SPT-E4030
Introduction to Traffic Management

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Learning Objectives …

• Understanding of the objectives and methods of traffic management
• Knowing the basic principles of traffic management
• Being able to choose the appropriate measures for traffic management
• Knowing the factors that have effect on the choice
• Being able to plan the signal control and the use of traffic signs
• Knowing the possibilities offered by the new technology
• Being able to choose appropriate technologies for a given challenge

• We cover the traditional measures first, while paving the way to towards intelligent transport and smart mobility
• Please note: Although some planning aspects are considered, but this is not primarily a planning course. Here we aim to focus more on the dynamical aspect of traffic and transportation.
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Activity</th>
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<tbody>
<tr>
<td>15.04.2019</td>
<td>12-15</td>
<td>Introduction to traffic control</td>
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<td>16.04.2019</td>
<td>9-12</td>
<td>Traffic safety management</td>
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<td>17.04.2019</td>
<td>12-14</td>
<td>Overview of intelligent transport</td>
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<td>22.04.2019</td>
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<td>23.04.2019</td>
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<td>Launch of group project on intelligent transport systems</td>
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<td>24.04.2019</td>
<td>12-14</td>
<td>Sensors, data and information</td>
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<td>29.04.2019</td>
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<td>Traffic signal control</td>
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<td>30.04.2019</td>
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<td>Simulation exercise 1: making of intersection models</td>
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<td>(PC class 301d in K-building, Otakaari 4)</td>
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<td>01.05.2019</td>
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<td>1st of May, Wappu</td>
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<td>06.05.2019</td>
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<td>Traffic Management on major arterials</td>
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<td>07.05.2019</td>
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<td>Guidance to group project on intelligent transport systems</td>
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<td>08.05.2019</td>
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<td>Mobility Management</td>
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<td>13.05.2019</td>
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<td>Vehicle Automation</td>
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<td>14.05.2019</td>
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<td>Simulation exercise 2: Executing the simulations</td>
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<td>15.05.2019</td>
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<td>Rail traffic management, visiting lecturer Antero Alku</td>
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<td>20.05.2019</td>
<td>12-15</td>
<td>Intelligent logistics, visiting lecturer Karri Rantasila</td>
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<td>21.05.2019</td>
<td>9-12</td>
<td>Presentation of group project on intelligent transport systems</td>
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<tr>
<td>22.05.2019</td>
<td>14-16</td>
<td>Site visit to Road traffic management centre, Pasila, Helsinki</td>
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<td>27.05.2019</td>
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<td>Presentation of the results of the simulation exercise M240</td>
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<td>28.05.2019</td>
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<td>Course exam M240</td>
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Traffic Process
What kind of System is Traffic?

• Complex Adaptive System (CAS)
  – Living and evolving
  – Self-organizing

• Social system
  – Social norms and pressures apply
  – Legal system: rules and sanctions

• Technological system
  – Traffic networks and vehicles
  – Digitalization and automation
Traffic - a Complex Multi-agent System

• Far from equilibrium system
  • Constant work (energy & intelligence) has to be applied to maintain it
  • Small changes may shift the balance dramatically (e.g. Boeing 737 Max8)

• State space
  • The number of states the system be in is vast, beyond imagination
  • Innumerable, cannot make a list of all possible situations
    • Hard to manage with algorithmic processes such as traffic rules, control systems and automation

• Multi-agent system
  • Not internally consistent system (like engine for instance)
  • Conflicts of interests exists, accidents happen

• Adaptive
  • Traffic flows and traveling/driving behaviour are changing according to the conditions

• Resilient
  • Despite of traffic jams and accidents, the traffic system tends to recover
Traffic - a Challenging Process to Manage

• **Size**
  – Large geographic system

• **Not one system**
  – A network of systems

• **Complexity**
  – Travelers, vehicles, services, companies, authorities

• **Data**
  – Not always available

• **Modeling**
  – Not easy make model of the process

• **Optimum**
  – Not clearly defined

• **Actuation**
  – Various measures
  – Not all them are effective
Principles of control
How to Increase Order in Traffic?

We got to do some work
For example:

1. Build a road
   - Now you should follow the road
2. Introduce some rules
   - E.g. keep on the right-side (breaking the symmetry)
3. Put some signs
   - E.g. Maximum speed 50 km/h
4. Introduce control systems
   - E.g. Install traffic signals

• But what is work anyway?
  – Work is constrained release of energy
  – E.g. moving along the road, limiting the speed etc. are constrains as opposite to completely random movements
  – Therefore, when you travel using a road, you are doing work
  – In steps 1-4 we introduced new constrains
  – Introducing new constrains is also work
  – Work allows new work to done and so on
  – This is a form of self-organization called propagating organization of processes
What is Traffic Management?

