RWTH AACHEN UNIVERSITY

Attention Drivers!

- Analyzing Driver Distraction

Diploma Thesis at the
Media Computing Group
Prof. Dr. Jan Borchers
Computer Science Department
RWTH Aachen University

by
Dominik van Engelen

Thesis advisor:
Prof. Dr. Jan Borchers

Second examiner:
Prof. Dr. Klaus Wehrle

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I hereby declare that I have created this work completely on my own and used no other sources or tools than the ones listed, and that I have marked any citations accordingly.

Hiermit versichere ich, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt sowie Zitate kenntlich gemacht habe.

Aachen, March 2011
Dominik van Engelen

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Abstract

At least 25% of all accidents in the USA result from some kind of inattention of the driver (Stutts et al. [2001]). Driver distraction is already heavily involved in traffic accidents and it will become even more important in the near future due to in-vehicle systems and devices, which are increasingly installed in cars.

Analyzing driver distraction is a challenging task because driving itself is already a multitasking scenario and can not be explained by simplistic models. On the other hand, models with high complexity can hardly be used in the industry since development cycles have become rather short and need near-term predictions if an interface is useful or not.

In this thesis a general multitasking model for analysis is used and mapped to the specific area of driving. The 4-dimensional multiple resource model by Wickens uses different resources to describe tasks and has emerged as a well-accepted reference model. Potential conflicts in resource demands between tasks are identified and used to derive possible interferences. Furthermore another input modality, the haptic sense, is added to the model and the issue of having no red-line in task overload is addressed with the help of rescaling factors. This method is implemented via software.

The very complex problem of how to describe driving and secondary tasks is treated by differentiating them in atomar components and determining which resources are required in which quantity. This way it is possible to represent even complicated tasks as simple demand vectors for further calculations.

Althogh an empirical validation of this thesis remains to be done, the predictions of the model are in accord with familiar multitasking scenarios. In a workshop about task modeling five driving and five secondary tasks were created in cooperation. For all of them the model was able to calculate useful predictions.

The workshop also demonstrated the insufficient consideration of real-time requirements of secondary tasks. At this point the model could need further amendments.

Although confirmation by further studies is needed, the present results show that this approach could be a very helpful tool to support industry and interface designers and an important contribution to increased road safety.

Überblick

Bereits 2001 ging in mindestens 18,6% der polizeikundigen Autounfälle deren Ursache auf irgendeine Form von Fahrerablenkung zurück, welche durch geschicktes Design der Fahrzeug HMI beeinflussbar ist - Tendenz steigend (Stutts et al. [2001]). Auf Basis dieser Fakten und der Tatsache, dass heutzutage immer mehr technische Hilfssysteme in Fahrzeugen zum Einsatz kommen, ist der Fahrerablenkung eine besondere Bedeutung zuzumessen.
Jedoch ist die Analyse von Fahrerablenkung in höchstem Maße komplex, da die Fahraufgabe selbst schon eine Form des Multitaskings darstellt. Dementsprechend sind einfache Modelle, die lediglich eindimensional die Aufmerksamkeitsschwelle beschreiben, nicht sinnvoll einsetzbar.
In dieser Bachelorarbeit wird eine innovative, industrietaugliche Methode zur schnellen Abschätzung des Einflusses von sekundären Aufgaben auf die Fahrerablenkung entwickelt. Dazu wurde das 4-dimensionale multiple Ressourcenmodel von Wickens adaptiert und um den taktilen Sinn erweitert. Das Modell identifiziert potenzielle Konflikte um Ressourcen und berechnet daraus Interferenzen. Zudem wird die Problematik eines fehlenden kritischen absoluten Interferenzwertes mittels Reskalierung adressiert. Des Weiteren wurde das Verfahren softwaregestützt implementiert.
Um sowohl Fahraufgaben als auch Sekundäraufgaben adäquat modelieren zu können, werden diese in atomare Aspekte zerlegt und im Hinblick auf ihre Resourcenbelegung untersucht. Die Resultate werden in Form von Bedarfsvektoren dargestellt und für weitere Berechungen mit dem 4-d Model genutzt.
Die entwickelte Methode wurde in ersten Tests erprobt und konnte ihre Eignung zur schnellen Anwendung unter Beweis stellen. In einem Workshop zum Thema Modellierung von Fahr- und Sekundäraufgaben wurden jeweils fünf Aufgaben modeliert. Die zugehörigen Interferenzberechungen des Models sind plausibel und decken sich mit realen Erfahrungswerten. Eine qualitative Bewertung der entwickelte Methode ist jedoch zum jetzigen Zeitpunkt nur eingeschränkt möglich, da der Abgleich mit empirischen Methoden noch aussteht.
Im Falle einer erfolgreichen Validierung könnte der hier vorgestellte Ansatz jedoch eine wertvolle Bereicherung für Industrie und Interface Designer sein und somit einen wesentlichen Beitrag zur allgemeinen Verkehrssicherheit leisten.

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Chapter 1

Introduction

At least 25% of all accidents in the USA, which are known by the police, result from some kind of inattention of the driver (Stutts et al. [2001]). Specific sources of distraction among distracted drivers were: Outside persons/objects/events, adjusting radio/CD, fellow passengers in the vehicle, eating/drinking, etc. When these sources are categorized, at least 18, 6% of the accidents can be related to the vehicle's human machine interface (HMI).

distraction is an important factor in accidents

Although the study of Stutts et al. [2001] is about ten years old it must be assumed that the problem of driver distraction is rising since more and more technical systems are integrated in vehicles nowadays. Consequently, vehicle's HMI design is more important than ever to prevent distraction from the primary driving task.

vehicle's HMI design is of high importance

When supporting HMI designers, the most important factors are time and money. There are methods to describe driver distraction, but most of them are time-consuming and costly. Methods of analysis have to be fast, practical, and inexpensive, otherwise they are useless from an industrial point of view without any reference to their actual value.

most important factors when supporting designers are time and money

On the other hand simple models, which treat the level of attention as an one-dimensional threshold, are not useful, because the very complex aspect of multitasking is over-

simple models are not sufficient

simplified. Moreover a simple time-line analysis is not sufficient because tasks also vary in attentional demands which are not influenced by time.

model should be fast, practicable, universally usable and capture the complexity

The goal of this thesis is to present a model which is capable of predicting interference between driving and secondary tasks. The analyzation with the help of the model should be fast and practicable without neglecting the complexity of multitasking and have scientific plausibility. Furthermore, it should have scientific plausibility and be universally usable for all kinds of driving and secondary tasks, even if the interface of the secondary task does not exist yet.

considered research questions

Therefore I will examine the following research questions: Which model is suitable for this kind of application? How can such a model be adapted and used for our requirements? How can one get a detailed description and understanding of driving? Which factors are relevant for secondary tasks and their interfaces? What can further research do to support the approach presented in this thesis?

chapter 2 contains basics, related work and industrial trends

Chapter 2 treats the topics human attention (2.1) and human attention models (2.2) to cover necessary psychological background. Subsequently to that, driver attention studies are considered at 2.3, which addresses empirical experiments more than theoretical models. Since industry is heavily involved in the topic of driver distraction as well, section 2.4 gives some examples from industry leaders discussing the topic, whereas section 2.5 covers the legal basis for suretyship.

chapter 3 considers the 4-dimensional multiple resource model

In chapter 3.1 Wickens' 4-dimensional multiple resouce model is introduced. This model provides the basis for our further investigations. After explaining it in greater detail, I will show how to make calculations with the model at 3.2. There are some pro and contra arguments for and against the 4-dimensional multiple resouce model at the end of chapter 3.1. During the next section, I give hints on how some of these contra arguments could be addressed.

chapter 4 analyzes the modeling of driver distraction

Subsequently, in chapter 4, we will address the question how to model driver distraction. Following to the definition (4.1), the atomar aspects of driving and its characterization will be threated at 4.2. In the next part (4.3) exemplary driving tasks are modeled for later calculations with the model. Similar to the atomar aspects of driving, section 4.4 investigates the nature of secondary tasks, followed by examples of secondary tasks in section 4.5. Ongoing, we will have a look at how to use the 4-d model in section 4.6. Since I implemented the calculations with the model in software, I will refer to that in section 4.7.

Chapter 5 describes a workshop about task modeling which I have done in the course of this thesis. While section 5.1 explains the workshop itself, section 5.2 highlights its results. In the end of this chapter (5.3) I consider the question what is still missing after the workshop.

chapter 5 contains the workshop about task modeling

The last chapter, number 6, summarizes the outcomings of this thesis at 6.1 and indicates future work to be done in this area of science at 6.2.

chapter 6 treats summary and future work

Chapter 2

Related work

This chapter contains five main sections. The first one deals with human attention, including topics like definition of attention, and why attention is important for this thesis. In the second section I will focus on psychological models for human attention and how they have changed over the time. The third section is about driver attention studies. A lot of research has been done and is done in this topic and I will give a short overview as well as a comparison why I write this thesis and what its benefits are. In the fourth section industrial trends are considered. Not only for research but also for industry driver distraction is a really important contemporary topic and almost every related company does its own research. The last section briefly introduces the european statement of principles, a collection of guiding principles, which summarizes essential safety aspects for in-vehicle systems.

structure of chapter 2: human attention, human attention models, driver attention studies, industrial trends, european statement of principles

2.1 Human Attention

Attention is the cognitive process of selectively concentrating on one aspect of the environment while ignoring other things. Attention has also been referred to as the allocation of processing resources (Anderson [2004]). A common example is the so called cocktail party effect where a person is able to listen exclusively to what another person is saying

definition of attention

while ignoring every other conversation in the room.

attention is closely linked to driver distraction

A task which is performed in parallel to a more important first task is called a secondary task. Performing a secondary task while driving has a lot to do with human attention. When the driver is no longer able to allocate enough processing resources to the driving task and his attention is completely focussed on the secondary task, the situation can become really dangerous and risky for all traffic participants. Therefore we should have a closer look at models for human attention.

developement of human attention research from abstract models to more concrete tasks

Attention has been a topic in psychology for the last 40 years and is one of the most intensely studied topics within psychology and cognitive neuroscience. During this time there is a trend from completely abstract models of human attention (Treisman and Gelade [1980], Posner et al. [1980], Posner [1980], Posner and Petersen [1990]) to models of more concrete tasks such as rapid scene analysis or selective visual attention (Itti et al. [1998], Desimone and Duncan [1995]).

Wickens' multiple resource model has emerged as a well-accepted reference model

One particular model, the multiple resource model by Wickens, was released in 2002 and emerged as a reference in multiple resource theory. The model fulfils neurophysiological plausibility as well as design decisions and has appeared to stand the test of time in its ability to account for three decades of dual-task research and to support design decisions (Wickens [2008]). This model will be explained in detail in chapter 3.1.

use Wickens' model for analysis and interference predictions

In this thesis, I will use Wickens model to analyze driver distraction and show how this model can be used to predict interference between driving and secondary tasks.

2.2 Human Attention Models

human attention models predict human attention behavior

A human attention model is a model created to simulate human attention. In general, such a model is generated out of observation and empirical data and should help to predict human attention behavior.

The view of attention changed over the time from an all-or-none single-channel bottleneck view of attention (Broadbent [1971], Welford [1967]) to parallel processing and divided attention (Kieras [2007], Salvucci and Taatgen [2008], Boles et al. [2007]).

change in view of attention from single to parallel processing

2.2.1 Predicting Dual-task Performance with the Multiple Resources Questionnaire (MRQ)

The human attention model by Boles et al. [2007] uses a statistical method (factor analysis) to measure workload in particular mental processes. Auditory and visual processing has further been differentiated within each hemisphere (brain region) into subprocesses. In this manner, 14 separate resources of perception emerge (and 17 overall).

statistically analyzing mental processes to identify resources

In their experiments, the mean ratings showed high diagnosticity in identifying specific mental processing bottlenecks. Though, with the profilation of more resources, it becomes more difficult to precisely associate each with brain locations (and therefore gain full neurophysiological plausiblitily).

pro: high diagnosticity, contra: full neurophysiological plausiblitily

2.2.2 Control of Cognition

Kieras [2007] and Meyer constructed a human information-processing architecture that is especially suited for modeling dual-task performance, named EPIC (Executive Process-Interactive Control). The EPIC architecture includes peripheral sensory-motor processors surrounding a production-rule cognitive processor, and is being used to construct computational models for basic multiple-task situations.

information-processing architecture to construct computational models for basic multiple-task situations

The main difference to other cognitive architectures is the focus on perceptual and motor operations. Many features of the EPIC architecture have later been incorporated into other cognitive architectures.

difference to other models is the focus on perceptual and motor operations

2.2.3 Threaded Cognition: An Integrated Theory of Concurrent Multitasking

streams of thought represented as threads of processing

The model by Salvucci and Taatgen [2008] of threaded cognition posits that streams of thought can be represented as threads of processing coordinated by a serial procedural resource and executed across other available resources (e.g., perceptual and motor resources).

predictions how multitasking results in interference

By instantiating this mechanism as a computational model, threaded cognition provides explicit predictions of how multitasking behavior can result in interference, or lack thereof, for a given set of tasks. Like the EPIC architecture (2.2.2), this model invokes multiple resource constructs within perceptual modalities to account for dual-task interference patterns.

