If participants answered “Strongly Agree” or “Agree”, it means they gave a positive support of this one factor for system. If they answered “Not agree and not disagree”, it means they neither agreed with this one question nor disagreed with it. If they answered “Strongly disagree” or “Disagree”, it means they gave a negative support for the factor.

Table 5 shows what are the questions asked and the number of answers for each question about the aspect usability for the system. There is strong evidence that participants are happy with easy instructions of the system and clear feedbacks provided. However, one participant disagreed with the question “I feel comfortable to interact with the system”. One participant felt strongly confused, one participant felt confused and two participants were neutral interaction with system. This shows that it can be confusing to interact with the system. One participant thought that feedback information provided is overloaded and two participants thought the feedback information overload is neutral. Since six participants agreed that the system provides sufficient feedback, we can conclude that for most users the system provides proper feedback information, but there is possibility that the feedback provided is too much. 3 participants were neutral about “It is easy to anticipate what happens next when I am interacting with the system”. Thus, it can be concluded that the system is at least not very hard to anticipate for users to interact with.

Table 5. Evaluation result: Perceived Ease of Use

Question	**Number of answers**				
	5	4	3	2	1
I am able to figure out how to use the system on my own.	4	2	1		
Instructions of the system are easy to understand	6	1			
Feedback of the system is clear	6	1			
I feel comfortable to interact with the system	3	3		1	
I feel confused to interact with the system	1	1	2	3	
The system provides sufficient feedback	4	2	1		
I found the system’s transitions from one feature to another to be smooth and consistent	4	3			
Feedback information of system does not overload	3	1	2	1	
It is easy to anticipate what happens next when I am interacting with the system	2	2	3		
The system is easy to use in overall	5	2			

Table 6 shows the questions asked and the number of answers about usefulness aspect of the system. The question “Using the system strengthens my capability to drive more fuel-efficiently” considered the fuel-efficient driving factors in level 2 and 3 of SA. Level 2 corresponds to comprehension of fuel economy and level 3 strengthens the capability to take actions to save fuel. The question “Using the system alerts me what bad behavior I may have when driving” reflects SA level 1 through awareness of bad behavior during driving and level 2 through understanding of it. The question “Using the system supports me preventing bad driving behaviors” reflects SA level 3 through projection of actions taken to avoid bad driving behaviors.

The question “Using the system instructs me to plan a faster and smoother driving route” reflects SA level 3 through projection of trip planning. The question “Using the system assists me on tracking where and how I drove previously" reflects SA level 1 through perception of location and level 2 through understanding of how users drive. The question "Using the system helps me search my history driving data" reflects SA level 1 through perception of history driving data. The question "Using the system helps me analyse what are the speed limits" reflects SA level 1 through perception of speed limit.

From the result, one participant disagreed that the system does not limit the wish to drive. One participant is neutral about using the system to get instructions to plan a faster and smoother driving route. There is strong evidence that people are happy with the alerts about bad driving behavior, tracking location and searching for history data.

Table 6. Evaluation result: Perceived Usefulness

SA level	**Question**	**Number of answers**				
		5	4	3	2	1
	Using the system does not limit how I wish to drive	5	1		1	
2,3	Using the system strengthens my capability to drive more fuel-efficiently	3	4			
1,2	Using the system alerts me what bad behavior I may have when driving	6	1			
3	Using the system supports me preventing bad driving behaviors	5	2			
3	Using the system instructs me to plan a faster and smoother driving route	4	2	1		
1,2	Using the system assists me on tracking where and how I drove previously	6	1			
1	Using the system helps me search my history driving data	6	1			
1	Using the system helps me analyse what are the speed limits.	3	4			

Table 7 shows what are the questions asked and the number of answers about the aspect of participants' awareness of their bad behavior appearances and how to improve fuel economy. The question "Was it slippery during my last trip" reflects SA level 1 and level 2 through perception and understanding of slipperyness. The question "Was my last trip in motorway mostly" reflects SA level 1 and level 2 through perception and understanding of type of road. The question "Did I have too high speed occurrences during last trip" reflects SA level 1 and level 2 perception and understanding of high speed occurrences. The question "Did I have too high acceleration occurrences during last trip" reflects SA level 1 and level 2 perception and understanding of high acceleration occurrences.

The question "What were the main shortcomings of my driving behavior during the last trip regarding fuel efficiency?" reflects SA level 2 through understanding of driving behavior shortcomings. The question "How can I save some fuel?" reflects SA level 3 through projection of action taken to save fuel.

From Table 7, answers show that most trips of participants were not slippery and mainly driven on normal road. Even though majority of participants didn't over speed or aggressively accelerated, two of them over speeded and drove aggressively. And they pointed out that in their opinion over speed, sudden break and start and stop of the car too many times are the shortcomings regarding to fuel-efficiency of their drive.

