1. Introduction

1. Concepts

- Telecommunication + Informatics → Telematics

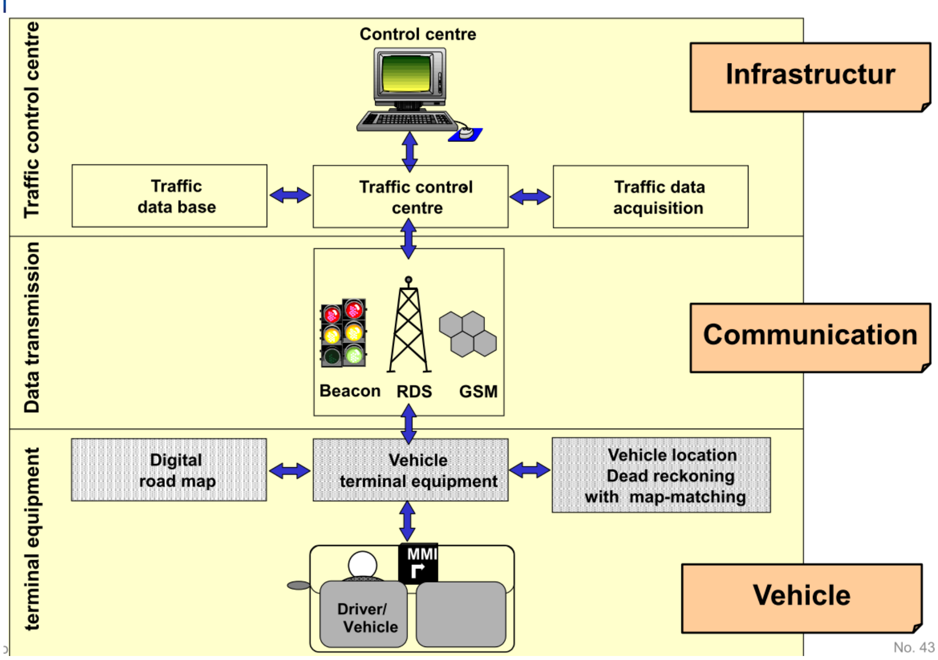
- **Telematics**
  - ✓ Transport and processing of information
  - ✓ Advanced telecommunication services

- **Transport telematics**
  - ✓ Acquisition, processing and transmission of transport relevant data and information
  - ✓ Applications: traffic guidance system, driver assistance systems, safety services, navigation services, information services, etc.

- ***Why?*** *→ Ensure mobility!*
  Enhancement of safety
  Increase of efficiency
  Reduction of adverse impacts on environment
  →Ensure mobility

- Intelligent Transport Systems **(ITS)** →synonym for transport telematics
  - Definition: Worldwide initiative to add information and communication technologies to transport infrastructure and vehicles.

System architecture of transport telematics

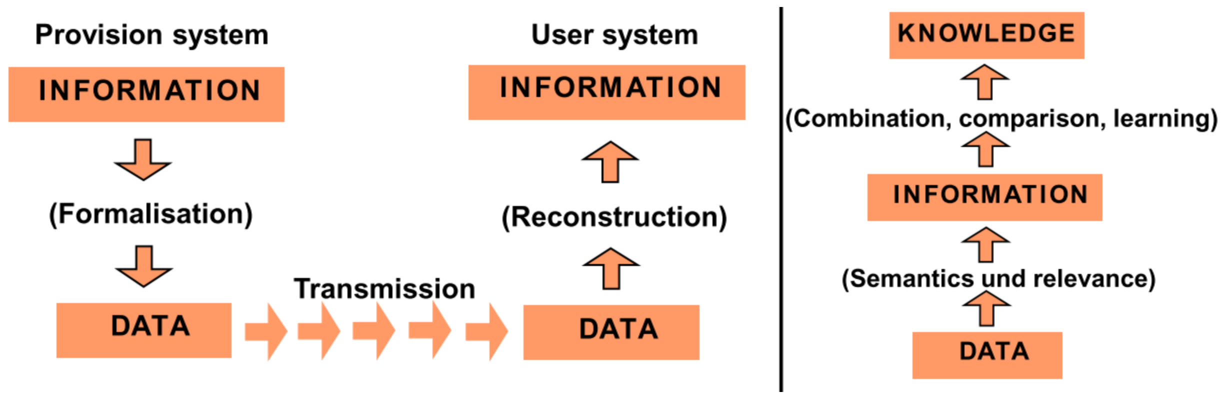


- **Obstacles**
  - ✓ Supply of necessary data (traffic data, geo data) with sufficient quality.
  - ✓ Organizational and legal barriers.
  - ✓ Development cost of telematics systems.
  - ✓ Harmonization and standardization missing.
  - ✓ Adverse impacts due to increasing complexity and cross-linking of the components.

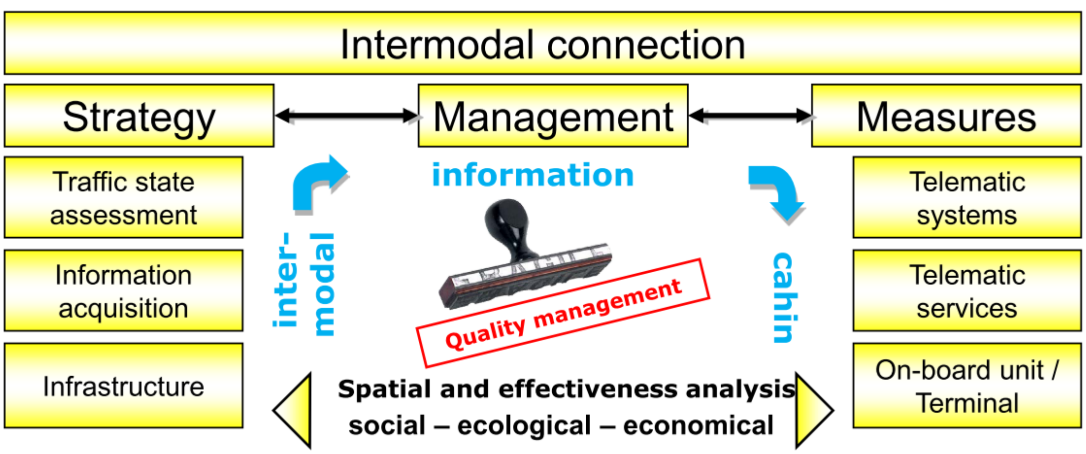
2. Data vs. Information

- **Data:** A formalized collection of facts, concepts and instructions, usable for communication or processing (humans or automated methods)

