Using human-compatible reference values in design of cooperative dynamic human-machine systems

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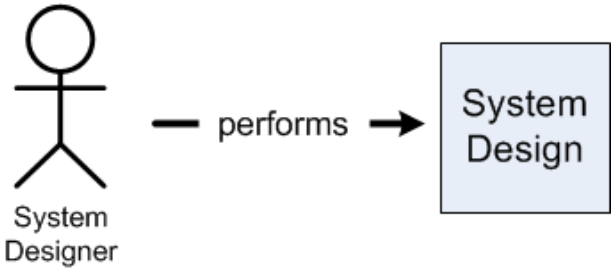
What is a cooperative dynamic system?

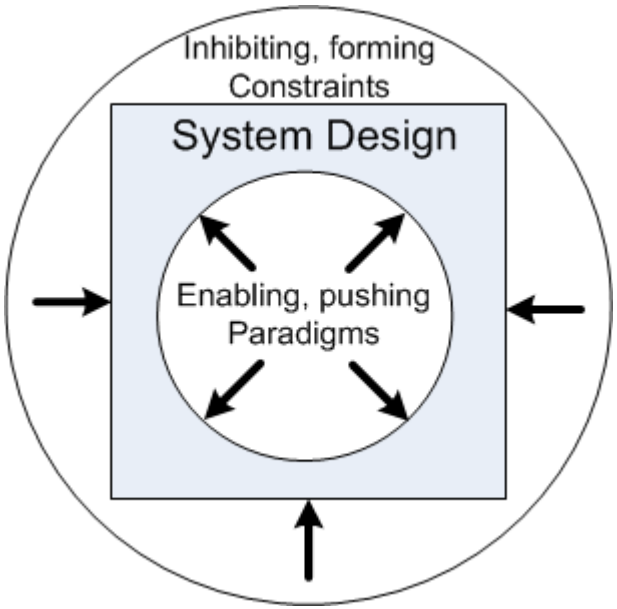
- **Cockpits and assistance** in modern vehicles (aircraft, cars, vessels, trains etc.)
- **Traffic** and traffic **management**
- Industrial and office systems
- Robot and swarm control etc.

- **Common ground:**
  - 0..n **human agents**
  - 0..n **machine agents**
  - At least two cognitive agents
  - Interaction (**cooperation**) between agents

Picture sources: boeing, volvo, ros.org

How does system design work?