2.2.4 Modeling drivers' visual attention allocation while interacting with in-vehicle technologies

predict visual scanning behavior of driver

A computational model of visual attention while interacting with in-vehicle technologies was developed by Horrey et al. [2006]. This model focuses on driver performance and visual scanning and can predict to which points the driver is looking. The model is based upon former research on visual attention. Researchers discovered that the allocation of visual attention to different parts of the visual field is driven by four factors: Salience, Effort, Expectancy, and Value (SEEV).

focal vision increased scanning behavior while ambient vision does not

Overall, the task priority had a significant impact on scanning, meaning that focal vision (for in-vehicle tasks) caused increased scanning behavior while ambient vision (for lane keeping) resulted in no increment in scanning. For more details on focal vs. ambient vision see chapter 3.1.4.

2.3 Driver Attention Studies

Because the topic driver attention is a broad field, most researchers try to restrict their studies to a subpart of driver distraction. Since these studies get their results from experiments in the real world, a good model should be capable of explaining their outcomes.

good models should explain results of studies

2.3.1 Collision warning design to mitigate driver distraction

Hoffman and Hayes [2004] researched on how alert strategy and alert modality affect how well collision warning systems mitigate driver distraction and direct drivers' attention to the car ahead when it unexpectedly brakes. They set up two experiments in which drivers interacted with in-vehicle systems (email) and a collision warning system signaled a braking lead vehicle. Therefore, they used graded alerts, i.e. alerts which increase in their intesity, like a warning signal becoming louder if the distance to another car decreases.

experiments on alert strategies and modalities

Their results showed that graded alerts led to a greater safety margin and a lower rate of inappropriate responses to nuisance warnings. Moreover, graded alerts were more trusted than single stage alerts. Furthermore they discovered that haptic alerts (a vibrating seat in their experiments) were perceived as less annoying and more appropriate. In conclusion, graded haptic alerts should be considered as an alternative or addition to traditional alerts (sounds and warning lights). The 4d-model can give hints which alerts to use for such collision avoidance strategies.

results with graded alerts were better than single stage alerts

2.3.2 Effects of voice technology on test track driving performance

Ranney et al. [2005] observed the effects of voice technology in cars. In general, performing in-vehicle tasks leads to

voice-based interfaces reduce distraction diversion of both peripheral (visual and manual) and attentional (cognitive) resources from driving. In their experiments, performing secondary tasks resulted in significant decrements to vehicle control, target detection, and car-following performance. In contrast, their voice-based interface helped reduce the distracting effects of secondary task performance.

results match predictions of Wickens' model

This matches their assumption, that the auditory mode will involve less interference than the visual mode because driving inputs are mainly visual, which was derived from the multiple resource model of Wickens.

2.3.3 The impact of distraction mitigation strategies on driving performance

influence of adaptive interfaces was analyzed

The influence of adaptive interfaces was analyzed by Donmez et al. [2006]. For that purpose an advising strategy that alerts drivers of potential dangers and a locking strategy that prevents the driver from continuing a discrete task were presented to drivers of different ages in two modes (auditory, visual) and two road conditions (curves, braking events). In these experiments, the subject was driving on a curvy road and was informed that the system would either advise them or lock them out when the roadway required their attention, specifically when the lead vehicle was braking or there was a curve ahead. While driving, the subject had to perform visual and auditory secondary tasks.

adaptive interfaces can reduce abrupt braking and improve braking response

The experiments showed that visual distractions were worse than auditory ones for curve driving and drivers did brake more abruptly under auditory distractions. The locking strategy also resulted in longer minimum reaction time to collision. Their study results in the observation that adaptive interfaces can reduce abrupt braking on curve entries resulting from auditory distractions and can also improve the braking response for distracted drivers.

2.3.4 Driver distraction, telematics design, and workload managers: Safety issues and solutions

Closely related to driver distraction, the research on workload managers bridges the gap between theoretical models and usability. A workload manager is a device that attempts to determine if a driver is overloaded or distracted, and if they are, alters the avaibility of telematics and the operation of warning systems (Green [2004]).

workload managers determine if a driver is overloaded or distracted

Green identifies the unique nature of telematic tasks and describes likely workload manager architectures, applicable regulations, and industry efforts. For instance, when to present non-safety critical messages to the driver based on the speed, windshield wiper movement, and other vehicle data. He also mentions that dialog managers in the Volvo S40 and V40 block telephone calls when drivers are turning or changing lanes, situations where drivers should be focusing on the primary task of driving. In summary workload managers are very useful to assist driving and can provide great safety benefits.

workload managers are useful to assist driving and can provide safety benefits

2.3.5 Overview Driver Attention Studies

Table 2.1 contains a short summary of the considered studies.

2.4 Industrial Trends

The Navigation Strategies USA[1] event is the primer conference on consumer-centric navigation products, featuring top names from companies such as Nokia, Volkswagen, Ford SYNC, Panasonic, Wikitude Drive, GM, Virgin Mobile, T-Mobile, Sprint, BMW, Pandora and TomTom.

Navigation Strategies USA event is North America's biggest navigation conference

Dev Khare from Venrock stated, that automotive original

Phone usage in-car discussion by experts

[1] http://www.thewherebusiness.com/navigationusa/index.shtml

Study	Main result	What is missing
2.3.1	graded alerts led to a greater safety, haptic alerts were perceived as less annoying and more appropriate → reduce distraction related crashes	when does driver distraction start? → should be avoided much earlier in the chain of cause and effect
2.3.2	voice technology leads to fewer distractions while driving	voice technology cannot be used for everything → comparison with other interfaces as alternatives would be helpful
2.3.3	adaptive interfaces improves breaking response	study does not include events that impose great demand, such as braking events that occur on the curve entry
2.3.4	workload managers can assist driving and provide safety benefits	workload managers rules → Wickens' model can be used to derive those rules

Table 2.1: Overview Driver Attention Studies

equipment manufacturers (OEMs) will loose their influence on mobile devices and in-vehicle technology, including all their margins on navigation, radio, etc., if they don't act soon.

people want all areas of typical consumer services in their vehicle

Considering what services people want in their cars, suggestions spanned all areas of typical consumer services, e.g., phone calls, emails, voice search on the web, internet radio, local POI search, navigation, and social network access (Facebook, Twitter).

consequence for industry is increased competition between OEMs and personal devices brought into vehicles

This trend to personalization includes vehicle specific apps as well as access to all the other apps in consumers' lives. In consequence, there will be increased competition between OEMs and personal devices brought into vehicles. Important questions, like where the navigation software will be installed, will be guided by the key aspect of how fast new services can be integrated.

driver distraction is highly actual in industry

To see how closely the topic driver distraction is linked to industry, look at the following three statements to the question "What are the challenges of using the vehicle as an app platform, and what could hinder growth in this area?".

- Byron Shaw from GM stated driver distraction and regulation to be the most important issues for GM right now.
- Dev Khare from Venrock emphasizes that apps have to be certified for safety, and
- Stephan Durach from BMW mentions, that simple handling within the car is a major aspect, so that the driver is able to concentrate on his major task - driving.

2.5 European Statement of Principles

The European Statement of Principles on Human Machine Interfaces (HMI) for In-Vehicle Information and Communication Systems (ESoP) is a collection of guiding principles and summarizes essential safety aspects for in-vehicle systems. "These guiding principles have been produced by a group of experts representing public organizations and industry set up as a Task Force by the European Commission in January 1998" ESoP[2] . In 2006, an new version of the ESoP was released including some extensions regarding mobile devices like nomadic devices, mobile phones and PDAs.

the ESoP is a collection of guiding principles for in-vehicle systems

The ESoP consists of 43 principles, explanations of these principles, good vs. bad examples, references to standards and suggestions, not only for safety but also for usability aspects. This statement of principles could be of help for manufacturers to address the following critical issues:

the ESoP contains 43 principles for safety and usability aspects

- How to design and locate information and communication systems in such a way that their use does not interfere with the driving task.
- How to present information without impairing the driver's field of vision.

[2] ftp://ftp.cordis.europa.eu/pub/telematics/docs/tap$_{transport/hmi.pdf}$

- How to design system interaction such that the driver maintains safe control of the vehicle, feels comfortable, and confident with the system, and is ready to respond to unexpected occurrences.

main topics: overall design, installation, information presentation, interaction, ...

The ESoP addresses the overall design, installation, information presentation, interaction with displays and controls, system behavior, and information about the system. The statement of principles does not cover aspects of information and communication systems not related to HMI such as electrical characteristics, material properties, system performance, and legal aspects.

problems with the ESoP: lot of principles are insufficiently concrete

Although the ESoP addresses important safety aspects, it can be quite hard to handle as a manufacturer because a lot of principles are insufficiently concrete. I will show how to derive more concrete guidelines with the help of Wickens 4-d model.

negative example

For example, principle 2.1.2 states: "The system should be designed in such a way so that the allocation of driver attention to the system displays or controls remain compatible with the attentional demand of the driving situation" (ESo [1998]). But what means 'compatible with the attentional demand of the driving situation'? This statement is not only subjective, but also highly case sensitive, according to every single driving situation.

Chapter 3

Theoretical Model

3.1 The 4-dimensional Multiple Resource Model

In this chapter I will introduce Wickens 4-dimensional multiple resource model (Wickens [2002, 2008]). As stated before, a model for analyzing driver distraction has to be capable of multitasking to address workload prediction adequately. Wickens' model meets this demands, and I will show how the model is useful both as a design tool and in means of predicting multitask workload overload (Wickens [2008]).

Wickens' model is capable of multitasking and fullfills requirements

The multiple resource model proposes that there are four important categorical and dichotomous dimensions that account for variance in time-sharing performance. That is, in the original form of the model, each dimension has two discrete levels.

the 4-d model is structured in 4 dimensions: stages, modalities, codes, and visual channels

The quintessence is that there will be greater interference between two tasks if they share stages (perceptual/cognitive vs. response), sensory modalities (auditory vs. visual), codes (visual vs. spatial), and channels of visual information (focal vs. ambient) (Wickens [2002]). These four dimensions are shown schematically in figure 3.1.

there will be greater interference between two tasks if they share dimensions

In the following part I will describe the four dimensions

the following subsections will explain these dimensions

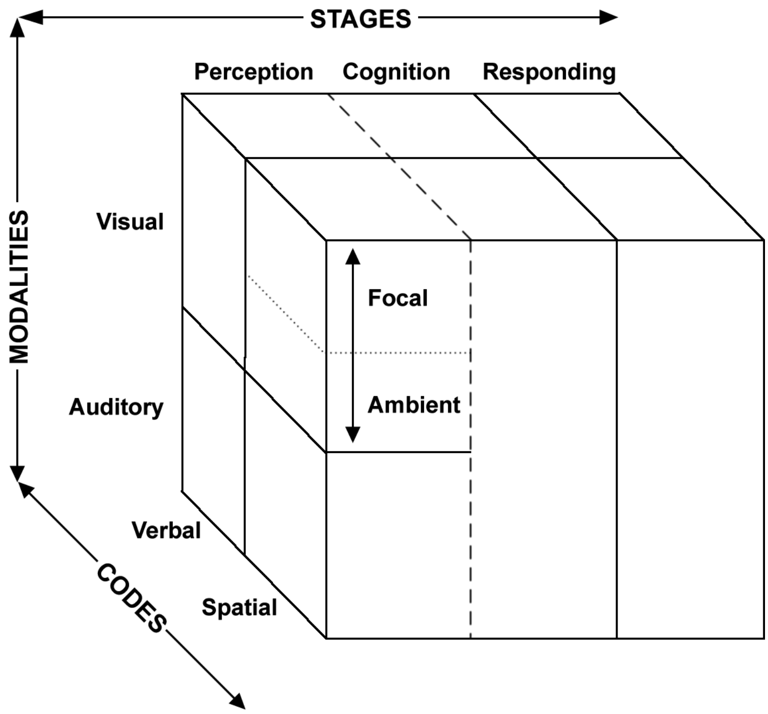

Figure 3.1: The 4-d multiple resource model in it's original version

in greater detail. Another interesting point to mention is the fact, that all of these differences can be associated with distinct physiological mechanisms.

3.1.1 Stages

perceptual and cognitive tasks use different resources than responding tasks

The *stages of processing* dimension indicates that perceptual and cognitive tasks use different resources than responding tasks (Wickens [2008]). Perceptual tasks demand understanding of sensory information like processing visual or auditive information. Cognitive tasks, like remember a symbol or estimate the distance between your vehicle and another one, use the same mental resources unlike responding tasks. Such tasks correspond to the selection and execution of actions.

stage dichotomy is supported by experiments

This stage dichotomy is supported by both experiments as well as physical differences. Experiments have shown that when the difficulty of responding in a task is varied this manipulation does not affect performance of a concurrent task whose demands are more perceptual and cognitive in nature and vice versa (Wickens [2002]).