- **Information:** Purpose-oriented knowledge necessary to reach intended aims.
  Information results from the application of rules and instructions on data
  Information is meaningful data



- **Information chain**



2. Digital Map: GDF Format

1. Classification of maps and geo data

Format	Type	Coordinate sys.	Source	Content
Raster	Cadastral map	UTM	Public	Features
Vector	City map	WGS84	Commercial	Attributes
	Base map	…		Thematic/Topographic

2. Commercial Data sources

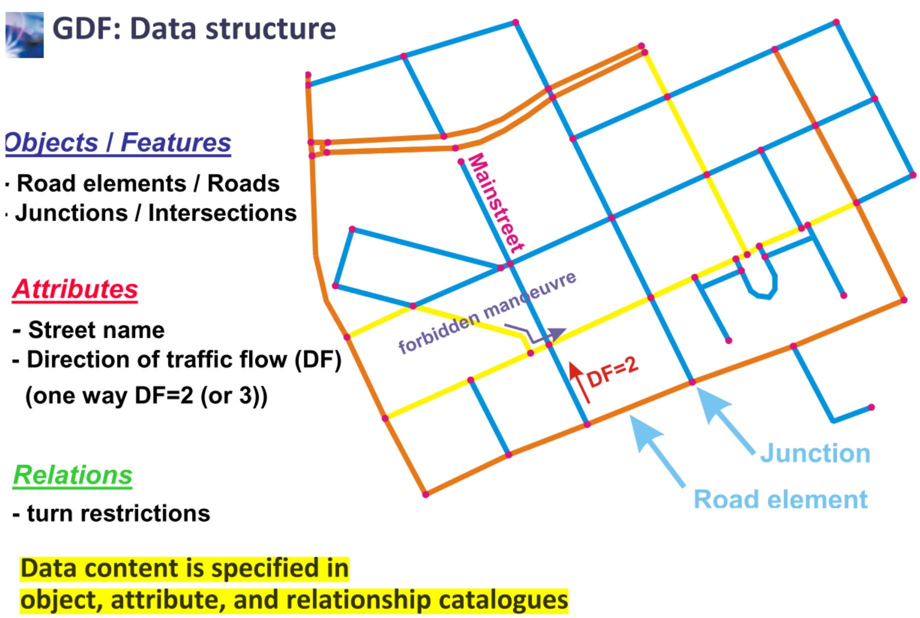
- Traditional map publisher: publisher of analogue road maps and city maps
- (Digital) Maps for navigation systems: GDF
- Data provider: Aggregation/ refinement of geo data
- Open source and WWW: Google maps, OpenStreetMap

3. Geographic Data File (GDF)

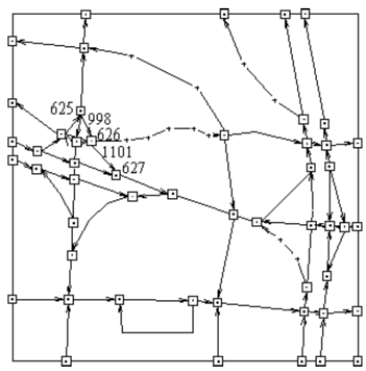
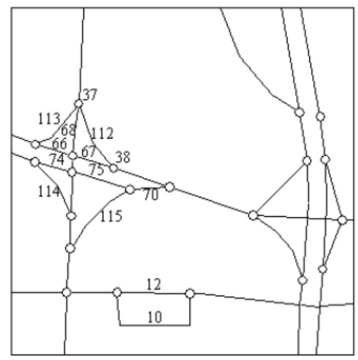
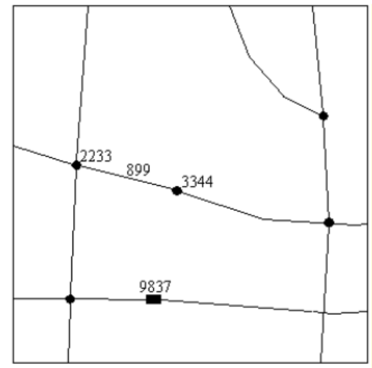
- **Definition**: Specification of data content, data capturing and exchange formats (based on NTF→National Transfer Format).

- **Content of specification**
  - ✓ **Feature catalogue:** listing of the features
  - ✓ **Attribute catalogue:** listing of the attributes
  - ✓ **Relationship catalogue:** listing of the relationships between features
  - ✓ **Feature representation scheme:** how the features are represented.
  - ✓ **Quality description:** the way to measure the quality of the GDF data.

  - ✓ **General Data Model:** detailed definition of data modelling.
  - ✓ **Global Data Catalogue:** informs about metadata (data of acquisition, data source, method of projection)
  - ✓ **Media Record Specification:** description of data exchange format.



4. Representation scheme

Level 0: Geometry	Level 1: Simple features	Level 2: Complex features
		
Geometry Basic geometric/topological primitives. Nodes edges and faces Coordinates define the spatial arrangement.	Simple features Points – Lines – Areas 1-1 feature / real object relation	Complex features Grouping (using simple features) Description of the road network (from driver POV)

Modelling of traffic flow

Direction of traffic flow:

- allowed in both direction
- closed in both direction
- closed in positive direction and open in negative direction
- closed in negative direction and open in positive direction