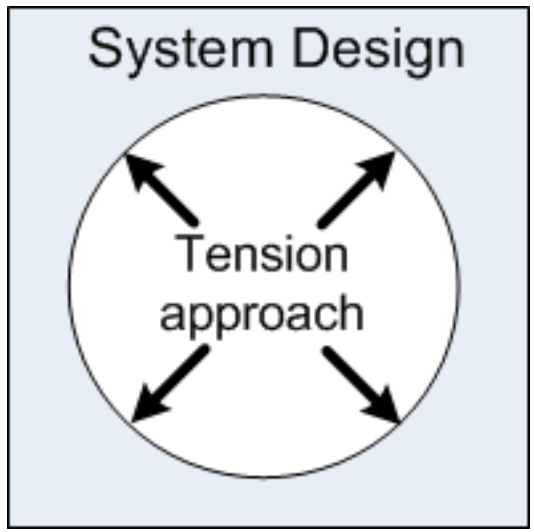




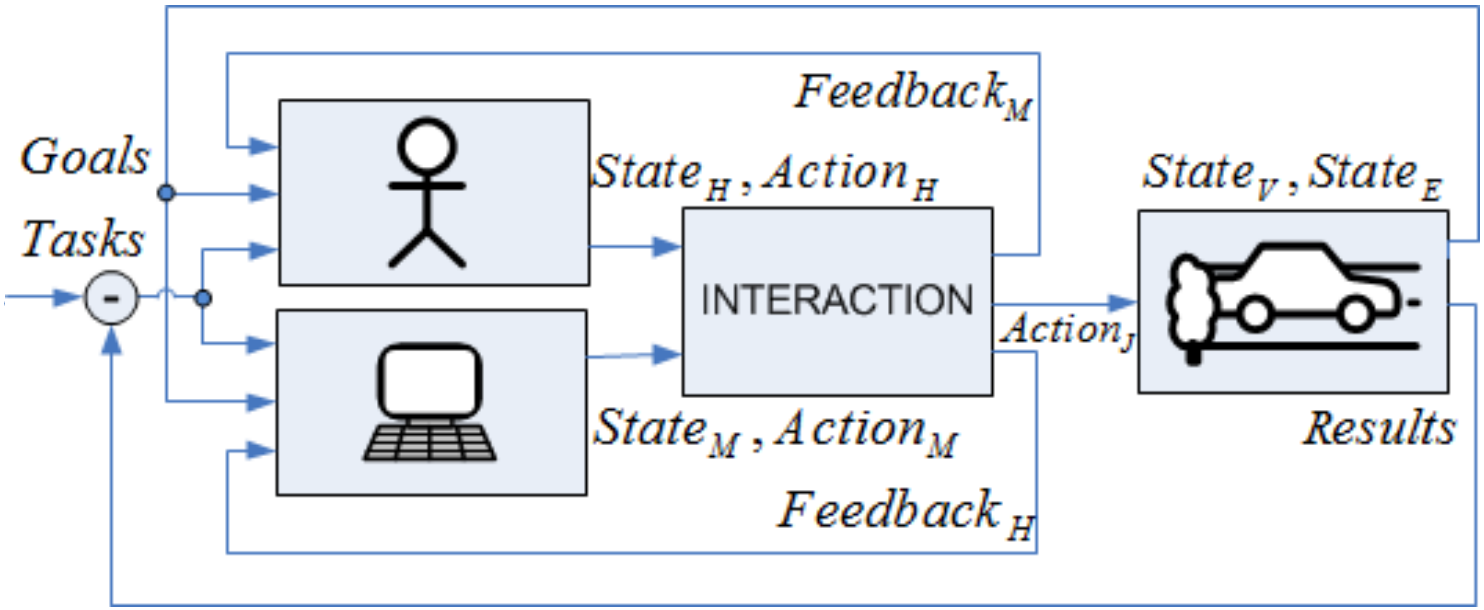
- There are always **forming and inhibiting constraints** in system design
  - Existing designs
  - Tight design processes
  - Resource constraints
  - **How to not design?**
- System design needs also **enabling and pushing paradigms**
  - Design approaches
    - e.g. user centered design
  - Metaphors
    - e.g. desktop-metaphor
  - **How to design?**

Overview

- Theoretical **background** to the enabling and pushing ‚**tension approach**‘
- Using the tension approach in **automotive domain**
  - **Operationalization of tensions** in a top-down deductive process
  - **Evaluation of tensions** in a bottom-up inductive process
- Summary and **Outlook**

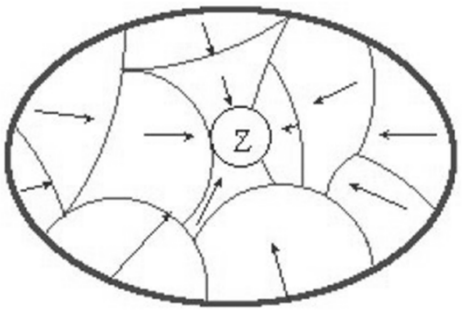


Technical perspective: common human-machine configuration in automotive

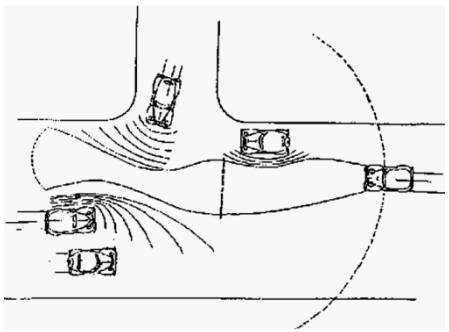


- At least **five closed control loops**
- No explicit controller and synchronization unit yet
  - **Suboptimal system stability and usability**

Psychological and Human Factors perspective: Lewin‘s ‚Forces‘ and Gibson‘s ‚Affordances‘



- **Lewin** describes motivational processes in the way where the human, being in a particular state, is experiencing ‚**psychological forces**‘ toward another state
- For example, being in the state ‘hungry’, we perform actions in order to get some food and to reach the state ‘full’
- Lewin names the ‘inner’ psychological forces ***tensions***



- **Gibson** introduces **affordances** as an **object quality** opening ‘**action opportunities**’ interfering with the current human state
- For example, if we are tired and see a chair, the object chair is affording, ‘pulling’ us to sit down