It is important that the stage dichotomy can be associated with different brain structures. That is, speech and motor activity tend to be controlled by frontal regions in the brain (forward of the central sulcus), while perceptual and language comprehension activity tends to be posterior of the central sulcus.

stage dichotomy is also supported by neuroscience

However, since resource-demanding perceptual tasks and cognitive tasks involving working memory to store or transform information are both supported by common resources, there will be substantial interference between these two as well. For example, visual search coupled with mental rotation, or speech comprehension coupled with verbal rehearsal, both provide examples of operations at different stages (perceptual and cognitive) that will compete for common stage-defined resources, and will thus be likely to interfere.

perception and cognition are both supported by common resources and therefore interfere with each other

3.1.2 Processing Codes

The *codes of processing* dimension indicates that analogue/spacial activity uses different resources than does categorical/symbolic activity (usually verbal or linguistic), a dichotomy expressed in perception, working memory, and action (Wickens [2008]). The separation of spatial and verbal resources seemingly accounts for the relatively high degree of efficiency with which manual and vocal responses can be timeshared, assuming that manual responses are usually spatial in nature (tracking, steering) and vocal ones are usually verbal (speaking) (Wickens [2002]). For a neuroscientific explanation that this separation can often be associated with the two cerebral hemispheres see (Polson and Friedman [1988]).

spacial activity uses different resources than verbal activity

The processing codes are especially useful to predict when it might or might not be advantageous to employ voice

example: processing codes are used to employ voice vs. manual control vs. manual control. More detailed, manual control may disrupt performance in a task environment imposing demands on spatial working memory (e.g. driving), whereas voice control may disrupt performance of tasks with heavy verbal demands.

3.1.3 Perceptual Modalities

auditory perception uses different resources than visual perception

The *perceptual modalities* dimension, which is nested within perception and not within cognition or response, indicates that auditory perception uses different resources than visual perception (Wickens [2008]). Wickens explains this as cross-modal time-sharing (combining a visual with an auditory task) is better than intra-modal time-sharing (combining two tasks, which require the same perceptual modality, i.e., auditory + auditory or visual + visual).

while driving, secondary tasks should demand little visual perception

Since driving is always the primary task in this thesis, the secondary task should include as little visual perception as necessary because driving has heavy visual attention demands.

cross-modal time-sharing is better than intra-modal time-sharing

The advantage of cross-modal over intra-modal time-sharing can be explained by peripheral factors: "Two competing visual channels (VV), if they are far enough apart, will require visual scanning between them - an added cost. If they are too close together they may impose confusion and masking, just as two auditory messages (AA) may mask one another if they occupy nearby or overlapping temporal frequencies" (Wickens [2002]).

exceptions in which two displays are more practical than one display and one auditory message

It is important to keep in mind that cross-modal timesharing is generally better than intra-modal timesharing, but there are also exceptions in which two displays are more practical than one display and one auditory message, because auditory perception is not preemptive.

extension with tactile perception

One issue is that in the current version of the multiple resource model tactile interference is not included (Wickens [2008]). Wickens confirmed that he is working on an extension of his model to include a tactile channel and suggests that this added tactile channel will probably have very similar properties to current auditory resource. He argues, that the extension can be integrated into the existing model and will not change any basic concept. Therefore, I added the tactile component to the perceptual modalities dimension. In consequence, the new figure of the 4-d model looks like this (3.2).

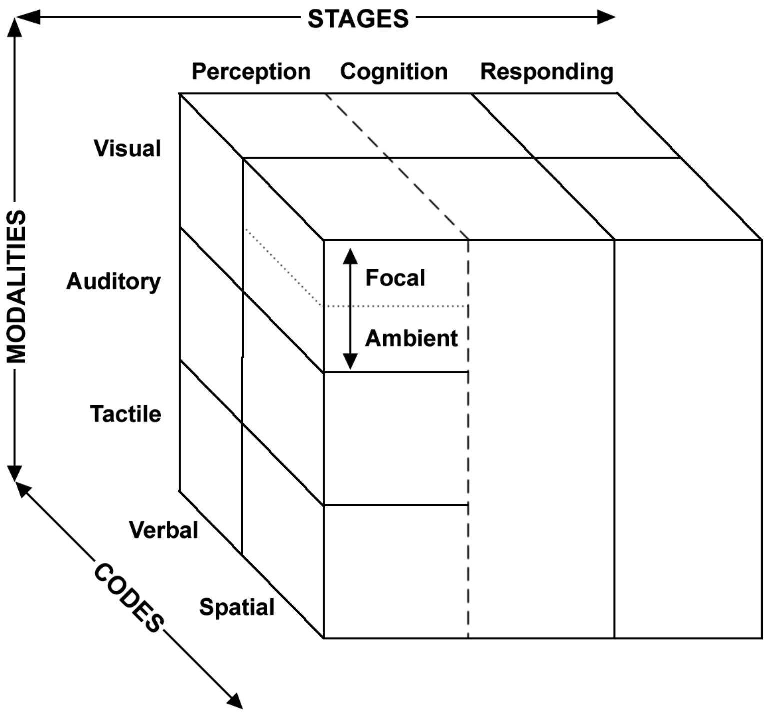

Figure 3.2: The 4-d multiple resource model with added tactile modality

3.1.4 Visual Channels

The *visual channels* dimension was added later to the previous three. It is a nested dimension within visual spatial resources and distinguishes between focal and ambient vision.

visual channels is a nested visual dimension

The primary functions of the focal visual system are visual search, object recognition, and other tasks requiring high visual acuity, including reading text. Thus, use of focal vision is tightly linked to eye movements (Horrey et al.

functions of focal vision are visual search, object recognition, and other

[2006]).

functions of ambient vision is sensing orientation and ego motion

In contrast, ambient vision is used for sensing orientation and ego motion (the direction and speed with which one moves through the environment). This parallel processing is used very much while driving, for example when keeping the car moving forward in the centre of the lane (ambient vision) while reading a road sign, glancing at the rear view mirror or recognizing a hazardous object in the middle of the road (focal vision) (Wickens [2002]).

limitations of ambient vision: not effectively support hazard detection

Studies have shown that ambient vision can support certain driving tasks, but not others. For example, Summala et al. [1996] showed that experienced drivers could use ambient visual resources to maintain vehicle control (lane keeping), even without fixating directly on the outside world. In subsequent work, Summala, Lamble and Laakso showed that ambient vision did not effectively support the important driving task of hazard detection (Summala et al. [1998]).

3.1.5 Overview: Possible Resource Demands

11 resources with examples

After characterizing the four dimensions, the following table could help to survey the possible resource demands.

previous publications did not include tactile resources and often did not distinguish between spatial and verbal vision

Note that previous publications often simplified visual perception as being focal or ambient and did not distinguish between spatial and verbal for this part of perception, even though this is more accurate. Moreover, as stated above (3.1.3), the perception of tactile information has not been officially added to the model, yet.

3.2 Computations with the 4-d Model

greatest value of the model is in predicting relative differences between different task configurations

The computational multiple resource model has its greatest value in predicting the relative differences in task interference between different task configurations. Stated in other terms, the model can be used to predict the level of disruption or interference between two tasks when they have to

Stage	Resource	abbr	Example
Perception	Visual-Spatial-Focal	Vsf	estimate distances
Perception	Visual-Spatial-Ambient	Vsa	lane keeping
Perception	Visual-Verbal	Vv	reading text, reading traffic signs
Perception	Auditive-Spatial	As	audio location
Perception	Auditive-Verbal	Av	listen to a message
Perception	Tactile-Spatial	Ts	feel distances between buttons
Perception	Tactile-Verbal	Tv	reading braille
Cognition	Cogntive-Spatial	Cs	mental rotation, rehearsing a mental image
Cognition	Cogntive-Verbal	Cv	rehearsing a phone number or other list
Responding	Response-Spatial	Rs	all kinds of manual activities
Responding	Response-Verbal	Rv	speaking, voice-controle

Table 3.1: Overview resources with examples

be time-shared. In a high demand multi-task environment, like driving, the model can be employed either in a more informal intuitive fashion or in a more formal computational fashion (Wickens [2002, 2008]).

In the informal use, the model can help designers to make decisions such as when it is better to use voice control than manual control, to use auditory rather than visual displays, or to use spatial graphic, rather than verbal material.

informal use of model: help designers to make decisions

In a more formal use, the model can be applied to compute the amount of interference predicted between two tasks.

formal use of model: compute interference between two tasks

An advantage of the multiple resource model over other models that base upon timeline analysis is the value added by varying quantitative and qualitative resource demands. Tasks also vary in their resource demands in ways not accounted for by time. E.g., driving while reading provides a lot of interference (above the overload level), whereas driving while listening to the identical message, will often be well below the overload threshold, even though both of these circumstances occupy the same amount of time in a timeline analysis.

advantage over timeline analysis is the value added by varying quantitative and qualitative resource demands

Before we can start to derive interference values from the model, we have to create a task analysis shell and a conflict matrix. This is explained in the two following subsections.

task analysis shell and conflict matrix are needed to begin calculations

3.2.1 Create Task Analysis Shell

components of resource vectors: qualitative and quantitative levels of demanded resources

First of all, we create a task analysis shell, i.e., construct a resource vector for each task. Every resource vector contains two different types of information: Firstly **which** resources are demanded (the qualitative level of resource demands) and secondly **how many** of the different resources are demanded (the qualitative level of resource demands).

scale for quantitative specification from 0 to 3

For this quantitative specification a simple four-level coding has emerged to be adequate for most circumstances (Wickens [2008]). Thus, each task-component is specified as being insignificant (0), easy (1), moderate (2) or difficult (3), depending on task characteristics and overall difficulty. This specification is independent of which resources may be demanded (e.g., perception vs. response, auditory vs. visual vs. tactile).

example resource vector for vehicle control

For example, the task of vehicle control in automobile driving may be represented as demanding: visual (focal and ambient) + tactile (spatial) + cognitive (spatial) + manual resources, and therefore the corresponding table could look like this:

Task	**Demand Vector**											**Sum of Demanded Resources**
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
Vehicle Control	2	2	2	0	0	1	0	2	0	2	0	11

Table 3.2: Example Demand Vector

In conclusion, this task is characterized by the demand vector [2,2,2,0,0,1,0,2,0,2,0].

3.2.2 Construct the Conflict Matrix

function of conflict matrix: represent conflict between resource pairs

In this step the amount of conflict between resource pairs across tasks is determined. This is very essential to represent the **multiple** aspect of the model.

conflict values are derived from a heuristic

The conflict values are derived from a heuristic. We assume that the amount of conflict is proportional to the number of shared resources within the 4-d model. Since the conflict values are symmetric, we restrict ourselves to an upper triangle matrix.

Later on, we can adjust particular conflict values, if they are not suitable. If two tasks cannot share a resource, their conflict value should be 1.0 (, e.g., voice response cannot be shared). If two tasks can perfectly share a resource, their conflict value should be 0.

later adjust single values

The numbers for each cell are determined as follows.

single steps

1. Every channel pair has a baseline conflict value of 0.2. This describes a fundamental cost of concurrence or general capacity for which all tasks compete in a time sharing situation.

   baseline conflict value of 0.2

2. Each added dimension of overlapping resources increments the conflict value by 0.2.

   penalize overlapping resource demands by adding 0.2

3. Since cognitive resources do not involve the Auditory-Visual-Tactile modality distinction, their conflict within perceptual resources (that do involve this distinction) is defined as an average value between sharing and separate modality resources. For these average values, we have to look at the whole row/column, not just the triangle matrix.

   cognitive resources get an average value between sharing and separate modality resources

4. In certain circumstances, e.g., given the physical separation of the interfaces for the two channels, the corresponding conflict values should be adjusted. Thus, for example, the value of the visual-spatial perception channel will be lowered, if the two visual sources are close together, and increased to the extent that they are widely separated, particularly if they both demand focal processing for their performance. Note that this adjustment of conflict values should not be based on differences in single task demands, since these were already captured by the single task analysis shell.

   adjust particular values can be reasonable

3.2.3 Resulting Conflict Matrix

previous heuristic leads to the following conflict matrix

When we apply the previous heuristic, our corresponding conflict matrix looks like this:

	Vsf	**Vsa**	**Vv**	**As**	**Av**	**Ts**	**Tv**	**Cs**	**Cv**	**Rs**	**Rv**
Vsf	1	0,8	0,6	0,6	0,4	0,6	0,4	0,75	0,47	0,4	0,2
Vsa		1	0,6	0,6	0,4	0,6	0,4	0,75	0,47	0,4	0,2
Vv			0,8	0,4	0,6	0,4	0,6	0,5	0,67	0,2	0,4
As				0,8	0,6	0,6	0,4	0,65	0,47	0,4	0,2
Av					0,8	0,4	0,6	0,45	0,67	0,2	0,4
Ts						0,8	0,6	0,65	0,47	0,4	0,2
Tv							0,8	0,45	0,67	0,2	0,4
Cs								0,8	0,6	0,4	0,2
Cv									0,8	0,2	0,4
Rs										0,8	0,6
Rv											0,8

Table 3.3: Conflict Matrix without adjustments

exemplary calculation for the combination [Vsa,Vsf]

E.g., the conflict value for the combination [Vsa,Vsf] is derived as

0.2 (basic conflict value) + 0.2 (both Perception) + 0.2 (both V(visual)) + 0.2 (both s(spatial)) = 0.8.

adjust values in conflict matrix

Since two verbal responses (speaking) at the same time are not possible it makes sense to adjust this conflict value to 1.0 instead of 0.8, which would be the value derived from the heuristic. Similarly, Wickens adjusted the conflict values between cognitive und response resources (Wickens [2002]).

conflict matrix for further calculations

This leads us to the adjusted conflict matrix 3.4, which will be used for further calculations in this bachelor thesis.