Attribute model: each feature can carry any number of attributes

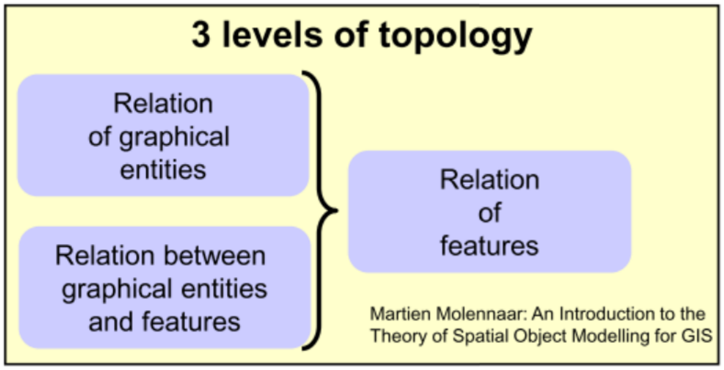
- Complex attributes
- Segmented attributes
  - ✓ Absolute segmentation: related to the length in the geometrical representation (from a defined starting point)
  - ✓ Relative segmentation: related to measured length by a percentage velue
- Time-dependent attributes

Segmented attributes
Not-segmented attributes

Data model for semantic relations
Prohibited manoeuvre
Restricted manoeuvre
Priority manoeuvre

5. Topology

- deals with characteristics of geometric entities, which are invariant to metric transformations (distortions).
- metric proportions have no importance.
- defined only by position and structure of entities (arrangement in space).
- describes non-metrical spatial connections.



6. Maps differ from each other over the same standard

- different interpretation of acquisition rules.
- different acquisition tasks.
- different data sources.
- completely independent acquisition.

7. GDF acquisition

Variation 1	**Variation 2**
Secondary data: orthophotos, topographic maps and use of digital data bases Primary data capturing: - attributes of road elements - Turn restrictions & signage	Mobile mapping vehicles Road geometry acquisition by positioning system Attributes/relations by geocoded video images

8. Further development of GDF

Project NextMAP

Set-up of requirements to future digital road maps
Development of navigation systems to advanced driver assistant systems (ADAS)
Enhanced requirement to content manufactures

Project ActMAP

Dynamic update of onboard digital road maps
Mechanism for nap updates: incremental update, real-time update

3. Digital Map: Further digital maps

1. ATKIS – Official Topographic Cartographic Information System

- **Models:**
  - ✓ DLM – Digital Landscape Model
  - ✓ DTK – Digital Topographic Map
  - ✓ DGM – Digital Terrain Model
  - ✓ DOP – Digital Ortho Photo

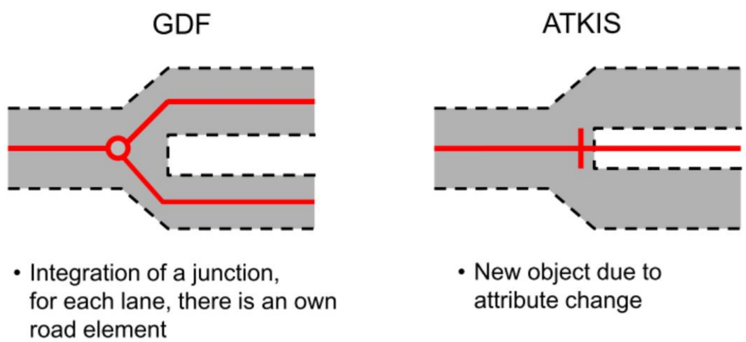
- Data content is defined by an object catalogue: hierarchical model.
- ATKIS is not suitable for navigation routing (essential data is missing eg. turn relations).
- Feature representation of roads
    - ✓ Road:

  Linear, road is a complex feature composed of center lines, center line represents spatial basic feature
    - ✓ Road with divided carriageway:

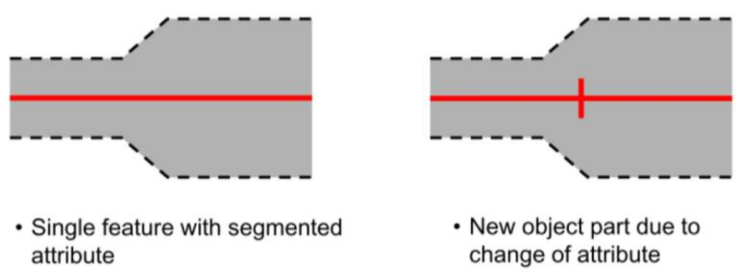
  Linear and areal, road is a complex feature composed of carriageway axes and center line, areas between are classified with feature type ‘road traffic’

2. ATKIS vs. GDF

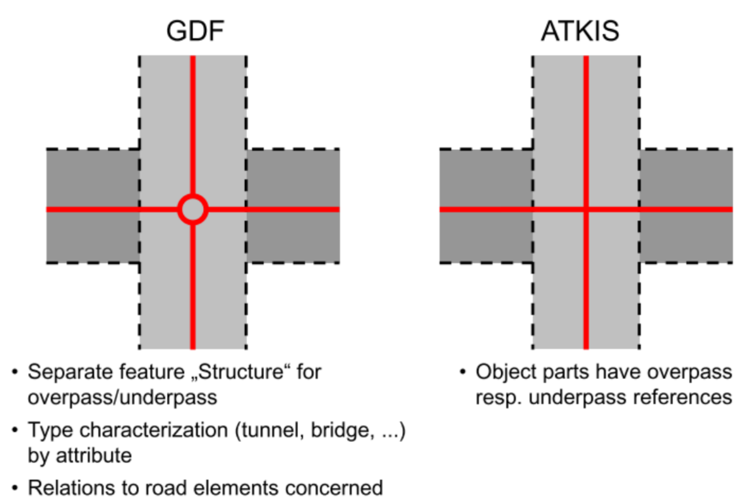
GDF	ATKIS
Attributes are only used for features. Simple and complex features. None raster data	More levels of definition. Simple and complex features. None semantic relationships.



Change from common to separated lanes



Change from two-lane to multi-lane on a common carriageway



Overpass and underpass

3.OKSTRA → objektkatalog für das Strassen und Verkehrskehrswesen

(Feature catalogue for road engineering and transportation)

- Realization of a continuous information flow by data exchange without lost of any data and information
- Surveying agencies, road administration, federal government and states, planning and engineering offices
- OKSTRA is structured into 3
  - ✓ New construction data (draft, engineer structures, surveying, land register…)
  - ✓ Traffic data (signposting, accident data, traffic intensity…)
  - ✓ Existing data (road condition, structure data, inventory data, network data…)

4. OpenStreetMap → OSM

- is a collaborative project to create a free editable map of the world.
- maps are created by users worldwide using data from portable GPS devices, aerial photography and other free sources. users authorize the rights to OSM.
- OSM has all rights to the data

Data model

- OSM uses an own data model based in XML. There are no restrictions on attributes for the objects
- depending on the projects specific requirements, commercial reliable sources are preferred.