- Both useful **psychological** concepts operate with **terms being near to physical and technical** terms like force and ***tension***
- Opportunity to **model the behavior of humans and machines** both on a **higher level and on a common ground**

Picture sources: Lewin, Gibson

Tension as reference value in a system design

- **Thesis:** A cognitive system being in a particular state is controlled by multiple tensions directed toward actions leading to other system states
- **Hypothesis:** Humans are aimed to follow tensions toward actions leading to optimal states and machines can be designed to do so as well
- **Definition for automotive domain:**

$$\vec{Tension}_{ACTION} = f(State_H, State_M, State_V, State_E, \vec{Tension}_{OPTIMAL})$$

- **$Tension_{ACTION}$** is a **directed** motivational value **toward a particular action**

- **$State_{H,M,V,E}$** are **composed values**
  - **$State_H$** : human factors, current and preferred human actions and states
  - **$State_M$** : current and preferred and alternative machine actions and states
  - **$State_V$** : current and future vehicle states and vehicle dynamics
  - **$State_E$** : environmental data like dangerousness of situation, traffic rules etc.

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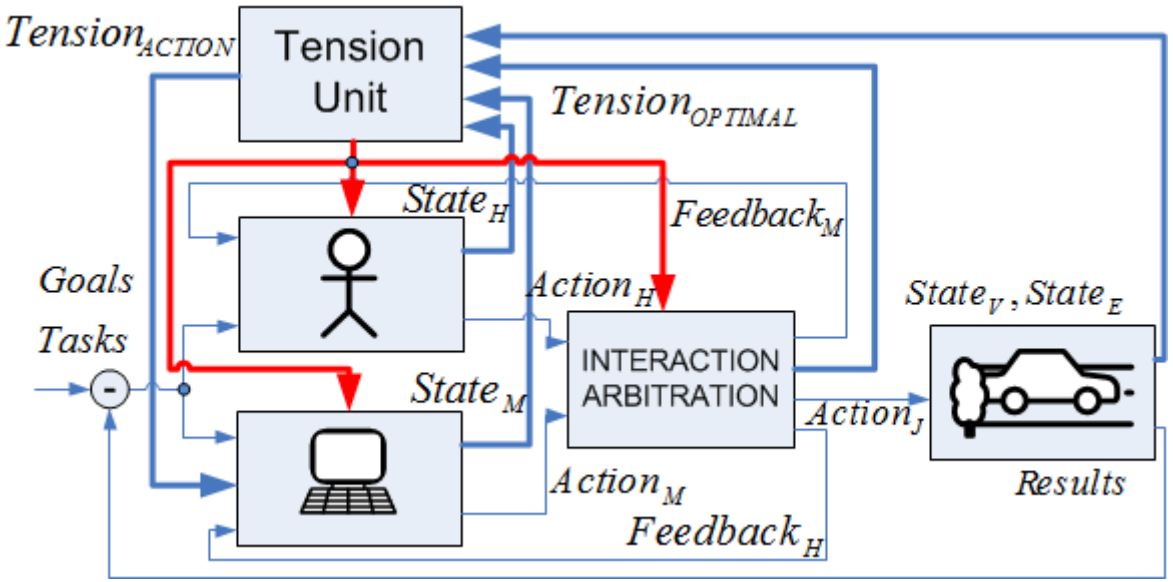
- **Tension$_{ACTION}$** can be **separated** in **categories** in order to control and synchronize correspondent behavior within the designed system
  - e.g. longitudinal, lateral or automation level transition behavior
- **Tension$_{OPTIMAL}$** is **directed** toward the **optimal action** and can be regarded as a **reference tension** within the system
  - It is a **reference** for the human **as well** as for the machine behavior
- **Tension$_{OPTIMAL}$** can be determined by a former design decision, e.g. using **Yerkes-Dodson law**, or **arbitrated** dynamically