3.2.4 Computation of Interference Values

until now we have a task analysis shell and a conflict matrix

At this point we have a task analysis shell and a conflict matrix, which are necessary and essential to derive interference values.

	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv
Vsf	1	0,8	0,6	0,6	0,4	0,6	0,4	0,75	0,47	0,4	0,2
Vsa		1	0,6	0,6	0,4	0,6	0,4	0,75	0,47	0,4	0,2
Vv			0,8	0,4	0,6	0,4	0,6	0,5	0,67	0,2	0,4
As				0,8	0,6	0,6	0,4	0,65	0,47	0,4	0,2
Av					0,8	0,4	0,6	0,45	0,67	0,2	0,4
Ts						0,8	0,6	0,65	0,47	0,4	0,2
Tv							0,8	0,45	0,67	0,2	0,4
Cs								0,8	0,6	0,6	0,4
Cv									0,8	0,4	0,6
Rs										0,8	0,6
Rv											1

Table 3.4: Conflict Matrix with adjustments

The total interference between a time-shared pair of tasks is represented by the by the sum of two components:

interference value is composed of a demand component and a multiple resource conflict component

1. a **demand component** (specifying the resource demand), and
2. a **multiple resource conflict component** (specifying the degree to which overlapping resources are required).

For the demand component, each task combination gets a total resource demand value. Thus, it is computed by summing the average demand across all 11 resources within a task and summing over both tasks.

demand component is average resource demand over two tasks

Assume we have created the following task analysis shell in 3.2.1 for two tasks A and B.

example task analysis shell

Task	**Demand Vector**											**Sum of Demanded Resources**
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
Task A	2	2	2	0	0	2	0	2	1	2	0	13
Task B	0	1	0	0	3	0	2	0	3	0	3	12

Table 3.5: Demand components for two tasks A and B

In this case the task combination A and B gets a demand value of

example calculation for demand component between A and B

$\frac{13}{11} + \frac{12}{11} = 2,27.$

amount of interference increases with difficulty of tasks

The underlying assumption is, the amount of interference increases with the difficulty (resource demands) of one or both of the time-shared tasks.

theoretical range of demand value: 0 - 6

Applying these numbers, the total task demand for two tasks can theoretically range from 0 (two automated tasks) to 6 (two difficult tasks). In real task scenarios the upper and lower bound will not occur because neither it does make sense to analyze two completely automated tasks nor there are tasks which need every resource capacity at once. I will refer to that at section 4.6.1.

conflict component is derived by summing over conflict matrix entries demanded by both tasks

For the resource conflict component, the two tasks are compared, in the extent to which they share demands on common levels of each of the four dimensions, which means summing the conflict matrix components of all cells that are demanded by both tasks.

			Task A										
			Perceptual							Cognitive		Response	
			Vsf	Vsv	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv
		Ex.	2	2	2	0	0	2	0	2	1	2	0
Task B	Vsf	0	1	0,8	0,6	0,6	0,4	0,6	0,4	0,75	0,47	0,4	0,2
	Vsv	1		**1**	**0,6**	0,6	0,4	**0,6**	0,4	**0,75**	**0,47**	**0,4**	0,2
	Vv	0			0,8	0,4	0,6	0,4	0,6	0,5	0,67	0,2	0,4
	As	0				0,8	0,6	0,6	0,4	0,65	0,47	0,4	0,2
	Av	3					0,8	**0,4**	0,6	**0,45**	**0,67**	**0,2**	0,4
	Ts	0						0,8	0,6	0,65	0,47	0,4	0,2
	Tv	2							0,8	**0,45**	**0,67**	**0,2**	0,4
	Cs	0								0,8	0,6	0,6	0,4
	Cv	3									**0,8**	**0,4**	0,6
	Rs	0										0,8	0,6
	Rv	3											1

Table 3.6: Conflict matrix for task A and B

example calculation of conflict component between A and B

In this case the task combination A and B gets a demand value of

$$1 + 0,6 + 0,6 + 0,75 + 0,47 + 0,4 + 0,4 + 0,45 + 0,67 + 0,2 + 0,45 + 0,67 + 0,2 + 0,8 + 0,4 = 8,06.$$

The conflict component can therefore range from 0 (every resource pair of the two tasks has at least one 0-entry) to 66 (both tasks need all possible resources and the conflict matrix contains nothing else than 1.0).

theoretical range of conflict component: 0 - 66

3.2.5 Normalize Interference Values

In the original form of Wickens' multiple resource model it is possible that the conflict component dominates the total interference and the demand component becomes irrelevant, even if it should represent two difficult tasks.

problem: conflict component dominates the total interference

To compensate this weak point of the model, we introduce a scale factor which relativizes these values. Therefore, we multiply the conflict component by

solution: introduce a scale factor which relativizes these values

$$\frac{2 * \text{maximum task difficulty}}{\text{sum of all conflict matrix entries}}$$

.

As a result, the conflict component for our examples with maximum task difficulty of 3 and 66 conflict matrix entries also stays in between the range from 0 to 6.

new range of the conflict component: 0 - 6

In the previous case, the conflict value does not stay in between the range from 0 to 6. After rescaling we get:

rescaling our example

$$\frac{2 * 3}{36,09} * 8,06 = 0,17 * 8,06 = 1,37$$

In the last step, the total interference is then computed as the sum of the demand and the conflict component, giving a total interference value between 0 and 12.

finally add the two components

In our example we get a total interference value of

complete the example

$$2,27 + 1,37 = 3,64$$

.

3.3 Discussion of the Multiple Resource Model

this section discusses pro and contra arguments of the 4-d model

A short overview of positive and negative aspects of the multiple resource model is presented in this section. One particular contra point, the problem of no red-line, will be adressed later at section 4.6.1.

3.3.1 Pro

Wickens had two main criteria for his 4-d model

Wickens himself stated that the rationale for defining these four dimensions is based strongly on the confluence and joint satisfaction of two criteria (Wickens [2008]).

first criterion: neurophysiological plausability

1. As mentioned before, these four dimensions should have neurophysiological plausability, not just be an exclusively theory-based invented construction. Since all parts in the 4-d model can be linked to different parts of the brain, the construction fulfills this requirement.

second criterion: support of design decisions

2. The model should help designers to make relatively straightforward decisions. Instead of being totally abstract and theoretically Wickens was also interested in practical usefulness of the model. This criterion emerged from his human factors orientation.

4-d model satisfies both criteria

Both points, neurophysiological plausability and design decisions, appeared to be fairly well satisfied in the proposed cube model.

model has stand the test of time

Furthermore, the model has appeared to stand the test of time in its ability to account for three decades of dual-task research and to support design decisions (Wickens [2008]).

additional advantages are

Besides these two main aspects the model has additional advantages (Tas [2003]):

the model is simple in computation

- The model is relatively simple in computation. No deeper mathematical understanding is necessary to calculate conflict values between tasks. Because of this, practical usefulness is not compromised.

- It is flexible in its applications. We will use it to analyze driver distraction, but it is not restricted to that area. Other multitasking scenarios can be analyzed with it's help as well.

the model is flexible in its applications

- It can make adequate performance predictions. As far as the modeled scenarios have been evaluated with real experiments the model predicts useful results. Though, more experiments should be done to evaluate the model and collect further data.

the model can make adequate performance predictions

3.3.2 Contra

Unfortunately, there are some weak points, too.

there are some weak points

- The prediction of total interference values does not inform which task suffers from the overload (Wickens [2008]).

no information which task suffers from overload

- Other mechanisms, unrelated to resources, are not involved. Although it is possible that other aspects influence interference between two tasks as well (Wickens [2008]).

other aspects than resources are not involved

- There are no fixed rules for resource allocation and therefore some expertise is required to establish conflict values and demand vectors (Wickens [2002]).

no fixed rules for resource allocation

- Officially, the tactile input modality is still missing. After contacting Wickens I added the tactile perception to be able to include this very important sense in task modeling as well. The official extension of the model will be covered in one of Wickens' upcoming publications.

officially tactile modality is still missing

- There is no characterization of resource demand on a single scale with some kind of 'red line' (Wickens [2008], Tas [2003]) I try to adress that issue at section 4.6.1, but this approach should only be viewed as a recommendation, not a rule.

no single scale with red line

Chapter 4

Modeling Driver Distraction

4.1 Definition of Driver Distraction

There is currently no universally agreed upon definition of driver distraction. Most of them agree that distraction involves a shifting of attention away from the driving task, e.g. "Driver distraction can be defined as the diminished attention of the driver to the driving task" (Donmez et al. [2006]).

no universally agreed upon definition of driver distraction

However, a lot of these definitions fail to address the fact that not all events or objects that divert attention from the driving task are going to create a distraction. If there is no negative effect of the secondary task on driving performance or control, then distraction has not occurred.

failure of most definitions: not everything that diverts attention creates distraction

Therefore, Young [2007] defines driver distraction as "occurring when a driver's attention is, voluntarily or involuntarily, diverted away from the driving task by an event or object to the extend that the driver is no longer able to perform the driving task adequately or safely".

definition in this thesis

Since driver distraction has become a very important area of science, new models are invented to explain this specific situation. Young [2007] categorizes distraction into four

categorization of dd into visual, auditory, physical, and cognitive distraction distinct types:

- visual distraction, e.g., the driver neglects to look at the road
- auditory distraction, e.g., the driver focuses his/her attention on auditory signals rather than on the road environment
- biomechanical (physical) distraction, e.g., the driver removes one/both hands from the steering wheel
- cognitive distraction, e.g., the driver is distracted by his/her thoughts.

special about driver distraction models is multitasking

But what makes driver distraction so interesting and complex to explain? The most important difference to previous attention models is the fact, that a model for driver distraction must be capable of multitasking. All previous models are not sufficient, if they cannot explain or predict the behavior of a driver performing a secondary task while driving.

drivers allocate attentional resources to driving and non-driving tasks

When using the vehicle, drivers must continually allocate their attentional resources to both driving and non-driving tasks. Because many aspects of the driving task become automated with experience, drivers are often capable of dividing their attention between concurrent tasks without any consequences to driving performance or safety.

reasons for distraction: complexity of secondary task, demands of driving tasks

Distraction can occur either because the secondary task is so complex or compelling that drivers fail to allocate (or prioritize) sufficient attention to driving, or because the demands of the driving task are so high that they do not allow the performance of a secondary task at any level (Young [2007]).

4.2 Atomar Aspects of Driving

break up multitasking into smaller parts

In this chapter we will have a closer look at the basic components of driving. This is necessary since we want to

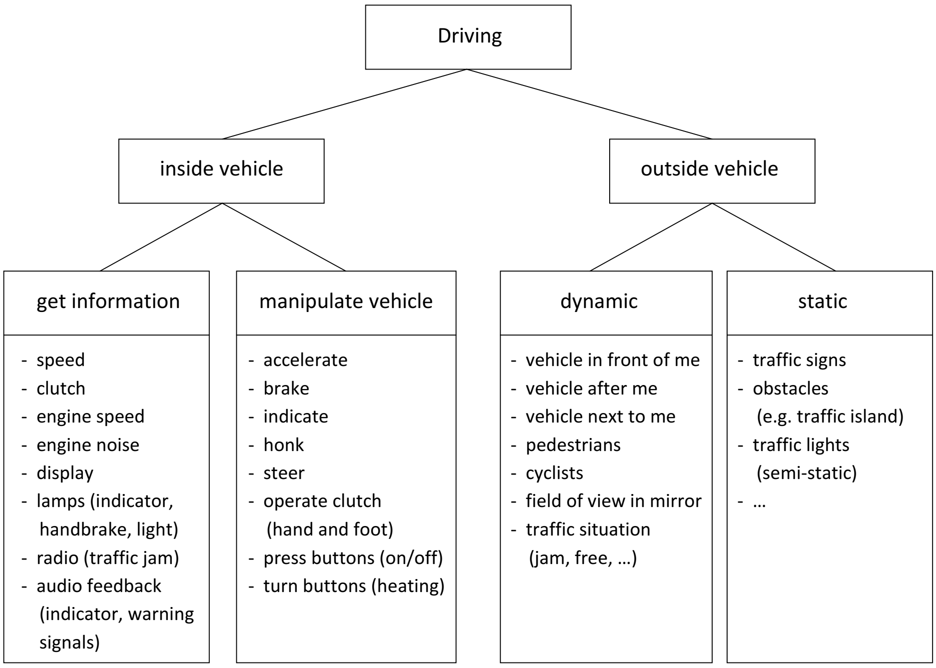

Figure 4.1: Atomic driving components

consider multitasking and therefore should know which atomar components are involved in the driving task.