Data format

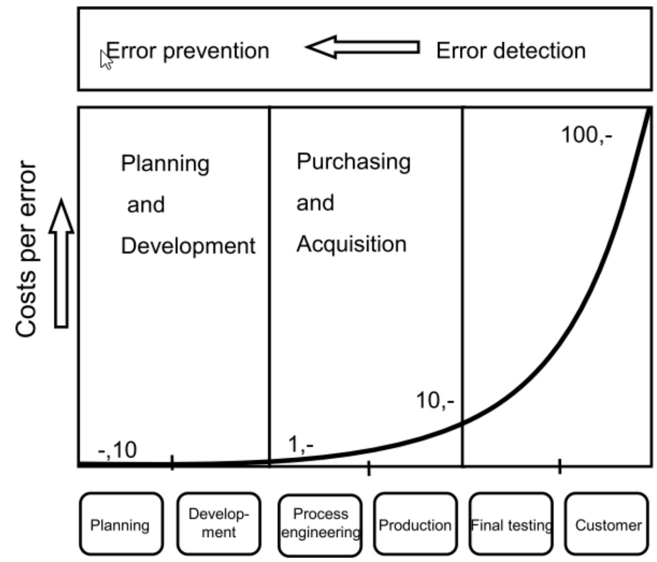
- Export in common raster data png,jpg,pdf
- Export in vector based format XML

5. Navigation Data Standard → NDS

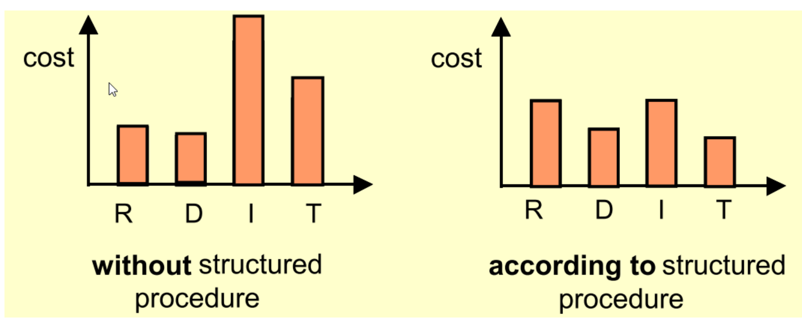
Open Lane Model

3. Requirement analysis

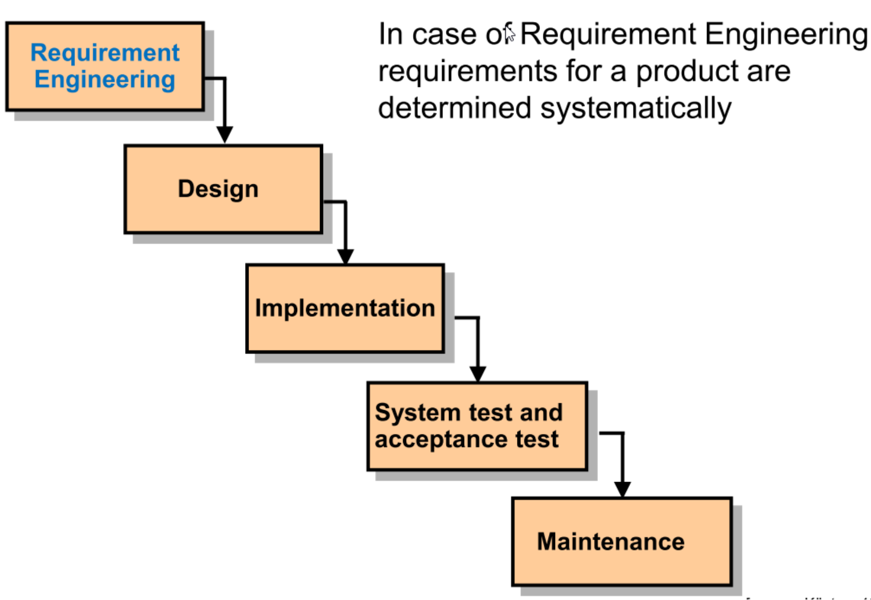
- is the basis of information system development (software development).
- **errors** during this activity can be corrected with considerable costs:



- A **structured** procedure is followed in order to achieve the customer's satisfaction and to save money from error detection.



- **Phases:**



1. Requirement engineering

- Business requirements are gathered in this phase.
- This phase is mainly focus of project managers.
- Requirement must determine:
  - ✓ Who's going to use the system?
  - ✓ What will the output be?
- Requirement Engineering documentation is created → serves as guideline for next phase models.

2. Design

- System and software design is prepared from the requirement specifications.
- System design helps in defining the overall system architecture.

3. Implementation

- Coding phase → Code is developed and tested against the requirement engineering documentation to be sure that the product is solving all the requirements.

4. Final check (+maintenance)

- Product is delivered to the customer (after successful testing).
- Maintenance is also important in case that problems come up.