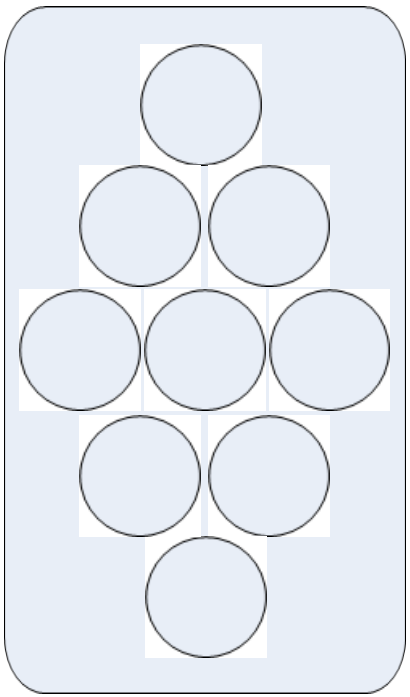
Technical perspective: enhancement of the common human-machine configuration by a ‚tension unit‘

$$\vec{Tension}_{ACTION} = f(State_H, State_M, State_V, State_E, \vec{Tension}_{OPTIMAL})$$



- Additional ‚tension unit‘ responsible for **control** and **synchronization** of the behavior of system parts in the integrative manner
  - More **human-compatible** reference values for system control
- This can be realized technically by a **model predictive controller**