Such a consideration can be very interesting but also difficult because driving itself involves the continual multitasking of a number of subprocesses that make use of the driver's cognition, perception, and motor movements (Salvucci [2002]).

interesting but challenging consideration since driving already is multitasking

4.2.1 Identify Basic Components

First of all, we have to **identify** these subtasks. This can be done by dividing the driving task into smaller and smaller subtasks. Figure 4.1 classifies activities, which are involved in driving.

identify basic components by dividing the driving task into subtasks

As you can see, driving involves much more activities than oneself is usually aware of. This list is not entitled to be

driving involves a lot activities

complete, but shows one way to identify subprocesses systematically.

4.2.2 Mapping between Components and Resources

identify demanded resources with the help of table 3.1

In the next step, after we have identified several subprocesses, we have to classify **which** resources are demanded by them. This classification can be done easily with the help of table 3.1.

example no. 1: read traffic signs

We choose a task, e.g., *read traffic signs*, and contemplate the different possible resources from the table. Since traffic signs must be recognized at a glance, this task demands **visual focal and verbal resources**, whereas tactile and auditive resources are not involved. Though the read traffic sign(s) must be recognized, processed and understood and, in consequence, **cognitive processing** is also demanded, depending on the nature of the visual processing (verbal or spatial or both).

example no. 2: operate steering wheel

To give another example, we choose the task *operate steering wheel*. Since the driver has to have at least one hand at the steering wheel, no visual resources are required to localize it. One may disagree and can argue that you need some visual resources to analyze the result of your steering wheel movements. If this is your point of view, feel free to change the later demand vectors for your analyzation. The auditory channel is not relevant for this task as well, whereas tactile, cognitive and responding processes in their spatial classification are all necessary. The tactile spatial resources will help to feel the position of the steering wheel (turned, center position, ...). The cognitive spatial resource is used to interpret this information and to calculate, in which direction the steering wheel must be turned to achieve the desired effect whereas the responding spatial resource is needed to accomplish the operation "turn steering wheel".

more classifications in the following table

Table 4.1 contains some of these classifications, including the previous two examples:

task	**demanded resources**
read traffic signs	verbal (symbols, text) vision, cognitive verbal processing
estimate + correct distance between ownvehicle and (dynamic and static) obstacles	focal spatial vision, ambient spatial vision, cognitive spatial processing, spatial responding
lane keeping	ambient spatial vision, tactile spatial, cognitive spatial processing, spatial responding
check speedometer,tachometer, ...	focal spatial vision, verbal vision, cognitive verbal processing
check/recognize other display elements	verbal vision, ambient vision, cognitive verbal processing
look at mirrors	focal spatial vision, ambient spatial vision, cognitive spatial processing
accelerate, decelerate, brake, operate clutch	tactile spatial processing, auditory processing (feedback), cognitive spatial processing, spatial responding
operate steering wheel	tactile spatial processing, cognitive processing, spatial responding
use indicator	tactile spatial (distance) processing, tactile verbal (recognize correct arm) processing, cognitive spatial processing, spatial responding
auditory feedback from vehicle (hear engine, indicator,...)	auditory spatial (where) processing, auditory verbal (what) processing, cognitive spatial processing, cognitive verbal processing

Table 4.1: Typical driving subtasks and their resource demands

4.2.3 Assign Values

determine quantity of demanded resources

Finally, we have to determine **how many** resources are demanded by the identified subprocesses.

two possibilities: intuitively or with the help ofA

Either this can be done intuitively since we chose a very simple demand classification in chapter 3.2.1, namely insignificant (0), easy (1), moderate (2) or difficult (3), or, we can use the scale of Aldrich et al. [1989]. You can find the scale in the appendix (A).

extension of Aldrich's scale with our resource names and our scale values

This quantitative scale of demand for different molecular tasks was developed by researchers and is still in use in software tools nowadays (Wickens [2002]). For the purpose of this thesis, I extended this table by two columns: The *Resource* column maps the described task to the considered resources of the 4-d model (see again 3.1) and the *New Value* column represents the original scale values in our simplified classification, ranging from 0 to 3.

4.2.4 Special Conditions

particular driving situations can be affected by driving surface, wind, light, traffic conditions, etc.

Once we understood driving as a set of subcomponents, we can use this knowledge to create resource vectors for different driving situations. Note that these driving scenarios are exemplary. It is also possible to adjust the values in order to match different conditions. Particular situations can be affected by

- driving surface (rain, black ice, snow, bouldering, ...)
- wind regime
- lighting conditions
- visibility conditions
- traffic conditions (holdup, emergency lights, ...)

and can be treated suitable by adjusting the corresponding demand values.

4.3 Exemplary Driving Tasks

In this part we will construct demand vectors for exemplary driving tasks. We will try to model normal situations, including city driving, rural road driving and highway driving, but also situations which are very stressful.

next: construct demand vectors for exemplary driving tasks

All these demand vectors in section 4.3 and section 4.5 were constructed in a workshop about task modeling. For more information about this workshop, see section 5.1.

demand vectors result from a workshop (see 5.1)

4.3.1 City Driving

We now consider driving in the city as first example. Therefore, we have to contemplate which subprocesses are involved and how strong their ressource demands are in this particular environment.

first example: city driving

Driving in the city usually involves many dynamic changes in the environment, namely other vehicles, cyclers and pedestrians who all have their individual goals. Thus, the trafficflow must integrate a lot of different conditions in contrast to speedway driving, where the speed of most road users is different, but their direction is the same.

characterization of city environment: many dynamic changes, different traffic participant

This leads to a lot of accelerating, decelerating and braking to control your own vehicle and make adjustments to the current driving situation (resources: tactile spatial, cognitive spatial, responding spatial). In addition, you need much attentive observation of the environment - direct observation as well as looking at mirrors (resources: visual spatial focal, visual spatial ambient, cognitive spatial). In between you have to check the speedometer (resources: visual verbal, cognitive verbal), use the indicator, read traffic signs (resources: visual verbal, visual spatial focal, cognitive verbal) etc.

involved subtasks and resources

It is noteworthy that this task, as all driving tasks, heavily depends on the traffic situation. Driving through the city at rush hour causes much more cognitive load than on a sunday morning.

task heavily depends on traffic situation

A resource allocation table for our city driving task could look like this:

Task	Demand Vector											Sum of Demanded Resources
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
City Driving	2	2	1	1	0	1	0	3	1	2	0	13

Table 4.2: Demand vector for city driving

4.3.2 Rural Road Driving

second example: rural road driving

Our second exemplary driving task is driving on a rural road. Generally, the cognitive load for this driving task is not as high as for city driving.

particular subtasks and resources

The lane keeping task can sometimes be more pronounced than in the city because of the higher average speed (resources: visual spatial ambient, tactile spatial, cognitive spatial, responding spatial), whereas breaking, accelerating and estimation of distances etc. (resources: cognitive spatial, responding spatial) are not done as often as in the city.

more space for secondary tasks

In consequence, the lower degree of involving our visual and cognitive resources leaves more room for secondary activities.

Task	Demand Vector											Sum of Demanded Resources
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
Rural Road	1	2	1	1	0	1	0	1	1	1	0	9

Table 4.3: Demand vector for rural road driving

4.3.3 Highway Driving

third example: highway driving

Our third considered driving task is driving on the highway. Highway driving is characterized by very high velocity which hampers other subtasks.

For example, the difficulty of reading traffic signs (resources: visual verbal, visual focal spatial, cognitive verbal, cognitive spatial), lane keeping (resources: visual spatial ambient, tactile spatial, cognitive spatial, responding spatial), and observation of your environment, mainly other vehicles, (resources: visual spatial focal, visual spatial ambient, cognitive spatial) can increase significantly in special conditions. The higher velocity extends braking distances and the sensitivity of vehicle guidance as well. Additionally, your car becomes more susceptible to squalls and changing wind regimes if you, for example, overtake another car or truck.

changed conditions compared to previous examples because of speed

Thus, the following table contains two task variations of highway driving, namely normal highway driving and highway driving through a building site.

two variants of highway driving: normal and through a building site

Task	**Demand Vector**											**Sum of Dem. Res.**
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
Highway Normal	2	2	1	1	1	1	0	2	1	2	0	13
with Building S.	2	3	1	1	1	2	0	3	1	2	0	16

Table 4.4: Demand vectors for highway driving tasks

4.3.4 Worst Driving Tasks

It is easy to obtain that even such a difficult driving task as highway driving through a building site does never reach the theoretical maximum sum of demanded resources (which is 33 on our scale).

theoretical maximum demand value is never reached in real applications

At section 3.3.2 I mentioned that there is no characterization of resource demand on a single scale with some kind of 'red line'.

there is no characterization of a red line

The following approach could help to get a benchmark in terms of task difficulty:

get a benchmark for task difficulty

First of all, we model different driving tasks, as usual. Then, in the second step, we try to model really diffi-

model normal and difficult driving tasks cult and challenging once, like highway driving through a building site. In our group meeting, we identified the task **searching a parking lot in the city with a foreign car** as being the most challenging for us.

WDT will be needed later on s a reference point for our scale

When we later perform our calculations with the model, we will use this worst driving task (WDT) as a reference point for our scale.

4.4 Secondary In-Vehicle Tasks

model secondary tasks directly from the interaction we want to model

Similar to driving tasks, we have to characterize secondary tasks in matters of resource demands, i.e., which of the resources from table 3.1 are used in the secondary task and how many. Since these secondary tasks are not fixed, such a classification can be done directly from the interaction we want to model.

most important: input and output modalities

The most important aspects for our analyzation are the input and output modalities.

input modalities: hands, voice

Input for a in-vehicle device is usually done via hands or via voice. In the case of manually input it can be useful to distinguish between buttons, which give a natural tactile feedback, and touchdisplays which usually dont have this characterization.

output modalities: sound, haptic, visual

In terms of output and information representation, devices can utilize auditory (sound), tactile (haptic) and/or visual (display) senses. To alleviate the mapping between resource demands and secondary tasks the subdivision of sound into signal vs. message seems to be reasonable.

overview classification of secondary tasks

These classification of secondary tasks is visualized in the following figure:

4.5 Exemplary Secondary Tasks

five modeled secondary tasks

In the next part of this section, we will have a look at five

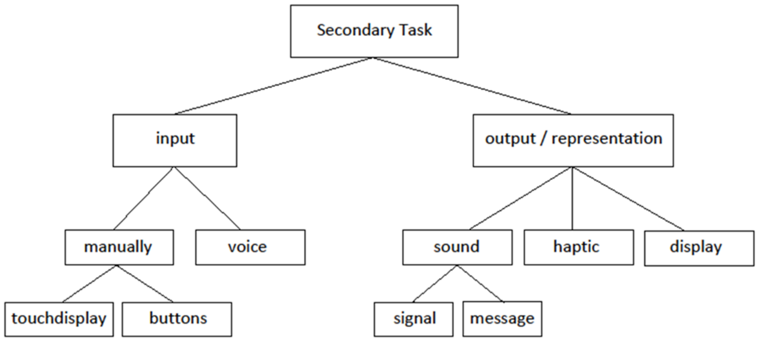

Figure 4.2: Classification of secondary tasks

secondary tasks. They should represent the spectrum from easy daily activities (listen to the radio) to complex secondary tasks like install an app or play a game.

All these demand vectors for secondary tasks, just as the once for our driving tasks in section 4.3, were created in a workshop about task modeling. See section 5.1 for further information.

demand vectors result from a workshop (see 5.1)

4.5.1 Search Radio Frequency

Our first secondary task will be to search a certain frequency on the radio. Assume you have a traditional model without any extras like in picture 4.3.

what our radio looks like

If the radio is not already switched on, you will have to do that first. This will not need many visual resources (visual spatial focal) since the ON button is different from all the rest and very easy to locate. Maybe you do not even have to look at the radio and can find the button by its shape and position, using your haptic sense (resource: tactile spatial and verbal). In both cases you will have to respond spatial to push the button.

procedure of switching on the radio

After the radio is switched on, we will search our favourite station (assuming that this one is not already programmed onto a button). We start our search by looking at the actual radio frequency and compare it to the frequency of your

start search certain frequency

Figure 4.3: Traditional car radio

favourite station (visual spatial focal vision, visual verbal vision + cognitive verbal processing).

get the right frequency by comparing actual frequency and searched frequency

Then we select one of the two buttons to adjust the frequency and push it. In this case it is more likely that we have to take another look at the radio to find the correct button, since they are not as easy to feel as the big ON/OFF-button. Besides from that, we have to look at the street from time to time, leaving only short gazes for getting the information from the radio we need. Because of this, the pushing time of the buttons to select the frequency will be roughly estimated and depends on the difference between the actual station number and the one we want to achieve.

demanded resources for this task

During this whole process, we need visual spatial focal and visual verbal resources to read the numbers on the display, tactile spatial resources to feel the state of the button (pushed/released), cognitive verbal processing to compare numbers and respond spatial resources to push/release the button and maybe switch over to the other one, if we did not get the right frequency at the first time. Maybe it is possible to use auditory verbal processing to recognize the actual station, but this will not work in every situation.