The **collecting techniques** to determine the requirements are:

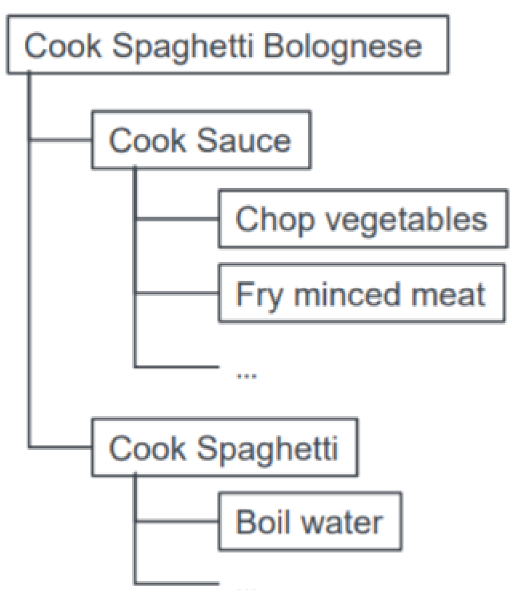
- interviews
- questionnaires
- specific workshops
- available documentation

The **Modelling methods** to document and structure the requirements are important, e.g. (Unified Model Language) UML case diagram, Function tree…

Modelling Methods

1. Function analysis

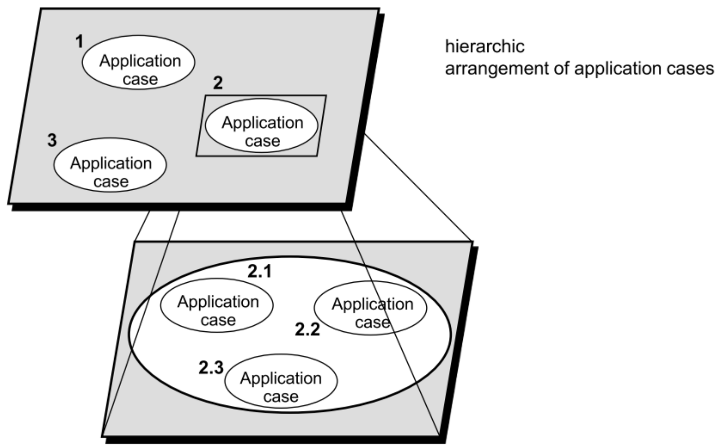
- A **function** describes an activity within a higher context.
- By **function tree** different parts of the system can be constructed.



2. Questions to determine the object:

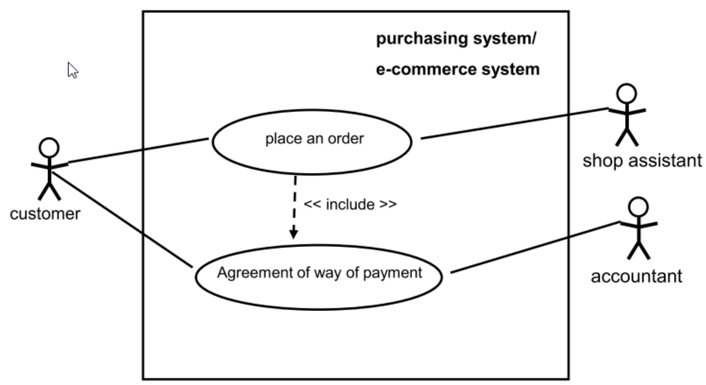
- Which objects are involved? (person, location, devices, forms…)
- Attributes of the objects? (how are the objects structured, where are they, when…)
- Objects relations? (what is linked, what happen and where…)
- How is the communication done? (who communicates at which time to whom…)

3. Arrangement of use cases



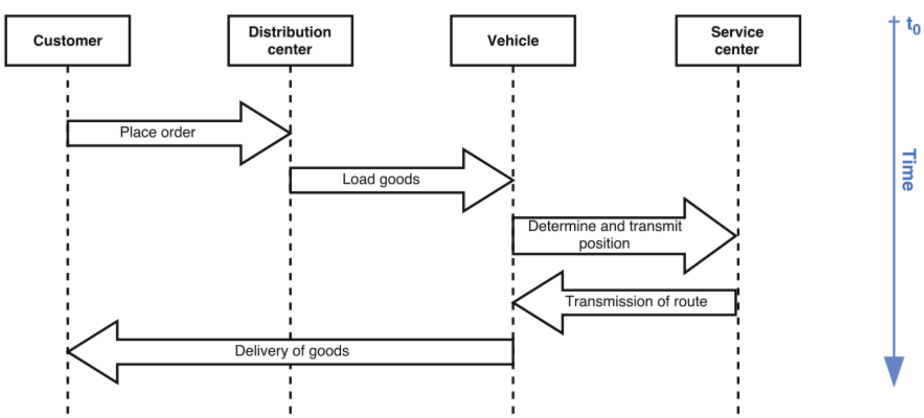
4. Use Case Diagram

- is a visual description of the relationship between actors and use cases.
- an use case describes typical interaction between user and system.



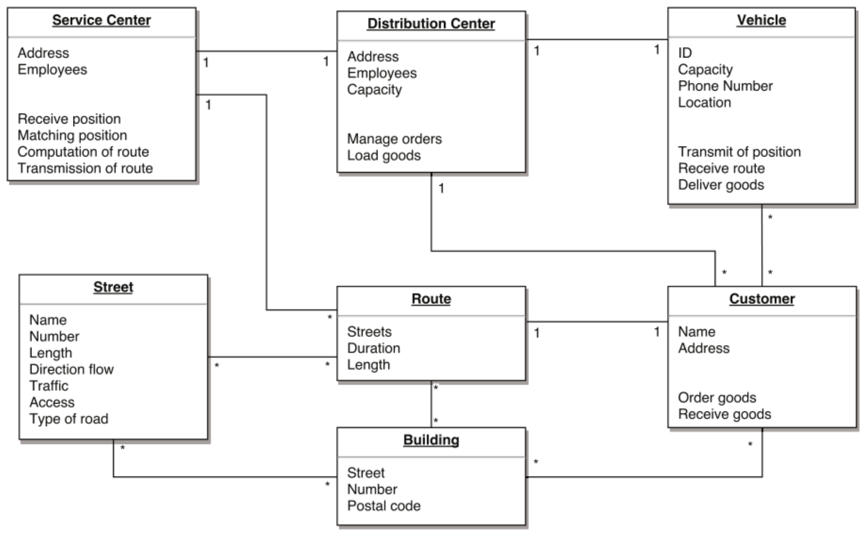
5. Sequence Diagram

- modelling interactions in a time flow (from source to destination)→ Dynamic circumstances are illustrated.



6. Class Diagram

- is a type of static structure diagram
- describes the structure of a system by showing the system classes, attributes, operations and relationships.
- a class describes the quantity of objects with a common behavior and characteristics (attributes).
- an attribute is a data element being contained in every object in a class.