Connection of ‚tension approach' to related concepts

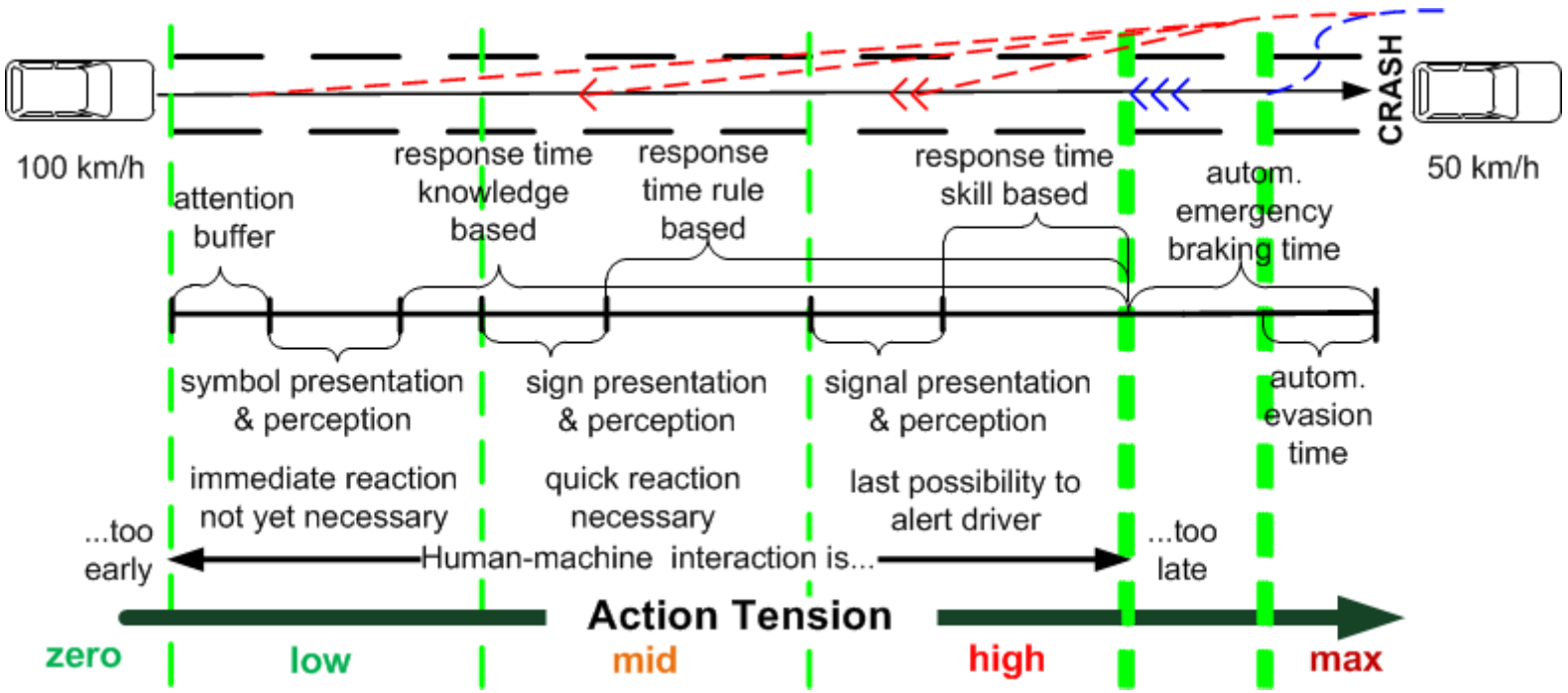


- **Onken: 'danger model'** that contains a non-directional value named **'time reserve'** describing a time slot for a possible **action to avoid danger**
- **Rhede: 'warning toolbox'** as **situation criticality** based **warning and escalation** approach in interaction design
- These and other related concepts (e.g. risk) are highly compatible to the tension approach, although they seem to provide rather ***descriptive scalar*** metrics
- We propose ***prospective directed*** and more **solution oriented** metrics to emphasize e.g. the direction toward **certain possible actions** to reach the same system state
- Tension approach can be seen as an **integrative framework** for design **different** kinds of cognitive systems instead of description of singular design methods and reference values in particular domains

Top-Down action tension operationalization in approach brake and/or evade driving scenario

$$\vec{Tension}_{ACTION} = f(State_H, State_M, State_V, State_E, \vec{Tension}_{OPTIMAL})$$

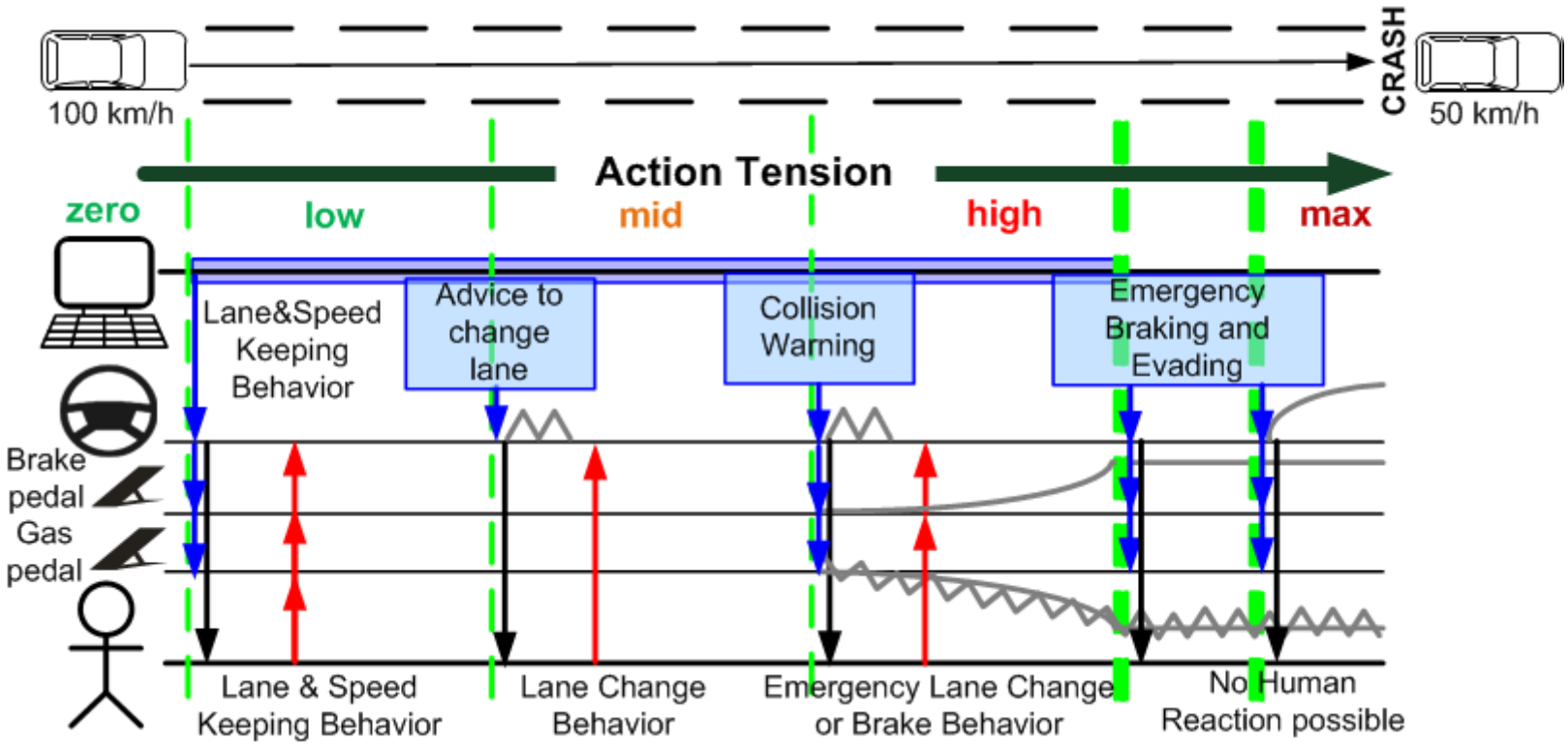
- Using **T**ime **T**o **C**ollision for description of $State_V$, $State_E$ and $Tension_{OPTIMAL}$
- Synchronization borders, $State_H$ and $State_M$ derived from literature