Our corresponding demand vector for this task looks like this:

Task	Demand Vector											Sum of Demanded Resources
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
Search Radio Fr.	2	0	2	0	1	2	1	0	1	1	0	10

Table 4.5: Demand vector for searching a certain radio frequency

4.5.2 Listen to the Radio

Now we will have a closer look at the secondary task **listen to the radio**. In contrast to the previous secondary task, the modeling of this one can be done really straight forward:

modeling of listen to the radio can be done straight forward

When you listen to the radio, you need auditory verbal and a few spatial resources to perceive the song or message and cognitive verbal resources to process your perception. The number of demanded resources may vary in terms of what you perceive. If you listen to a song, the cognitive load is usually not as high as if you listen to an important road message. Some of us may sing along with their favourite song, so we include a little responding verbal, too.

demanded resources for listen to the radio

A typical secondary task ”Listen to the Radio” could look like this:

Task	Demand Vector											Sum of Demanded Resources
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
Listen Radio	0	0	0	1	2	0	0	0	2	0	1	6

Table 4.6: Demand vector for listen to the radio

As you can see, even if the device in this and the previous secondary task (search a certain frequency on the radio) is the same, the resource demands are completely different and so the difficulty of the task is. While setting up the radio has a total resource demand of 10, listening to the radio only results in a sum of 6.

same device, different resource demands and task difficulty

Another very important aspect is the factor of time. As long as the performed secondary task is not time-critical, like the

listen to the radio is interruptible

previous two, you can interrupt it and later on continue with what you have done before to give all your attention to the more important primary task of driving.

secondary tasks should be forbid if they are time-critical

If there is no possibility to interrupt the secondary task, it should not be possible to be performed as long as the vehicle is in motion.

4.5.3 Play Tetris

modern entertainment secondary task: Tetris

We recently looked at two very common secondary tasks while driving. However, this thesis would not be contemporary if we would ignore the possibilities of nowadays in-vehicle systems, including entertainment functionalities as well. For this reason, our third considered secondary task is to play the computer game Tetris at the vehicles driving console via touchscreen.

use touchscreen, sound, characterized as being difficult

Let us assume the game uses a touchscreen (resources: focal spatial and verbal vision, tactile spatial, response spatial), and sound (resources: auditory verbal). Furthermore, the game should requiere heavy mental demands (resources: cognitive spatial and verbal). So we model the task play Tetris as follows:

Task	**Demand Vector**											**Sum of Demanded Resources**
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
Play Tetris	3	1	3	0	1	2	0	3	1	3	0	17

Table 4.7: Demand vector for playing Tetris via touchscreen

4.5.4 Worst Secondary Tasks

playing games while driving should be forbidden

Playing games while driving seriously compromises safety and should only be allowed, if the motor is turned off. Additionally, it is a time-critical secondary task, which makes it even more inappropriate while driving.

WST Tetris as reference

To do this justice, I will refer to playing Tetris as our **worst**

secondary task (WST), similar to 4.3.4 as our worst driving task.

4.5.5 Further Secondary Tasks

We modeled two more secondary tasks in our workshop.

two more examples

For these tasks I will restrict myself to a short description and the resulting demand vectors.

only results of worshop are presented

The first one was install an app on your smartphone. The second one concerned a service in higher class automobiles from BMW, called BMW Assist[1] .

install an app and use BMW Assist

This service works in the following way: You can start a request by pushing a button in your centre console. The car makes a telephone connection to the BMW service headquarters and automatically transmits your vehicle's status and position data. Then you can tell them by phone that you, for example, would like to drive to the nearest restaurant. The people from the service station will search for what you requested and send the information directly to your navigation device in your car.

description of BMW Assist

Task	**Demand Vector**											**Sum of Demanded Resources**
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
Install App	2	1	3	0	1	1	0	2	2	2	0	14
BMW Assist	1	0	0	0	2	1	0	1	3	0	2	10

Table 4.8: Demand vectors for further secondary tasks

4.6 How to use the 4-d model

In this chapter I will demonstrate the profit of the multiple resource model within three scenarios in which the model is used to predict interference between driving and a secondary tasks.

next: use of the model in three different scenarios

[1]http://www.bmw.com/com/en/owners/navigation/assist$_1$.*html*

influence of driving conditions, influence of secondary task, context sesitivity

These three scenarios differentiate between their approaches. In the first scenario the influence of the driving conditions is analyzed. The second scenario deals with the effect of variances in secondary tasks, whereas the third scenario derives its' values out of context sensitivity between these two.

use demand vectors from before

We already created demand vectors for the following tasks and we will use these demand vectors in later calculations.

Task	**Demand Vector**											**Sum of Dem. Res.**
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
Rural Road	1	2	1	1	0	1	0	1	1	1	0	9
Highway Normal	2	2	1	1	1	1	0	2	1	2	0	13
City Driving	2	2	1	1	0	1	0	3	1	2	0	13
Search Radio Fr.	2	0	2	0	1	2	1	0	1	1	0	10
Install App	2	1	3	0	1	1	0	2	2	2	0	14
BMW Assist	1	0	0	0	2	1	0	1	3	0	2	10

Table 4.9: Overview: Driving and secondary tasks for the following situations

4.6.1 Reference Values

idea behind the model: compare different multitasking scenarios

As stated before, the idea behind the model is to compare different multitasking scenarios and judge, which one will be better than the other, for example if it is better to use voice or manual control during the same driving situation.

Wickens: model is for relative differences, not for absolute predictions

Wickens explicitely mentions this point in his work: The primary value of such a model is predicting relative differences in multitasking between different conditions or interfaces. It is not designed to make absolute predictions of performance (Wickens [2008]).

hints in terms of an overload-threshold would be helpful

However, it would be useful to have at least some hints which resulting inteference values are allowed, which are critical and which are most likely above the overload-threshold.

we need two new scaling factors

For this reason I introduce another scaling factor for each of the two (demand and conflict) components.

While the demand vector values from the theoretical model have the possibility to reach a total sum of 33, this value will never be reached when modeling a real scenario. Comparably, the same problem occurs with the number of overlapping resources. Thus, I introduced a worst driving task (4.3.4) and a worst secondary task (4.5.4).

max theoretical values are never reached

The idea behind the two further scaling factors is to see the demand and conflict component between the worst driving task and the worst secondary task as 100%, or in terms of our model, as a 6 on the scale.

see demand and conflict component between WDT and WST as 100%

If you calculate the interference between searching a parking lot in the city with a foreign car and play Tetris, you can derive these scaling factors as follows:

calculate scaling factors

The general scaling factor for the demand component between two tasks is

general demand scaling factor

$$\frac{22 * \text{maximum conflict value}}{\text{Resources demanded by WDT + WST}}$$

in our case:

$$\frac{22 * 3}{18 + 17} = 1,89$$

in our examples

The general scaling factor for the conflict component of a task is

general conflict scaling factor

$$\frac{2 * \text{maximum conflict value}}{\text{conflict component between WDT and WST}}$$

in our case:

$$\frac{2 * 3}{4,23} = 1,42$$

in our examples

Most calculations with the model using such a rescaling confirmed, that a critical value for the demand as well as for

trying to define red line area: $\frac{2}{3}$ of conflict between WDT and WST the conflict component is around 4.0 of 6, which is equivalent to $\frac{2}{3}$ of the conflict values between the WDT and the WST.

4.6.2 Influence of Driving Environment

driving tasks restrict secondary tasks

Each driving situation has heavy influence on our possibilities to perform secondary in-vehicle tasks. Some driving situations leave a lot of freedom to do so while others will need a great deal of concentration and attention. We know this from our everyday experience.

model should be confirm with experience

In consequence, the model should be confirm with what we already know, but also useful to predict the influence of driving situations in general.

rural road vs. highway driving

Assume we want to check the difference in searching a certain radio frequency (fixed secondary task) while driving on a rural road (driving situaion 1) vs. driving on the highway (driving situaion 2).

calculate interference for first pair of tasks

We start with computing the **interference between rural road driving and searching a certain radio frequency**:

unscaled demand component 1

Demand component between rural road driving and search radio frequency:

$$\frac{9}{11} + \frac{10}{11} = 1,73$$

scaled demand component 1

Scaled demand component between rural road and search radio frequency:

$$1,89 * 1,73 = 3,23$$

calculate conflict component 1

For the conflict component we first add all relevant conflict values, i.e., those entries from the conflict matrix where both tasks, need the same resources. These entries are marked in the following conflict matrix:

unscaled conflict component 1

When we sum these entries up, we get

			Rural Road Driving										
			Perceptual							Cognitive		Response	
			Vsf	Vsv	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv
		Ex.	1	2	1	1	0	1	0	1	1	1	0
	Vsf	2	**1**	**0,8**	**0,6**	**0,6**	0,4	**0,6**	0,4	**0,75**	**0,47**	**0,4**	0,2
	Vsv	0		1	0,6	0,6	0,4	0,6	0,4	0,75	0,47	0,4	0,2
Set	Vv	2			**0,8**	**0,4**	0,6	**0,4**	0,6	**0,5**	**0,67**	**0,2**	0,4
	As	0				0,8	0,6	0,6	0,4	0,65	0,47	0,4	0,2
up	Av	1					0,8	**0,4**	0,6	**0,45**	**0,67**	**0,2**	0,4
	Ts	2						**0,8**	0,6	**0,65**	**0,47**	**0,4**	0,2
Radio	Tv	1							0,8	**0,45**	**0,67**	**0,2**	0,4
	Cs	0								0,8	0,6	0,6	0,4
	Cv	1									**0,8**	**0,4**	0,6
	Rs	1										**0,8**	0,6
	Rv	0											1

Table 4.10: Conflict matrix for rural road driving and searching a certain radio frequency

$$1 + 0,8 + 0,6 + 0,6 + 0,6 + 0,75 + 0,47 + 0,4 + 0,8 + 0,4 + 0,4 + 0,5 + 0,67 + 0,2 + 0,4 + 0,45 + 0,67 + 0,2 + 0,8 + 0,65 + 0,47 + 0,4 + 0,45 + 0,67 + 0,2 + 0,8 + 0,4 + 0,8 = 15,55$$

Now we have to do the first rescaling to map the conflict component to the intervall $0 - 6$:

intervall rescaling

$$\frac{6}{36,09} * 15,55 = 2,59$$

The second rescaling contains the comparison to the conflict component between the worst driving task and the worst secondary task:

scaled conflict component 1

$$1,42 * 2,59 = 3,68$$

When we add our scaled demand component and our scaled conflict component, we finally get

total interference value 1

$$3,23 + 3,68 = 6,91$$

as our total interference value between rural road driving and set up the radio.

calculate interference for second pair of tasks

To compare it with the other task combination, we need the other total interference value as well.

unscaled demand component 2

Demand between highway driving and search radio frequency:

$$\frac{13}{11} + \frac{10}{11} = 2,09$$

scaled demand component 2

Scaled demand component between highway and search radio frequency:

$$1,89 * 2,09 = 3,95$$

calculate conflict component 2

For the conflict component we have to add the conflict values:

			Highway Driving										
			Perceptual							Cognitive		Response	
			Vsf	Vsv	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv
		Ex.	2	2	1	1	1	1	0	2	1	2	0
Set up Radio	Vsf	2	**1**	**0,8**	**0,6**	**0,6**	**0,4**	**0,6**	0,4	**0,75**	**0,47**	**0,4**	0,2
	Vsv	0		1	0,6	0,6	0,4	0,6	0,4	0,75	0,47	0,4	0,2
	Vv	2			**0,8**	**0,4**	**0,6**	**0,4**	0,6	**0,5**	**0,67**	**0,2**	0,4
	As	0				0,8	0,6	0,6	0,4	0,65	0,47	0,4	0,2
	Av	1					**0,8**	**0,4**	0,6	**0,45**	**0,67**	**0,2**	0,4
	Ts	2						**0,8**	0,6	**0,65**	**0,47**	**0,4**	0,2
	Tv	1							0,8	**0,45**	**0,67**	**0,2**	0,4
	Cs	0								0,8	0,6	0,6	0,4
	Cv	1									**0,8**	**0,4**	0,6
	Rs	1										**0,8**	0,6
	Rv	0											1

Table 4.11: Conflict matrix for highway driving and searching a certain radio frequency

unscaled conflict component 2

Adding the overlapping resources leads to:

$$1+0,8+0,6+0,6+0,4+0,6+0,75+0,47+0,4+0,8+0,4+0,6+0,4+0,5+0,67+0,2+0,8+0,4+0,45+0,67+0,2+0,8+0,65+0,47+0,4+0,45+0,67+0,2+0,8+0,4+0,8 = 17,35$$

Again, we have to to the first rescaling to map the conflict component to the intervall $0 - 6$:

intervall rescaling

$$\frac{2 * 3}{36,09} * 17,35 = 2,88$$

Our relative scaling then computes to:

scaled conflict component 2

$$1,42 * 2,88 = 4,09$$

.