1. **Geographic data**
   - Zero-dimensional object: POI point
   - One-dimensional object: road line
   - Two-dimensional object: area polygon
   - 2.5-dimentional: elevation is thought of as a continuous field, a variable with a value everywhere in two dimension

2. **Scale**
   - Scale is in the detail: use in the sense of spatial resolution or the level of detailed in data
   - Scale is about extent: use to talk about the geographic extent or scope of a project
   - Scale of a map: use to refer to a map’s representative fraction (the ratio of distance on the map to distance on the ground)

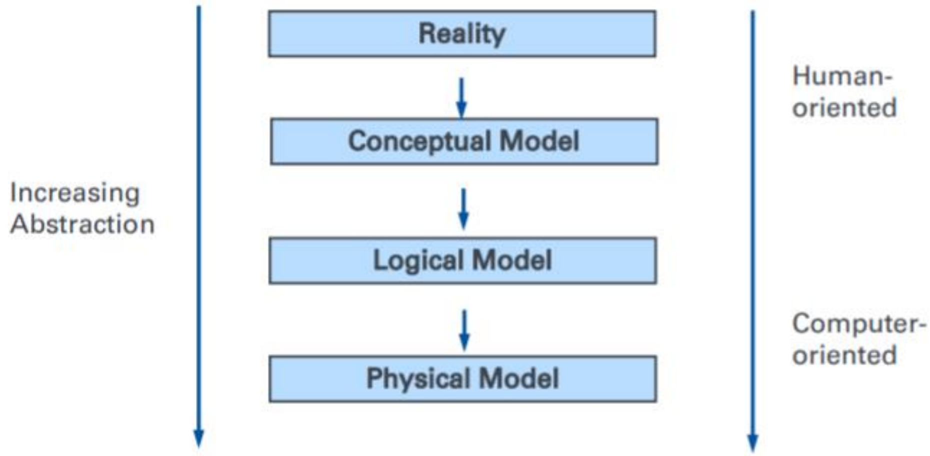
3. **Georeference**
   requirement of a georeference
   - Must be unique, so that there is only one location associated with a given georeferenced
   - The meaning is shared among all the people
   - Must be persistent through time

   Example of georeference with metric: cadastral system, public land survey system, UTM, GK coordinates.
   Example of georeference without metric: placement, postal address, postal code…

4. **Geodata**
   - Geometric primitives: point, line, polygon → based on the Euclidean geometry
   - Topological primitives: node, edge, face → description of the relationship between geographic objects
   - Geometry classes defined by the OGC: point, multipoint, line, linearRing, curve, multicurve, polygon, surface, multisurface → definition is used in databases like PostGIS, MySQL…

5. Data model

Four levels data model:



different levels of abstraction (levels of generalization or simplification)

Data model	Example applications
Computer-Aided Design (CAD)	Automating engineering design and drafting
Graphical (non topological)	simple mapping
Image	Image processing and simple grid analysis
Raster/Grid	Spatial analysis and modeling especially in environmental and natural resource applications
Vector/Georelational topological	many operations on vector geometric features in cartography, socio-economic and resource analysis and modeling
Network	Network analysis in transportation, hydrology and utilities
Triangulated Irregular Network (TIN)	Surfaces/terrain visualization, analysis, and modeling
Object	Many operations on all types of entities (raster/vector/TIN etc.) in all types of applications

complexity / evolution

6. Object-oriented concepts in GIS

- Object: is a self-contained package of information describing the characteristics and capabilities of an entity
- Relationship: an interaction between objects is called relationship
- Class: a collection of objects of same type. A class can be thought of as a template for objrcts.
- State: each class/object might include properties
- Behavior: each class/object might include methods

7. Database management system

Classification of database management system (DBMS)

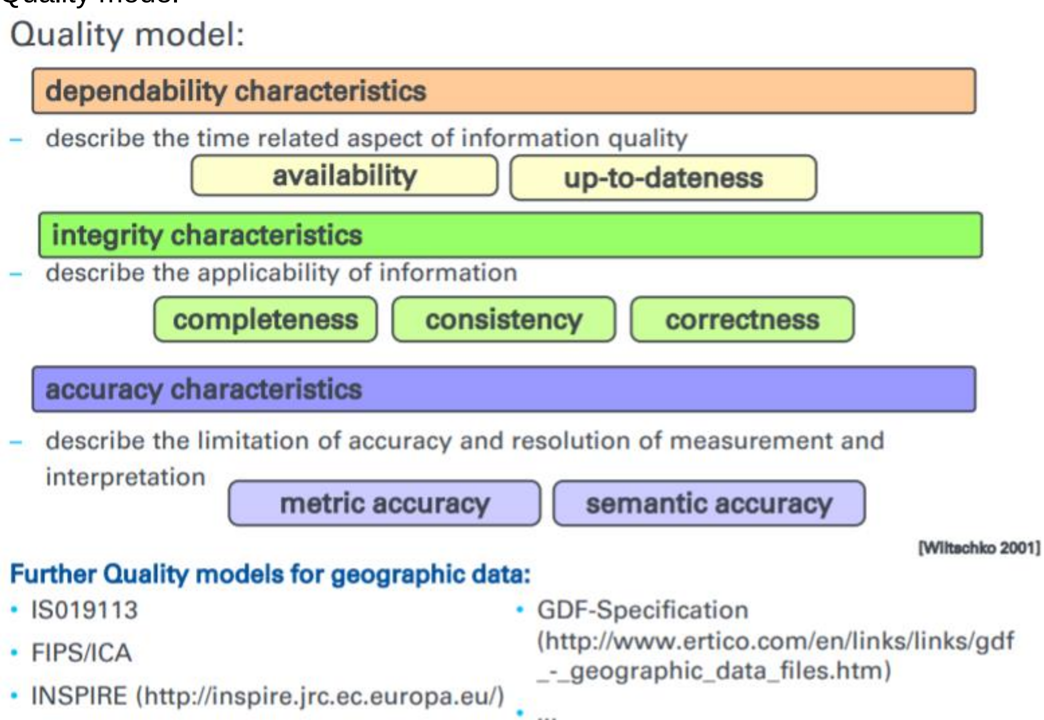
- Relational (RDBMS)
  - ✓ Set of tables, each of a two-dimensional list of records containing attributes about the objects under study
  - ✓ Over 95% of the data in DBMS are stored in RDBMS, because of the simple, flexible and useful structure
- Object (ODBMS)