Table 7. Evaluation result: Bad behavior awareness and fuel economy

SA level	**Question**	**Number of answers**			
1,2	Was it slippery during my last trip	Very Slippery	Slippery	Not Slippery	
			1	6	
1,2	Was my last trip in motorway mostly	High way	Road		
		2	5		
1,2	Did I have too high speed occurrences during last trip	Over speed	Not over speed		
		2	5		
1,2	Did I have too high acceleration occurrences during last trip	High Acceleration	Not High Acceleration		
		2	5		
2	What were the main shortcomings of my driving behavior during the last trip regarding fuel efficiency? (multi-choice)	Over speeding	Sudden Break	Not paying attention to pedestrian crossings	Other
		4	4		1 (stop and start too many times)
3	How can I save some fuel? (multi-choice)	Avoid stops	Steady speed	other	
		4	6		
	What were the suggestions to correct driving behavior for fuel saving? (open question)	“keep speed steady and avoid high acceleration” “avoid idling stops” “plan the best route” “avoid over speeding and keep steady speed” “Choose motorway instead of side road” “keep steady speed and plan trip ahead”			

One participant chose over speeding and stop and start too many times as the shortcomings of driving behavior. One participant chose over speeding and sudden break appeared in the last trip. Three Participants thought that avoiding stops and keeping steady speed helps to save fuel. One participant chose to avoid stops and three chose to keep steady speed. For the suggestions to correct driving behavior for fuel saving, participants gave answers: “keep speed steady and avoid high acceleration”, “avoid idling stops”, “plan the best route”, “avoid over speeding and keep steady speed”, “Choose motorway instead of side road” and “keep steady speed and plan trip ahead”.

7.5. Discussion

From Table 5, the result shows that in overall participants agreed that the application is easy to use. From Table 6, the result shows that in overall participants agreed that the application is useful and helpful for planning a trip, improving driving behavior and fuel-efficiency. From Table 7, the result shows that participants were able to become aware about the bad behavior appearances of their driving and they were able to know how to save fuel. Participants were inspired to came up with their own suggestions about fuel saving. From Table 6 and Table 7 the questions covered different factors about fuel efficiency to achieve SA and they provide clear ideas of support for SA level 1, level 2 and level 3.

From the evaluation, we can conclude that the application designed is easy to use, useful and helpful for fuel efficiency. Since the result shows the system design is easy to use, we are able to answer that the fulfillment of proposed design principles in Table 3 and the GUI design of Chapter 6 is effective. Fuel economy factors involved in evaluation questions explain how different levels of SA are supported. Moreover, participants provided their suggestions about how to correct driving behavior for fuel savings. However, since not every fuel efficiency factor to achieve SA has been covered in the evaluation questions, it is hard to explain how well is SA supported.

Gilman et al. [58] commented that design solution of DCMA demonstrates advanced details of trips driven combined with diverse information. Moreover, authors highlighted the importance to show first the most relevant information, graphs and putting content into context.

There are several limitations in this evaluation:

1. Participants include only one woman and the rest are men. This might bias the results. The reason for it is that the amount of Android users is far less than IOS users among young women in China.
2. Participants’ age is young, therefore they are more keen into technology, therefore may evaluate it more positively.
3. Since we cannot deploy the Driving Coach system to collect driving data from participants, the evaluation of SA support was challenging.

8. CONCLUSION AND FUTURE WORK

8.1. Conclusion

The Master's Thesis was focused on exploring on how to properly design ITS for fuel-efficient driving supporting SA. The objectives were achieved as follows:

- **Objective 1**: Study related work about SA, CA, ITS, and SA support with proper ITS design and implementation.
  - The literature was studied and definition of SA, CA and ITS are given. Moreover, SA and SA in ITS are discussed in greater details. Fuel efficiency and SA for fuel efficient systems are considered as well. To achieve SA for ITS, the level 1, level 2 and level 3 of SA should all be taken into consideration.
  - Based on our literature review of ITS with SA support in related work sections, it is noted that question of how to follow principles proposed by Matthews et al. [22] to minimize errors for an ITS with SA support is still open and requires investigations. In a sense, system presented in this thesis can be considered as a candidate to answer such question.
- **Objective 2**: Based on literature review, develop design principles and evaluation guidelines towards ITS supporting SA.
  - In this thesis, design and evaluation principles and guidelines are gathered from related work and formulated. Design principles in this thesis are focused on visual modality, safety and feedback. Evaluation guidelines cover factors for fuel efficiency to achieve SA and presenting methods to do evaluation.
  - The developed design principles and evaluation guidelines proposed in this thesis can be generalized and inspire the design and development of other ITS with SA support aiming at diverse operation goals.
- **Objective 3**: Implement and analyze ITS supporting SA by following identified principles and evaluate it with proposed guidelines.
  - DCMA system was designed and implemented by proposed design principles.
  - The system was evaluated from different perspectives: ease of use, usefulness, bad behavior awareness and fuel economy with a user study.
  - The evaluation results show that our system supports SA level 1 with perception of fuel efficient factors, level 2 with comprehension of driving situation, level 3 with actions taken to achieve fuel efficient driving.
  - The implementation work of the ITS is challenging. Thesis shows that, proper evaluation for assessment of SA support by ITS is challenging.