Bottom-up action tension evaluation

- **Usability Study: Question**: whether the top-down identified tension areas also resemble subjectively need for action by an assistance system
- **6 naïve subjects** were confronted with situations being prototypical for different action tension areas and rated on a **semantic differential**
- **Observation:** Tension areas matched to the perception of the subjects

Example of interaction design using the ‚tension approach'



incomprehensible	How comprehensible was this interaction design?							comprehensible
	-3	-2	-1	0	+1	+2	+3	
	0	0	0	0	0	3	3	

Summary and Outlook

- Tension approach is an enabling and pushing **meta-level design concept** and based on the well-known **scientific concepts**
- It enables an **ontological and holistic** kind of system understanding and offers a useful **framework for design** of cognitive systems
- It allow a **domain independent dialog** between the professionals from different domains

- The important **constraint** of the approach is the finding of an appropriate **manner to operationalize the tensions**

- The tension approach can help in **deriving** user-compatible **software and hardware frameworks** that would use tensions as reference values within the designed system
- It is planned to research a **formal analytical** kind of cognitive system **design and analysis** using human-machine arbitration concept toward the human-machine interference concept

References

Endsley, M. R. (2001): *Designing for Situation Awareness: An Approach to User-Centered Design.* ISBN 978-1420063554

Fastenmeier, W., Hinderer, J., Lehnig, U., Gstalter, H. (2001): *Analyse von Spurwechselvorgängen im Verkehr.* Zeitschrift für Arbeitswissenschaft 55, Nr. 1

Gibson J. J. (1977): *The Theory of Affordances. In Perceiving, Acting, and Knowing*, Eds. Robert Shaw and John Bransford, ISBN 0-470-99014-7

Green, M. (2000): *How Long Does It Take to Stop? Methodological Analysis of Driver Perception-Brake Times.* Transportation Human Factors, Vol.2:3, pp.195-216

Hayward, J.Ch. (1972): *Near miss determination through use of a scale of danger.* Report no. TTSC 7115, Pennsylvania State University, Pennsylvania

Heesen, M., Beller, J., Flemisch, F. (2011): *Making automation surprises less surprising.* Fortschritt-Berichte VDI, Reihe 22, No. 33

Kelsch, J. (2012): *Arbitration between Driver and Automation: why Overriding is just the Tip of the Iceberg.* InteractIVe Summer School, 04.-06. Jul. 2012, Corfu Island

Lewin, K. (1938): *The Conceptual Representation and the Measurement of Psychological Forces.* Psychological Theory, 4, Duke University Press, Durham, N.C.

Löper, C., Kelsch, J., Flemisch, F. (2008): *Kooperative, manöverbasierte Automation und Arbitrierung als Bausteine für hochautomatisiertes Fahren*. In: AAET 2008 - Automatisierungssysteme, Assistenzsysteme und eingebettete Systeme für Transportmittel Gesamtzentrum für Verkehr Braunschweig e.V. Seiten 215-237. ISBN 9783937655147.

Onken, R. (1994): *DAISY, an Adaptive, Knowledge-based Driver Monitoring and Warning System.* Proceedings of Intelligent Vehicles '94 Symposium, pp. 544-549

Rasmussen, J. (1986): *Information processing and human-machine interaction: An approach to cognitive engineering.* New York, North-Holland. pp. 101-115

Rhede, J., Wäller, C., Oel, P. (2011): *Der FAS Warnbaukasten.* Conference contribution for Der Fahrer im 21. Jahrhundert'. 08.-09. Nov. 2011, Braunschweig

Yerkes, R.M. & Dodson, J.D. (1908): *The relation of strength of stimulus to rapidity of habit-formation.* Journal of Comparative Neurology and Psychology, 18, pp. 459-482

Thank You

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Let's tense!