  Designed to address several weaknesses of RDBMS:
  - ✓ The inability to store complete objects directly in the database
  - ✓ To deal with rich data types such as geographic objects, sound and video
  - ✓ Poor performance of RDBMS for many types of geographic query
- Object-relational (ORDBMS)

  a RDBMS engine with an extensibility framework for handling objects

8. Data quality

- Definition: totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs. Degree to which a set of inherent characteristics fulfils requirements
- Quality model



9. **Data cost**

- Basis costs

  Hardware, software (GIS, data base, operating system), personal costs (basic salary, overhead)
- Project-specific costs

  Hardware (acquisition sensor), software (data acquisition), personal (production, conversion, data test)

5. Digital Maps: Applications + Topology

1. Location

Optimally locating *p* facilities to serve *n* customer demands at $n>p$ locations.

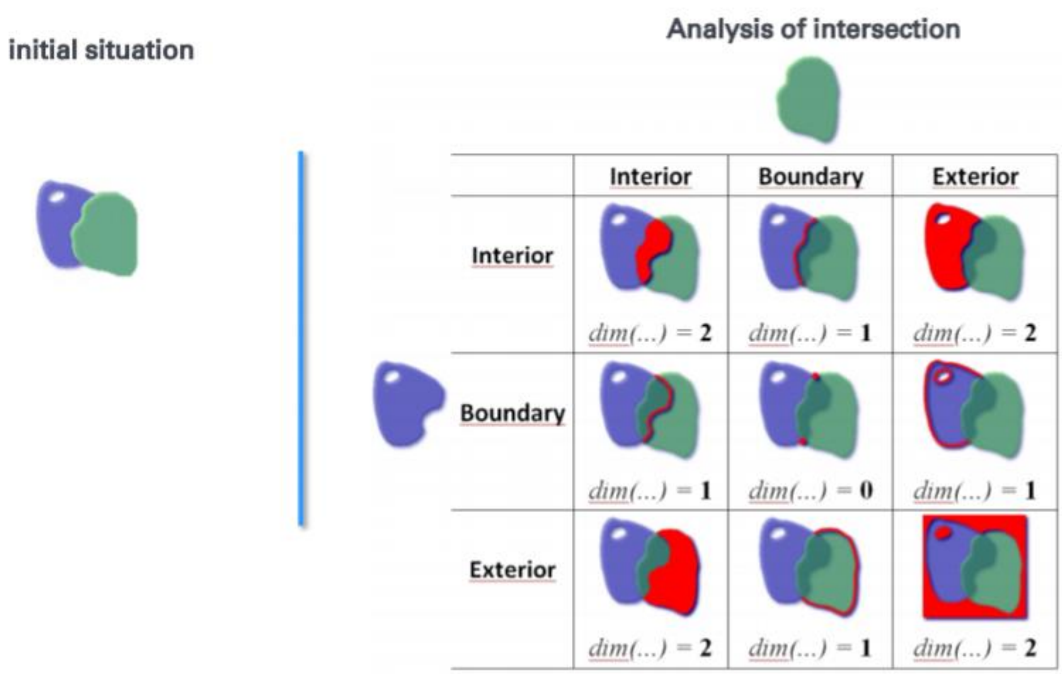
2. Topology

- **Topological properties**
  - ✓ distinction between point/line/area/volume.
  - ✓ adjacency (e.g. touching of land parcels, counties, nation states)
  - ✓ connectivity (e.g. junctions between street/roads/railroads/rivers)
  - ✓ containment: point lies inside an area

- **Different overlay methods in GIS**

  Dimensionally Extended Nine-Intersection Model (DE-9IM)

	Interior	Boundary	Exterior
Interior	dim(I(a)∩I(b))	dim(I(a)∩B(b))	dim(I(a)∩E(b))
Boundary	dim(B(a)∩I(b))	dim(B(a)∩B(b))	dim(B(a)∩E(b))
Exterior	dim(E(a)∩I(b))	dim(E(a)∩B(b))	dim(E(a)∩E(b))



- **Topology of networks**

  Networks form graphs, for which some techniques have been developed, such as:
  - ✓ Measuring connectivity.
  - ✓ Finding shortest path.
  - ✓ Network connectivity/distance.
  - ✓ Distance analysis.
  - ✓ Traveler Salesman Problem.
  - ✓ “Optimal place” analysis.

- **Network analysis terminology**
  - ✓ Vertex (node): a point location is a network node.
  - ✓ Edge: a directed or undirected link between two vertices that are directly connected is a edge
  - ✓ Degree (of a vertex): in an undirected graph the number of edges meeting at a vertex.
  - ✓ Graph: a collection of vertices and edges constitutes a graph
  - ✓ Path: a sequence of connected edges between vertices.
  - ✓ Connected graph: at least one path exists between every vertex and every other vertex in a graph.
  - ✓ Connectivity: is the minimum number of nodes or links that must fail in order to partition the network into two or more disjoint network
  - ✓ Planar graph: if a graph can be drawn in the plane in such a way as to ensure edges only intersect at points that are vertices.
  - ✓ Network: a collection of vertices and edges together with associated attribute data that may be represented and analyzed using graph theoretic methods
  - ✓ Diameter: the maximum number of links that must be traversed to reach any node along a shortest path.
  - ✓ Cycle: a path from a given vertex to itself that traverses other vertices
  - ✓ Tree: an n-vertex acyclic network or subnetwork in which every vertex is connected, the number of edges is n-1. A unique path exists between every pair of vertices in a tree

- **Standards/Requirements in transportation networks**
  - ✓ Topological correctness of network. Feature model: junction/road element
  - ✓ Orientation of network: each road element has a start-end junction defined.
  - ✓ Attributes can be modelled “orientated”
  - ✓ Segmented attributes are realized.
  - ✓ Support of semantic relations to define maneuvers.