8.2. Future work

In this thesis, visual modality is studied. It is very meaningful to investigate whether in certain circumstances, the proper combination of visual and audio elements could enhance SA.

Currently, our application is able to provide after-trip support. This indicates that it could be also beneficial if our application could be expanded to support drivers in real-time.

One of the interesting future research is to conduct comparison with other similar mobile applications in same domain of ITS with SA support for fuel efficiency. Such comparison is able to unveil if any difference exists when both systems follow design principles of SA support, and therefore contribute to the validity of our proposed principles. Moreover, the comparison can be extended to other domains of ITS.

Immersive driving simulator or emulators can be utilized in order to evaluate SA support of our system with different groups: before the drive, during the drive, and after the drive. This can potentially produce new findings about determining best timings to engage SA support in our system.

Besides, theories of measuring and quantifying the threshold of supplied amount of feedback from our system can be investigated.

In the future, there is a plan to integrate data gathered from pedestrians and cyclists and to provide a web application for visualizing all the data. As a platform, MapServer is selected. Right now, the installation of MapServer on CentOS has been finished and details about its installation procedures, possible problems and solutions are attached as an appendix.

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10. APPENDICES

Appendix 1. MapServer configuration for CentOS

Appendix 1. MapServer configuration for CentOS

This instruction will guide you though the installation of PostgreSQL and MapServer on CentOS.

1. Download and compile PostgreSQL:

The installation and configuration of MapServer for CentOS is challenging. For CentOS, there is a need of installing *readline-devel* and *zlib-devel* libraries before taking the procedure*:/configure*. If there is configuration error: "readline library not found", the link below helps with answer.
http://stackoverflow.com/questions/26129623/yum-showing-readline-installed-but-readline-command-not-working

After the above installations, commands *make world* and *make install-world* should be executed in order to include *contrib* libraries. Then, access right to *PostgreSQL* folder should be changed with the command *Chmod 755*. The link below is for PostgreSQL, http://www.postgresql.org/docs/devel/static/install-procedure.html

2. Download and compile Postgis:

Then, there is need to install and/or build GEOS, Proj.4,GDAL, LibXML2 and JSON-C as dependencies for Postgis. All the needed links for those libraries are listed:
https://docs.djangoproject.com/en/1.9/ref/contrib/gis/install/geolibs/
http://download.osgeo.org/gdal/2.0.2/gdal-2.0.2.tar.gz
http://postgis.net/source/

After that, GEOS should be installed and compiled.
http://trac.osgeo.org/geos/

3. Geos installation

First, also do *make all* and *make install-world* for having geos-devel modules. Next, do *./configure*, if an error like: "*could not find geos_c.h", you may need to specify* the directory of a geos-config file using *--with-geosconfig.*

If there is need to use GEOS functionality, the GEOS library is a must. Geos 3.0.3+ (might be higher according to the update) is preferred and is required for some functions such as ST_SimplifyPreserveTopology to be available. If *./configure* cannot find it, try using *--with-geos=PATH* to specify the full path to the *geos-config.*

While providing full path, if you have given proper permissions to */usr/local/include,* no need to specify the path yourself. One tip here is:
sudo chmod 755 -R /usr/local/include/. The command should be executed when the files have not been used during configuration of certain library sources. Go to folder */bin/mkdir,* if permission denied and error message is "*cannot create directory `/usr/local/pgsql/share/contrib': Permission denied",* the tip above should work as well. Then, do *make* and *sudo make install.*

When you configure: `./configure --with-geos=/usr/local/bin/geos-config` or: `./configure --with-geosconfig=/usr/local/bin/geos-config,` probably errors will appear:

(1) "configure: error: could not find pg_config within the current path." You may need to re-run configure with a `--with-pgconfig` parameter, and add the path of pg_config to global path by:

```
$ export PG_HOME=/Library/PostgreSQL/9.5
$ export PATH=$PATH:$PG_HOME/bin
```

(2) Two kinds of error message may appear:

a. "configure: error: the PGXS Makefile cannot be found."

b. "/usr/local/pgsql/lib/pgxs/src/makefiles/pgxs.mk cannot be found."

First, please install the PostgreSQL server development packages and re-run configure. PostgreSQL is broken down into several packages, and having `psql` installed doesn't imply that the development packages are also installed.

Second, do command *yum install libxml2-devel*.