And in the end we get a total interference value of

total interference value 2

$$3,95 + 4,09 = 8,04$$

As we can see, searching a certain radio frequency while driving on a rural road is not a big problem whereas performing the same task while driving on the highway causes a lot more intereference.

searching radio freqency on rural road better than on the highway

This is due to the fact that the overall sum of demanded resources is higher with the more complex driving task as well as the interference between these two tasks.

reason: sum of demanded resources and interference

Compared to the interference between our worst driving task and our worst secondary task (play Tetris), we obtain that in the first case none of the components is in the critical area above 4.0, whereas searching a certain radio frequency while driving on the highway should be avoided.

in terms of a red line: 1st pair ok, 2nd not

4.6.3 Influence of Secondary Tasks

In this part we will calculate the interference between the same driving situation and different secondary tasks.

approach no. 2

The fixed driving situation for this particular scenario will be normal city driving.

fixed driving task: normal city driving

BMW Assist vs. install an app

When we make use of the BMW Assist, this should still work while installing an app in such a traffic situation should cause a lot more problems. With the previous tasks the model predicts the following values:

unscaled demand component 1

Demand component of city driving + BMW Assist:

$$\frac{13}{11} + \frac{10}{11} = 2,09$$

scaled demand component 1

Scaled demand component:

$$1,89 * 2,09 = 3,95$$

unscaled conflict component 1

Sum of conflict values:

$$12,46$$

intervall rescaling

Rescaling:

$$\frac{6}{36,09} * 12,46 = 2,07$$

scaled conflict component 1

Scaled conflict component:

$$1,42 * 2,07 = 2,94$$

total interference value 1

Sum of scaled demand and scaled conflict component:

$$3,95 + 2,94 = 6,89$$

.

calculate second value

Now we have to calculate the second interference value between the pair of tasks city driving and install an app:

unscaled demand component 2

Demand component of city driving + install in app:

$$\frac{13}{11} + \frac{14}{11} = 2,45$$

scaled demand component 2

Scaled demand component:

$$1,89 * 2,45 = 4,63$$

Sum of conflict values:

unscaled conflict component 2

$$20,65$$

Rescaling:

intervall rescaling

$$\frac{6}{36,09} * 20,65 = 3,43$$

Scaled conflict component:

scaled conflict component 2

$$1,42 * 3,43 = 4,87$$

Sum of scaled demand and scaled conflict component:

total interference value 2

$$4,63 + 4,87 = 9,5$$

As we can see, using the BWM Assist in a normal city driving environment does not jar with any of our restrictions because both components (demand and conflict) are below 4.0.

result: BMW Assist ok

In contrast, installing an app in the same situation is a lot more challenging since both components are in the critical area above 4.0 and thus, this secondary task should be avoided while driving through the city.

result: install app not ok

4.6.4 Context-sensitive variances in Secondary Tasks

This subsection may be the most interesting one for designers of in-vehicle devices.

particular interesting for designers

While the driving situations can not be influenced by us, we are able to change the input and output modalities of a new device. At this point the model is useful to predict which particular resources can be used in a concrete situation to avoid conflict between the driving and the secondary task.

use model to avoid conflict with secondary task

Let us assume we are driving through the city. In the previous modeled task we needed 13 resources for that. We

goal: secondary task of average difficulty with minimal conflict now want to model a secondary task with as little conflict as possible, but still be of average difficulty. Since searching a certain radio frequency and installing an app both used 10 resources without exceeding the total resource demand value of 4.0 (see 4.6.3) we will stick to that.

in this task 3 resources are not in use: Av, Tv, Rv

If we have a closer look at the demand vector of city driving, [2,2,1,1,0,1,0,3,1,2,0], we can see that the resources

- Auditory Verbal
- Tactile Verbal
- Responding Verbal

are not used at all.

create new task out of free resources

Consequently, our design should focus on these resources. Since these large quantity of resources is focused on the verbal part, we will also need verbal cognitive resources and maybe some little auditive spatial once.

resulting demand vector could look like this

In this way we derive a demand vector for the device wich could look like this:

Task	Demand Vector											Sum of Demanded Resources
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
New Task A	0	0	0	1	2	0	3	0	2	0	2	10

Table 4.12: Demand vector for secondary task with little conflict

possible interface of secondary task

Such a task could combine a voice-controlled interface with haptic output in forms of symbols.

model predicts little interference in that case

In combination with city driving these tasks have a demand component of $3,94$ and a conflict component of $1,69$ and, thus, cause an interference value of $5,63$.

task B: same number of resources, high interference

In contrast, a new task B with the demand vector [1,1,1,1,1,1,1,1,1,1,0] needs the same number of resources, but its conflict component with city driving is $5,87$ and adds up to a total interference value of $9,81$.

At this point the model confirms the importance of interface design although it is in the driver's willingness to perform a secondary task while driving.

model confirms importance of interface design

At the same time it emphasizes designer's responsiblity for road safety since he can create devices which do not use heavy demanded resources or disable certain functions via workload managers, as described in section 2.3.4.

designer's responsibility for road safety

4.7 Software for Computations with the 4d-Model

The most challenging part in this approach to driver distraction is the modulation of driving and secondary tasks. Afterwards, the following computations can be done by a computer since these steps are clearely defined.

after creation of tasks, next steps can be automated

For this reason I wrote a computer program that calculates the demand and conflict components between task combinations together with their total interference value.

software for interference calculations

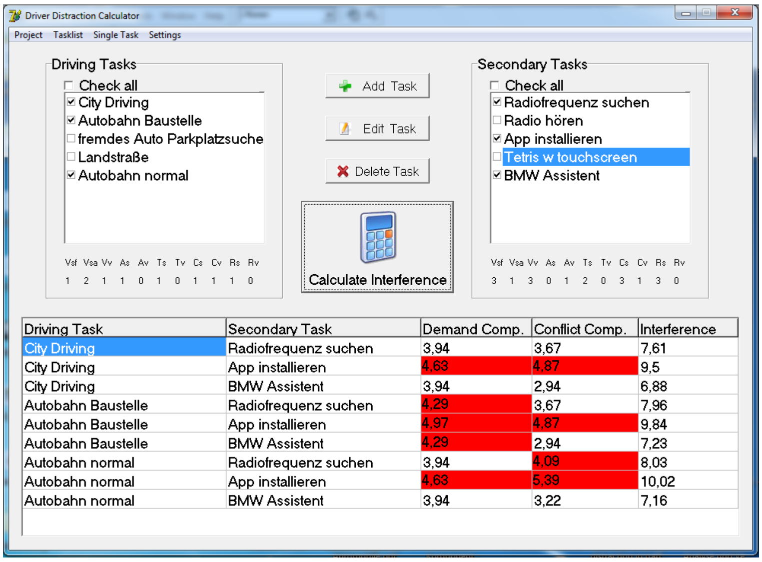

Figure 4.4: Software for computation of interference values

functions of the program: add/change/delete tasks, calculate interference, save/load projects, sort results

The program was written with Borland's Delphi 7 and allows the user to create, edit and delete single tasks for which an interference value should be calculated. Lists of tasks can be saved and loaded into other projects to interchange tasks that were already created between people who use the program. If you want to use a different conflict matrix and/or maximum demand value, these settings can be changed as well and saved as a whole project. Due to the fact that the rescaling from section 4.6.1 is not necessary to use the model, this feature can be enabled or, respectively, disabled by the user. Additionally the calculated values can be sorted by the name of the driving tasks, the name of the secondary tasks, their demand components, their conflict components, or their total interference values.

Chapter 5

Evaluation

5.1 Workshop about Task Modeling

In the following subsections I will explain the benefit of the workshop, its content, where it took place, and the relevant information about its participants.

following: what, how, where, who

5.1.1 Reason for the Workshop

Modeling tasks, driving as well as secondary tasks, is a highly subjective thing. While for the one person a certain situation may be percieved as being easy, the same situation can be judged totally different by another one.

modeling tasks is highly subjective

For this reason I decided to do a workshop about modeling driving and secondary tasks. This workshop should not only explain how tasks can be modeled but also help me to construct a number of tasks in cooperation with other drivers.

during workshop: construct tasks in cooperation

The idea behind this workshop was to use the experience and knowledge of different people with different driving skills to make the modeled tasks less subjective.

resulting tasks should be less subjective

5.1.2 Content of the Workshop

language: german, time: 3 hours

The workshop was held in german, scheduled for three hours, and structurized in the following way.

structure of the workshop

First of all, I gave an overview what I wanted to do within the three hours with this group.

- 25 min. Presentation
- 60 min. Creating driving tasks + break
- 15 min. Design aids driving tasks
- 60 min. Creating secondary tasks + break
- 15 min. Design aids secondary tasks

structure of the presentation

During the presentation, I went through the following points:

1. Motivation: Why am I doing this? Why is this topic interesting?
2. Goal of this workshop: What do I want to achieve?
3. How to model tasks?
4. Creating a driving task in cooperation.

5.1.3 Where did the Workshop took place

conference room P3 Ingenieurgesellschaft March 3rd

The workshop was held at the conference room of P3 Ingenieurgesellschaft mbH, Dennewartstrafle 25-27, D-52068 Aachen at March 3rd 2011 from 13:00 till 16:00.

5.1.4 Participants and Background

4 male participants between 24 and 38

We were four participants, including myself, at the age between 24 and 38. Besides the necessarity of wearing glasses,

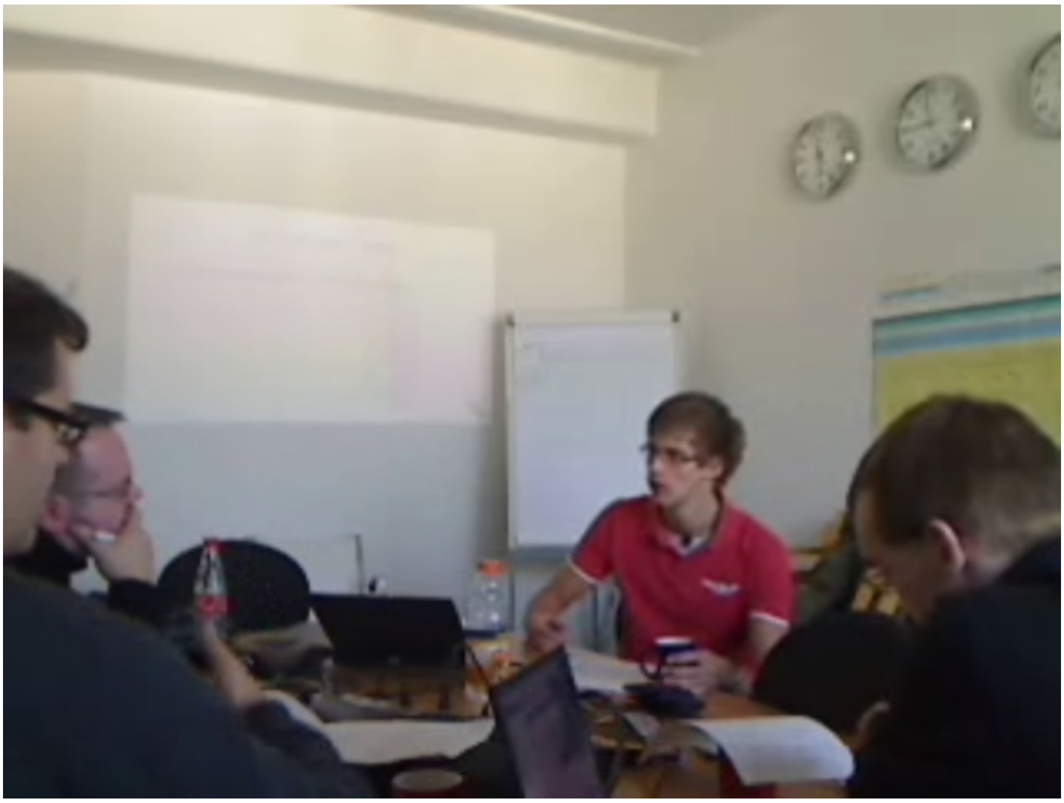

Figure 5.1: Workshop about Task Modeling

nobody had further restrictions to drive a vehicle. All participants were male and classified themselves as being safe drivers although their amount of driving varied between occasional and 30.000 km per annum.