• Management vs. Control
  – Control is a method to achieve a certain given objective
  – Management can be collection of methods to organize the process as a whole

• Management vs. Planning
  – Management is related to real-time or to a short time horizon
  – Planning is oriented into more distant the future

• Management vs. Leadership
  – Management can be quite practical approach to arrange things
  – Leadership is more holistic and goal driven approach focusing on the given objectives rather than the methodology
Control Loop in General

- **Control variable(s)**
  - Variable(s) to affect the process
- **State variable(s)**
  - Variable(s) describing the state of the process to be controlled
- **Target state**
  - State of the process to be achieved and maintained

![Control Loop Diagram]

1. Control variable(s) -> Process
2. Process -> State variable(s)
3. Controller -> Process
4. Process -> Comparison
5. Comparison -> Target State
6. Target State -> Comparison
Example of Simple Control Loop in Traffic

- Fixed time
- Traffic Actuated
- Adaptive
- Learning
- Artificial Intelligence
Open-loop control in Traffic

- Static or variable control
- Control signals
- Traffic (process)
- Traffic demand
- State of traffic
Closed-loop control in Traffic

- Control strategy
- State estimation
- Traffic (process)
- Analysis

Traffic demand → Control signals → Traffic (process) → Measurements → Detector Logic → Indicators → State estimate → Control strategy

State of the traffic → Traffic demand
Adaptive control of Traffic

- Learning the slow changes
- Providing new parameters to the control process
- New target state for the control layer
Elements of Traffic Management
Walking as a control process

- Our body is our primary vehicle
- Walking or running feels very easy, but it is very complex control process
- Maintaining balance on two feet
- Putting weight on each foot in cyclic manner, shifting the center of mass
- Eyes: looking ahead to avoid obstacles
- Ears: hearing of potential hazards beyond visible area

![Diagram of walking as a control process](image)
Walking Traffic

• What if traffic consists of walking only?
  – Slow speeds
  – Low kinetic energy
  – Low risk of collision
  – Low risk of injury, except …

• Need for traffic control systems is low

• The traffic "management" is based on self-organizing

• Traffic is a social process affected by
  – Autonomic skills (e.g. to avoid collisions in crowd)
  – Social pressure (e.g. to obey courtesy in interactions)
Walking in a Corridor

- Simulation of pedestrians in a corridor
- Based on social force model by Helbing
- Self-organization of lanes is emerging

Simulation by Jaeyoung Kwak
Adding the vehicles

• **Bicycles**
  – Some simple rules necessary, if together with pedestrians only
  – Together with motorized vehicles the rules become more complex

• **Motorized vehicles**
  – Vehicle to vehicle interactions
  – Yielding rules necessary between vehicles
  – Complex situations with pedestrians and bikers
  – More complex rules required to protect the vulnerable party

• **Safety measures**
  – Geometry
    • Separated channels: roadway, pavement, cycling paths
    • Pedestrian crossings, traffic islands?
    • Speed reduction by: bending or narrowing the lanes, humps for cars
  – Conflict management:
    • Yielding rules, yielding signs
    • Traffic signals
Self-organization and External Control

- Individual intentions
- Social pressures, Negotiations
- Traffic rules
- Road markings, Traffic signs
- Control systems
- Law enforcement
- Traffic environment

Human behavior
Self-organizing process
Priority Order of Traffic Control

1. Traffic policeman
2. Traffic signals
3. Traffic signs
4. Traffic rules
5. First-In-First-Out (FIFO)
Layers of Traffic Management

- **Vehicles**
  - Speed
  - Turning
  - Lane change

- **Mobility**
  - Traffic information
  - Route and mode guidance
  - Road pricing

- **Transport services**
  - Routes & timetables
  - Demand responsive public transport
  - Other: Taxi, Uber, etc.

- **Traffic flows**
  - Speed limits
  - Yield signs
  - Traffic signals

- **People**
  - Use of legs
    - Walking, biking, gas pedal
  - Use of arms
    - Steering

- **Control**
  - Routes & timetables
  - Demand responsive public transport
  - Other: Taxi, Uber, etc.
The Effectiveness of Control

Walking/biking | Car driving | Use of transport services

Mandatory control

Self-control

Suggestive “control”
Objectives of Traffic Control

1. Minimizing the probability of accidents
   - Indirect methods required

2. Improving the traffic fluency
   - Within the safety limits

3. Other goals
   - Environmental impact
   - Economic objectives
   - Energy efficiency
Complexity of Optimizing

- **Environmental optimum**
  - Various aspects

- **System optimum**
  - Multiple aspects

- **Operator optimum**
  - Competing actors

- **User optimum**
  - Variety of user preferences
From Traffic Control Towards Intelligent Transport
Human Psychology and Physiology in Traffic Control
Sensory System

- Vision
  - Environment
  - Traffic
  - Control signals
- Hearing
  - Approaching vehicles
  - Warning signals
- Balance
  - State of motion
    - Deceleration, acceleration, curve
  - Vibration, hump,
  - Friction of the ground
What We Need to Observe?