Third, install *Json-C* https://github.com/json-c/json-c

(3) In case of errors when installing libtool, refer to:

```
"libtool: Version mismatch error.  This is libtool 2.4.2, but the
libtool: definition of this LT_INIT comes from libtool 2.2.6b.
libtool: You should recreate aclocal.m4 with macros from libtool 2.4.2
libtool: and run autoconf again.
make[2]: *** [arraylist.lo] Error 63"
```

Solution for this problem can be found from the link:
http://stackoverflow.com/questions/3096989/libtool-version-mismatch-error

After all the procedures above, make installation is necessary, there is instruction about how to use cmake:https://cmake.org/install/ , a Linux make tool. In general, three steps are enough:

```
./bootstrap
make
sudo make install
```

4. Dependencies installation

Once Geos has been dinstalled successfully, some mandatory dependencies are needed, if they are not installed. Execute:

```
sudo yum install libpng-devel
sudo yum install freetype-devel
sudo yum install libjpeg-devel
```

5. Libraries installation

Some libraries are optional:

```
sudo yum install cairo-devel
sudo yum install giflib-devel
```

http://fribidi.org/

MapServer compilation from sources is given at:
http://mapserver.org/installation/unix.html

If Cmake error appears:

```
“CMake Error: Could not find CMAKE_ROOT !!!
CMake has most likely not been installed correctly.
Modules directory not found in
/usr/local/share/cmake-3.5
CMake Error: Error executing cmake::LoadCache(). Aborting.”
```

The error message hints it cannot find the file needed. In this case, it is not because file doesn’t exist, but due to the permission control. The Cmake tool cannot see the file and doesn’t have access to check the folder where it is. Thus, give the permission needed and Cmake it again will work. Go to the build folder, execute the following command to generate a configure file:

```
cmake -DWITH_FRIBIDI=0 -DWITH_HARFBUZZ=0 -DWITH_FCGI=0 -DWITH_CAIRO=0 ../ >../configure.out.txt
```

6. MapServer Installation

A very helpful description of MapServer and its installation instruction can be found from the official website: http://mapserver.org/installation/unix.html#installation**.**

First comes the installation of Apache server (if it’s not installed previously). Download Apache server from the link below:
https://www.linode.com/docs/websites/apache/run-php-cgi-apache-centos-6

Then, a configure file should be configured in order to support CGI. Go to folder “/etc/httpd/conf.d/” and create a new file named as: mapserver-cgi.conf, reference example can be found from the link but the syntax listed in the link is a bit wrong somehow, as no quotes are needed: http://www.server180.com/2014/11/how-to-configure-httpd-to-enable-cgi-on.html. The permission of the configure file has to be changed by `sudo chmod 755 mapserver-cgi.conf`, otherwise, there may be unknown syntax errors when you want to reload the service.

Through command `cat httpd.conf | grep 'cgi-bin'`, you can see: “ScriptAlias /cgi-bin/ “/var/www/cgi-bin” already defined in conf file”. Then, reload http server using command as follows: `service httpd reload` (Might need sudo if “syntax error” occurs). Create a symbolic link to the cgi-bin folder in: `/var/www/cgi-bin/` by copying mapserv file from `/usr/local/bin/mapserv` to `/var/www/cgi-bin/mapserv.` Remember to give proper permissions to the original mapserv file as well (at least 755).

If there is internal server error for HTTP://your-server/CGI-BIN/MAPSERV. The reason perhaps is not having an instance of PostgreSQL or the PostgreSQL is not open yet. Checking the running services using: `chkconfig –list`. Command pg_config --version will tell the version of PostgreSQL. Add an new user and password for PostgreSQL, then, go to :`mkdir /usr/local/pgsql/data` do `chown postgres:postgres /usr/local/pgsql/data, ls -ld /usr/local/pgsql/data, su –postgres.` For more detailed info, go to https://www.digitalocean.com/community/tutorials/how-to-add-delete-and-grant-sudo-privileges-to-users-on-a-debian-vps.

7. Database initiation

To initiate database is:

```
/usr/local/pgsql/bin/initdb -D /usr/local/pgsql/data/ --locale=en_US.UTF-8 --encoding=UNICODE
```

which is from the http://toroid.org/installing-postgres

If you don’t want to set the path of PGDATA, you can export it to the environment variable:

```
export PGDATA=/usr/local/pgsql/data
```

If success, start the database server using:

```
  /usr/local/pgsql/bin/postgres -D /usr/local/pgsql/data
```

or

```
  /usr/local/pgsql/bin/pg_ctl -D /usr/local/pgsql/data -l logfile start
./pg_ctl start -D /usr/local/pgsql/data &
```

To run a server as a background program, please look at:
http://www.postgresql.org/docs/9.1/static/server-start.html
http://www.thegeekstuff.com/2009/04/linux-postgresql-install-and-configure-from-source/