While three of us had made their driving experience almost exclusively in Germany, one of us could look back at four years of driving a lot in differenct coutries, mainly in Western Europe and North America. This person was also used to drive different rental cars while the others always had access to their own car or to a familiar one.

one participant with a lot of international experience

The group covered totally different car sizes, ranging from Smart ForTwo to MB Vito/VW T5. At the time of the workshop, the participants had an aged Opel, an Audi A4, a Peugeot 206 and a Saab 900, all equipped with manual transmission. Some of these cars had a build in navigation system, radio/mp3 player and an air conditioning system.

participants' experience with different cars

Some of the participants also mentioned to use additional brought-in electronic devices from time to time.

driving in countries with speed limits was perceived as more relaxed

It is noteworthy that the person who was used to drive in other countries perceived driving in countries with speed limits on their highways as being more relaxed and easy than in Germany, especially in the Netherlands, Switzerland and United States of America.

5.2 Results of the Workshop

following: resulting tasks, design aids, real-time requirements, and situation awareness

In this section I will analyze the results of the workshop. These include the resulting driving and secondary tasks, the outcomes of our design aids discussion, notes about real-time requirements, and a few words about situation awareness .

5.2.1 Resulting Tasks

5 driving and 5 secondary tasks

During the workshop we created five driving tasks and five secondary tasks in cooperation.

from normal to complex driving tasks

The driving tasks included normal activities like driving through the city, on a rural road, or on the highway and more complex and challenging tasks like driving through a building suite on the highway or searching a parking lot in the city with a foreign car.

wide range of secondary tasks

The secondary tasks were very widespread, too, including searching a certain frequency on the radio, listen to the radio, install an app on your mobile device, use a service like the BMW Assist to find the next hotel, and play Tetris on a touch screen in your vehicle's console.

overview: resulting demand vectors

The resulting demand vectors are listed in the following table.

Task	Demand Vector											Sum of Dem. Res.
	Perceptual							Cognition		Response		
	Vsf	Vsa	Vv	As	Av	Ts	Tv	Cs	Cv	Rs	Rv	
Driving Tasks												
City Driving	2	2	1	1	0	1	0	3	1	2	0	13
Rural Road	1	2	1	1	0	1	0	1	1	1	0	9
Highway Normal	2	2	1	1	1	1	0	2	1	2	0	13
w. Building Site	2	3	1	1	1	2	0	3	1	2	0	16
Parking Lot	3	2	2	1	1	2	1	3	1	2	0	18
Secondary Tasks												
Search Radio Fr	2	0	2	0	1	2	1	0	1	1	0	10
Listen Radio	0	0	0	1	2	0	0	0	2	0	1	6
Install App	2	1	3	0	1	1	0	2	2	2	0	14
BMW Assist	1	0	0	0	2	1	0	1	3	0	2	10
Tetris Touchscr	3	1	3	0	1	2	0	3	1	3	0	17

Table 5.1: The resulting demand vectors from our workshop

5.2.2 Design Aids

While we had no big problems to develope and discuss tasks for different situations, we were not able to produce general design aids.

we could not generate design aids

This could be due to the huge amount of variables influencing each modeled task. For example, the quantity of demanded resources varies, if the driving environment is unfamiliar or well known.

possible reason: huge amount of variables

Furthermore, we discussed that the same varialble, in our case having a passenger, can hamper driving task A and be a benefit for driving task B.

same variable can support one task while disturbing another

5.2.3 Real-time Requirements

In terms of secondary tasks, we especially highlighted the aspect of real-time requirements. Driving tasks always contain this aspect whereas it is of high importance if the secondary task is interruptable and, in this case, how well this can be done.

real-time requirements are crucial for secondary tasks difficulty of secondary task massively influenced by real-time requ.

Even the same secondary task could therefore be harmless, if it can be interrupted and continued easily every time or dangerous, if a long sequence of steps must be completed because otherwise the previous steps were useless.

5.2.4 Situation Awareness

use of resources is linked to task difficulty

Additionally, we worked out that it is hard to compare the different tasks because the more difficult a task is, the less a driver will notice his environment and thus will not make use of resources he would use in a less challenging situation.

corresponds to situation awareness model

This corresponds to the situation awareness model in which the situation awareness of a person depends on the state of the environment. A person's situation awareness then influences his decisions, which in turn affects his performance of actions, which again changes the state of the environment. For further information, see Endsley [1995].

5.3 What is still missing

no valid scientific evaluation

This thesis does not contain a valid evaluation and verification in terms of scientific demands.

this thesis should show a new approach

Instead it should show another approach to the topic of driver distraction and be the basis for further investigations in this topic.

why scientific evaluation is missing

There are several reasons for this:

validtation of the model is very complex

First of all, a validation of the model would be very complex. I did not have the time, funds, instruments, etc. to do this. Hints on how to validate the model are presented in 6.2.

too much for this thesis

Secondly, it would by far go beyond the scope of this thesis and thirdly, this work should not focused on statistical analysis but more on ideas and methods how to address such a complicated scientific question.

idea behind approach is more important

Chapter 6

Summary and future work

6.1 Summary and contributions

We have seen an interesting approach to the very complex problem of driver distraction. This topic is already highly contemporary and will become even more important in the near future. While most other approaches to driver distraction are often too complex, time-consuming or impracticable to be used in industry, Wickens' 4-d model offers fast estimations to judge multitasking scenarios.

quintessence: Wickens' 4-d model offers fast estimations to judge multitasking scenarios

The model is still a reference after all its years of existence. It is based upon neuroscientifically verified knowledge and thus, has high plausibility. Moreover it is relatively easy to derive design guidelines out of the model, which makes it a convenient aid to increase road safety. When conditions of multitasking resource overload already exist, the model can be used to recommend design changes.

models' advantages: still a reference, wellfounded by neuroscience, ...

However, one should be aware that the model has its primary value in predicting relative differences and not absolute predictions of performance (Wickens [2008], Tas [2003]).

primary value: predict relative differences

In terms of driving tasks, we have seen that each task itself

driving itself is already multitasking

is a composite of subtasks and can be very complex to be captured entirely.

designers can influence input and output modalities

While designers are not able to control driving situations, they have influence on the input and output modalities of the HMI. At this point, the model can make its contribution to road safety.

some expertise is required to model tasks

Nevertheless some expertise is required to model tasks. This may be the most difficult issue when using the model. While calculations of interference values can be automated via software, the task modeling itself should be done with reasonable care.

this thesis does not cover all aspects

This thesis does make no claims of being complete. Instead it should lay the groundwork for further investigations. Since there are some points left to evaluate the work of this thesis, a complete assessment can only be done with restrictions. It is noteworthy that the calculations with our modeled tasks had satisfactory results but this fact does not proof universal validity.

real-time requirements are not sufficiently considered

Moreover the workshop discovered the model's insufficient consideration of real-time requirements concerning secondary tasks. The possibility of preemptive multitasking heavily influences if a driver can or cannot engage in a secondary task without reaching the overload-level.

6.2 Future work

there is still a lot work to be done

There is still a lot to do in the area of research in driver distraction.

field study to validate model's predictions

Based upon this thesis there should be a field study to validate the model and its predictions. To achieve this the following steps are necessary:

modelling of driving tasks to a great extent

1. Create a fairly large quantity of modeled driving tasks. There should be as many participants as possible to rule out subjective appraisals. With the help of

statistically methods fairly representative results can be achieved.

2. The modeled driving tasks have to be performed in reality and their resource demands have to be measured. At this point it is again important to rule out as many undesired influences as possible. E.g. neither the investigator nor the test person should know the modeling results of the driving tasks and the investigator should ensure that he/she really measures the resource demands, etc.

perform the modeled driving tasks in reality

3. The same factors as in 1. and 2. have to be considered for secondary tasks. Not only a normalization of the results is important, but also the way of introducing the necessary information before participants can model a task. If this is done via a presentation or via a questionnaire, the result might rather concern the quality of the presentation/questionnaire and not, as intended, illustrate a high quality modulation.

do 1. and 2. for secondary tasks as well

4. Then, the model can be used to derive interference values between task combinations.

calculate interferences

5. Again, further experiments need to be done, because the previous ones only concerned driving tasks or secondary tasks alone, but not combined in a multitasking scenario.

perform experiences with task combinations

6. In the end, the results of the modeled tasks and the outcome of the experiments should be compared. Again statistical methods can help to proof if there exists real correlation between the values or just spurious correlation.

compare real values with calculated ones

Even in terms of the 4-d model there are still some questions left to answer.

challenging issues

First of all: How can real-time requirements be integrated in this concept? On the one hand it seems to be inevitable to include this particular form of requirements since we want to create a model that can make realistic predictions. On the other hand if the integration of real-time requirements leads to an explosion of complexity, the model will lose its practicability and versatility.

integration of real-time requirements

what drives the allocation policy

Secondly researchers have to understand what drives the allocation policy. While this allocation can be controlled relatively well in the laboratory, the real world is much more complex. Phenomena such as unwanted diversion of attention to interruptions, cognitive tunneling, and auditory preemption often operate in ways that are clearly at odds with optimal allocation (Wickens [2008]).

balance between model parsimony and performance variance

Thirdly: What is the best balance between cost and benefit? Especially in the case of analyzing driver distraction, visual scanning plays a particular role, but future research must seek the balance between model parsimony and performance variance (Wickens [2002]).

close this thesis by quoting Wickens

To close this thesis, I would like to cite Wickens again:

> *"These relative interference predictions may be useful for assessing the impact of various In-Vehicle Technologies in future automobiles and, in turn, may help validate the theoretical notions of multiple resources"*
>
> *—Tas [2003]*

Appendix A

Workload Scales

Scale Val.	Descriptors	Resource	New Val.
Response			
1.0	Speech	Response-Verbal	0
2.2	Discrete Actuation (Button, Toggle, Trigger)	Response-Spatial	1
2.6	Continuous Adjustive	Response-Spatial	1
4.6	Manipulative	Response-Spatial	2
5.8	Discrete Adjustive	Response-Spatial	2
6.5	Symbolic Production (Writing)	Response-Spatial Response-Verbal	3
7.0	Serial Discrete Manipulation (Keyboard Entries)	Response-Spatial Response-Verbal	3
Tactile			
1.0	Detect Discrete Activation of Switch (Toggle, Trigger, Button)	Tactile-Spatial Tactile-Verbal	0
4.0	Detect Preset Position or Status of Object	Tactile-Spatial	2
4.8	Detect Discrete Adjustment of Switch (Discrete Rotary or Discrete Lever Pos.)	Tactile-Spatial	2
5.5	Detect Serial Movements (Keyboard Entries)	Tactile-Spatial Tactile-Verbal	2
6.1	Detect Kinesthetic Cues Conflicting with Visual Cues	Tactile-Spatial Tactile-Verbal	3
6.7	Detect Continuous Adjustment of Switches (Rotary Rheostat, Thumbwheel)	Tactile-Spatial	3
7.0	Detect Continuous Adjustment of Controls	Tactile-Spatial Tactile-Verbal	3

Table A.1: Workload Component Scales from Aldrich et al. part 1

Scale Val.	Descriptors	Resource	New Val.
Visual			
1.0	Visually Register/Detect (Detect Occurrence of Image)	Visual-Verbal	0
3.7	Visually Discriminate (Detect Visual Differences)	Visual-Spatial-Ambient	1
4.0	Visually Inspect/Check (Discrete Inspection/Static Condition)	Visual-Spatial-Focal	2
5.0	Visually Locate/Align (Selective Orientation)	Visual-Spatial-Focal	2
5.4	Visually Track/Follow (Maintain Orientation)	Visual-Spatial-Focal Visual-Spatial-Ambient	2
5.9	Visually Read (Symbol)	Visual-Verbal	3
7.0	Visually Scan/Search/Monitor (Continuous/Seriel Inspection, Multiple Conditions)	Visual-Spatial-Focal Visual-Verbal	3
Cognitive			
1.0	Automatic (Simple Association)	Cognitive-Spacial Cognitive-Verbal	0
1.2	Alternative Selection	Cognitive-Spacial Cognitive-Verbal	0
3.7	Sign/Signal Recognition	Cognitive-Verbal	1
4.6	Evaluation/Judgment (Consider Single Aspect)	Cognitive-Spacial Cognitive-Verbal	2
5.3	Encoding/Decoding, Recall	Cognitive-Spatial Cognitive-Verbal	2
6.8	Evaluation/Judgment (Consider Several Aspects)	Cognitive-Spatial Cognitive-Verbal	3
7.0	Estimation, Calculation, Conversion	Cognitive-Spacial Cognitive-Verbal	3
Auditory			
1.0	Detect/Register Sound (Detect Occurence of Sound)	Auditory-Spatial	0
2.0	Orient to Sound (General Orientation/Attention)	Auditory-Spatial	1
4.2	Orient to Sound (Selective Orientation/Attention)	Auditory-Spatial	2
4.3	Verify Auditory Feedback (Detect Occurrence of Anticipated Sound)	Auditory-Verbal	2
4.9	Interpret Semantic Content (Speech)	Auditory-Verbal	2
6.6	Discriminate Sound Characteristics (Detect Auditory Differences)	Auditory-Spatial Auditory-Verbal	3
7.0	Interpret Sound Patterns (Pulse Rates, etc.)	Auditory-Verbal	3

Table A.2: Workload Component Scales from Aldrich et al. part 2

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