- The road
  - Staying on the road, lane or pavement
  - Possible obstacles
- Other road users
  - Pedestrians, cyclists, vehicles
  - Speed, direction and distance of the others
  - Intentions?
- Control
  - Road markings
  - Traffic signs
  - Traffic signals
## Frequency of Observations

<table>
<thead>
<tr>
<th>Event</th>
<th>Amount</th>
<th>Time</th>
<th>Amount</th>
<th>Distance</th>
</tr>
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<tbody>
<tr>
<td>Traffic events</td>
<td>5</td>
<td>1 s</td>
<td>300</td>
<td>1 km</td>
</tr>
<tr>
<td>Driver observations</td>
<td>2</td>
<td>1 s</td>
<td>120</td>
<td>1 km</td>
</tr>
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Average speed 60 km/h, dense traffic
The Precision of Vision

- The area of accurate vision is narrow
- Rapid eye movements take place subconsciously
- Brains are “modeling” the environment thus extending the feeling of vision
The peripheral vision is to perceive the space and observe movements.

The field of vision narrows down as the speed increases.
Visual Acuity

- **Visual acuity**
  - Larger target is easier to detect
  - Measuring with Snellen’s E-tables

- **Contrast**
  - Strong contrast improves visibility
    - Reflecting or illuminating signs
  - Color contrast
    - Black on white not optimal
    - Black on orange or White on green is better

- **Glare**
  - From bright sources like sun or car head lights
  - Mirroring from reflective surfaces
  - Can blind temporarily or reduce the visibility

- **Change**
  - Moving target is seen better than a static one
## Levels of Visual Acuity

*Visus*=1,0 is the resolution, when a person sees two points separately when they are in one arc minute angle.

<table>
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<tr>
<th>Value</th>
<th>Description</th>
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<tbody>
<tr>
<td>0,3</td>
<td>Low acuity</td>
</tr>
<tr>
<td>0,5</td>
<td>Passenger car limit</td>
</tr>
<tr>
<td>0,8</td>
<td>Truck limit</td>
</tr>
<tr>
<td>1,0</td>
<td>Normal</td>
</tr>
<tr>
<td>1,5</td>
<td>Very good</td>
</tr>
<tr>
<td>2,0</td>
<td>&quot;Hawkeyes&quot;</td>
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</table>
Visual Impairment

- A certain minimum level of vision is sufficient
- Senses adapt
  - Brains can fulfill missing information up to a certain extent
  - Continuous event is experienced as static
  - Exceptions get more attention

The probability of accident depending on vision
(The solid line)
Requirement for visual acuity

- Passenger car
  - 0.5
- Truck driver
  - Better eye 0.8
  - Worse eye 0.5
- Most people reach 1.25
Time for reaction

- The control should allow enough time for action
- About 5 seconds from the sign to action
- Important especially in route signing
Reducing the lighting level results to a less illumination from the luminaire thus, car headlights are more effective to make contrast.

Outdoor Lighting illuminate the road vertically and car head lights illuminate the road horizontally.

Contribution of car headlight with lowest level of luminaire lighting results in better visibility.
Reducing lighting level of luminaires results in reduction of visibility. In presence of glare, an extra light comes to drivers eye. Thus, the effectiveness of car headlight reduces.

In general, in presence of glare the highest level of light is needed.

Reducing lighting level of luminaires results in reduction of visibility.
Processing of Information
Factors in Information Processing

• Observations
  • Did we notice everything
• Knowledge
  • Do we recognize the situation
• Interpretation
  • Do we understand the situation correctly
• Memory
  • e.g. What was the speed limit ?
• Concentration
  • Are we focusing or having secondary tasks
• Skills
  • e.g. Prediction capability
• Attitudes
  • Risk taking tendency
• State of mind
  • e.g. In a hurry
Limited Processing Capacity

- Too much essential information arrives at the same time, then part of the information can be lost.

- Not essential, but strong stimulus
  - For example loud noise
  - May block the observation channel so that important information is lost.

- Similar information arriving through multiple channels, amplifies each other, making sure the information is received
  - For example visual and audio signal having the same meaning
Receiving of Information

- Symbols
  - Faster recognition than text
  - Not dependent on language
  - Understood?

- Text
  - Language dependent
  - Reading time n. 0.5–2 sec / word
  - Familiar font speeds up reading
  - Positive contrast (black on white) is better than negative
Recognition of Patterns

- **Closure**
  - Closed line is interpreted as a pattern

- **Familiarity**
  - Familiar and meaningful areas are seen as shapes

- **Joint elements**
  - Elements attached together are seen as one target
Similar types of stimulus are (e.g. turning sign) interpreted as belonging to the same group.
Extrapolating

A. The road geometry does not hint about the dell
B. The road seem to curve to the right, but suddenly curves to the left
C. Misleading information about the continuity of the road
Misleading Stimulus

A police car in front of the traffic sign:
The strong stimulus blocks from observing the traffic sign.
### Remembering the Observations

- Depends on the experienced importance of the sign
  - Other danger 28%
  - Other danger + surveillance 62%
  - Speed limit 70 km/h 78%
  - Speed limit 50 km/h 80%

- “Other danger” is considered less important and therefore or not remembered

- Speed limit sign is considered as important for the driver
Requirements for the Information

• **Observable**
  – Optimal visibility / contrast
  – Color contrast, blinking

• **Consistent**
  – Color and shape
  – Route signing up to the destination

• **Uniform**
  – Same principles in using the signs
  – Same principles in positioning the signs

• **Correct**
  – Route signing to the right direction
  – Warnings only when they are necessary

• **Not too many signs**
Decisions and Actions
Conscious and Subconscious Actions

• Conscious
  • Requires focusing
  • Is slow
  • Allows learning
• Subconscious
  • Fast
  • Automatic
  • Previously learned or natural
Limited Attention Resources
Driving task

- **Perception**
  - Assessment Errors
  - Complexity of Environment
  - Blocking Objects
- **Decision**
  - Wrong Interpretation
  - Unexperience
  - Risk Taking Tendency
- **Action**
  - Errors in Vehicle Control
  - Delay of Reaction
  - Limitations of Vehicle

Feedback
(The vehicle movement effect on vision)
Reaction to Stimulus

- A simplification of human observation
- Commonly used in simulation systems

\[ R(t+dt) = \lambda \times S(t) \]

- \( R \) = Reaction
- \( S \) = Stimulus
- \( \lambda \) = Sensitivity coefficient
- \( dt \) = reaction time
Reacting to Prediction

• Reaction time depends on situation
  • In unexpected situations the reaction time is more than 1.0 second
• In many cases the traffic situation can be predicted
  • With prediction capability, the delay caused by reaction time can be compensated
• Example in the picture:
  • The car in front is decelerating and the driver behind in reacting to anticipated new position

![Diagram showing reaction to prediction with light, original position, and predicted position.](image-url)
Reacting to Intentions

• Intentions are important in social process like traffic
  • We react differently to same stimulus if the intention was different
• Humans have very sophisticated skills of detecting intentions of the others
  • However the distance makes a difference
  • The social range is about max 150 meters
• How does that work in traffic?
  • In walking speed there is plenty of time of assess the intention of others
  • In motorized traffic the “social distance” increases
    • More difficult to anticipate intentions
    • Wrong interpretations
    • Less social control
    • More bad behavior
    • Compare to social media?
Micro-management

• How does traffic management work, when no traffic controller is present?
• Traffic rules seem to be very clear, so why not just obey them, right?
• E.g. Duty to yield: pedestrians, vehicles coming from right, when changing lane
• However, the reality is not that simple
• Traffic rules e.g. for yielding apply only when there is clearly a potential conflict
• In other situations generally the first-in-first-out (FIFO) principle applies
• E.g. you don’t stop waiting for a pedestrian that is far from the pedestrian crossing
• There is a grey area between yielding rules and FIFO-principle
• Within the grey area road users need to “negotiate” their way
• Negotiation requires some way of communication
• E.g. in some cases headlights can be flashed to give right-of-way
• More usual is change is a change of speed, which is also works as an indicator
• E.g. Deceleration: “I am yielding”, Acceleration: “I go first”
• There is a lot of variance from country to country
• Think about your own experiences in countries you have been
Micro-management (Lane change 1)

- The vehicle on the left lane does not decelerate
- The vehicle on the right lane takes this as a sign to obey the rule of yielding
Micro-management (lane change 2)

- The vehicle on the left lane decelerates (a courtesy yielding)
- The vehicle on the right lane takes this as a sign to accelerate and to go first
Micro-management (Pedestrian crossing)

- When traffic controller is not present, actors need to negotiate their movements
- The pedestrian has right-of-way, but may not use it, if the car is too close
- Pedestrian may want to establish an eye contact with the driver to allow safe passage
- If the eye-contact was formed and the vehicle starts to slow down, then it is a sign to go
- If the driver shows no sign of reducing the speed, the pedestrian may want to let it go first
- Alternatively the pedestrian may use her right-of-way, but a risk of collision is increased
- Especially if the driver assumed the pedestrian would wait
Closing Remarks

- Traffic is a complex adaptive multi-agent system
- Management of such a system is not straightforward
- Control measures can and should be applied, but there is a lot of self-organization and micro-management
- The features of human information processing and decision making capabilities should be taken account in traffic management
Questions?
Open discussion