- **Some key optimization problems in network analysis**
  - ✓ Hamiltonian circuit (HC)
  - ✓ Eulerian circuit (EC)
  - ✓ Shortest path (SP)
  - ✓ Spanning tree (ST)
  - ✓ Minimal spanning tree (MST)
  - ✓ Steiner MST, steiner tree
  - ✓ Travelling salesman problem (TSP)
  - ✓ Transportation problem, trans-shipment problem
  - ✓ Vehicle routing problem (VRP)
  - ✓ Arc routing problem (ARP)
  - ✓ Facility location: p-median/ p-center/ coverage

3. Routing algorithm

- The problem of finding an algorithm to calculate an optimal path.
- Main problem: organization of big data to guarantee a quick data access.

- **Traveling Salesman Problem (TSP)**
  - ✓ Certain number of places must be visited in a tour from the depot
  - ✓ The distances between places are known.
  - ✓ Selection of the best tour out of all possible orderings, in order to minimize the total distance traveled.
  - ✓ If n places to be visited, including the depot, then there are $\frac{(n-1)!}{2}$ possible tours.
  - ✓ This number grows very fast, $(n = 5 \to 12,\ n = 10 \to 181\,440)$ converting it in a time complex problem.
  - ✓ Data access strategies are used to get better response times.
  - ✓ Heuristics are implemented to get acceptable response times → Optimized result instead of best result is achieved.
  - ✓ Attributes (e.g. length, speed, restrictions, congestion) are often taken into account.
  - ✓ The “strictly” shortest path is often not suitable, because it involves too many turns or uses too many narrow streets, so algorithms are often programmed to find routes that use fast highways (freeways).
  - ✓ Solution algorithms: Dijkstra, Bellman’s Principle of Optimality, Floyd.Warshall, A-star, Kruskal…

6. Location referencing

- Examples of exchange of georeferenced information
-

Infrastructure to vehicle	Vehicle – vehicle	Vehicle to infrastructure
-map updates -traffic information -road safety features	-problems with own vehicle -detected problems on the road -info from other vehicles	-accident info -traffic jams

- Information referenced in **digital road maps**
- Each vehicle matches its position on the map (map matching)
- Different map suppliers, e.g. HereMaps, TomTom, OSM
- Location referencing is needed: map-based but map-independent
- Two different realizations:
  - ✓ Pre-coded location references
  - ✓ Dynamic location references

1. Description of problem

- **Needs:**
  - ✓ Exchange attribute information between different maps

- **Problems:**
  - ✓ Sender/receiver use different maps
    - ➔ Unmatched/not used georeferencing on sender side
  - ✓ Different representation of the road network.
    - ➔ Road elements differ between different maps
    - ➔ Missing objects
    - ➔ Different object IDs
    - ➔ Unmatched location/position

2. TPEG – Transport Protocol Experts Group

- protocol for exchange of Real Time Traffic Information (RTTI)
- developed further by TISA (Traveler Information Services Association) – non-profit Belgian association
- Purpose: describe real-world events and situational data with a spatio-temporal scope, described by:
  - ✓ Geographical location
  - ✓ Point in time respective duration
- Situational data supported on TPEG:
  - ✓ Municipal traffic (forecast) management system
  - ✓ Public transport operation
  - ✓ Weather observation
  - ✓ Parking info
- Distributed via RDS-TMC (Radio Data System – Traffic Message Channel)
- Limitations with TMC
  - ✓ Low and restricted bandwidth/capacity
  - ✓ Only static positions
  - ✓ Low coverage of networks
- TPEG uses DAB/DAB+ (Digital Audio Broadcasting) for transmission.

3. Pre-coded location references (ISO 17572)

- Location Reference (LR) is a clear identification of a spatial object.
- In Intelligent Transport Systems (ITS), transportation networks were coded as LR.
- All links using TMC are stored in a static location table.
- All receivers need this static table for location referencing
  - ✓ No real-time update possible for the table inside vehicle
  - ✓ Only one part of the network is stored (main roads)

4. Dynamic Location References

- **Agora/OpenLR solution: location referencing (general)**
  - ✓ Exchange of Road Safety Attributes (RSA) updates independent of map.
  - ✓ RSA is given as extended as possible → information about location
    - Intersection location
    - POI location
    - Attributive information (road class, type, street names)
    - Topological information

<u>AGORA</u>

- General location referencing method
- Objective: develop a method for generating LR, robust within differences in databases on submitter/receiver.
  - ✓ 50 Bytes message size limit
  - ✓ 95% hit rate
- Combination of 3 existing methods
  - ✓ Advanced Intersection Location (ILOC)
  - ✓ Pivot Point approach (Siemens)
  - ✓ GoodLane approach (Bosch)

- General method
  - ✓ List of all points along the path to describe the coded element (lines)
  - ✓ Sorting of points to describe the logical order
  - ✓ Each point belongs to one or more: 1) location, 2) intersection and/or 3) routing
  - ✓ WGS84 coordinates
  - ✓ Location reference has the following attributes:
    - Location Direction (LD)
    - Location Type (LT)

<u>OpenLR</u>

- Definition
  - ✓ Open, compact and royalty-free dynamic location referencing.
  - ✓ Dynamic location referencing method which enables data exchange and cross-referencing using digital maps from different sources.
- Objectives
  - ✓ Free and successful exchange of location-relevant content: transfer information from center to vehicle systems.
  - ✓ Universal standard
  - ✓ Quick enhancement by expert community →Open Source Model
- Requirements

  Map requirements on basis of GDF parameters.
  - ✓ Functional Road Class (FRC or FC)
  - ✓ Form of way (FOW)
  - ✓ Geometrical shape
  - ✓ Coordinates in WGS84
- All attributes need to be mapped to corresponding OpenLR values.

7. Communication technologies

1. Terms and definitions

- **Telecommunication**
  Umbrella term for all kinds of information transmission containing:
  - ✓ Telecommunication equipment
  - ✓ Organizational/operational facilities
  - ✓ Legal regulation for introduction, operation and use of the facilities

- Unidirectional: communication in one direction → mostly collective approaches (broadcast)
- Bidirectional: communication in both direction → mostly individualized information

2. Long range systems

- **RDS – Radio Data System (1987)**
  Small amounts of data using conventional analogue FM Radio broadcast
  Low transmission rate: 1kBit/s

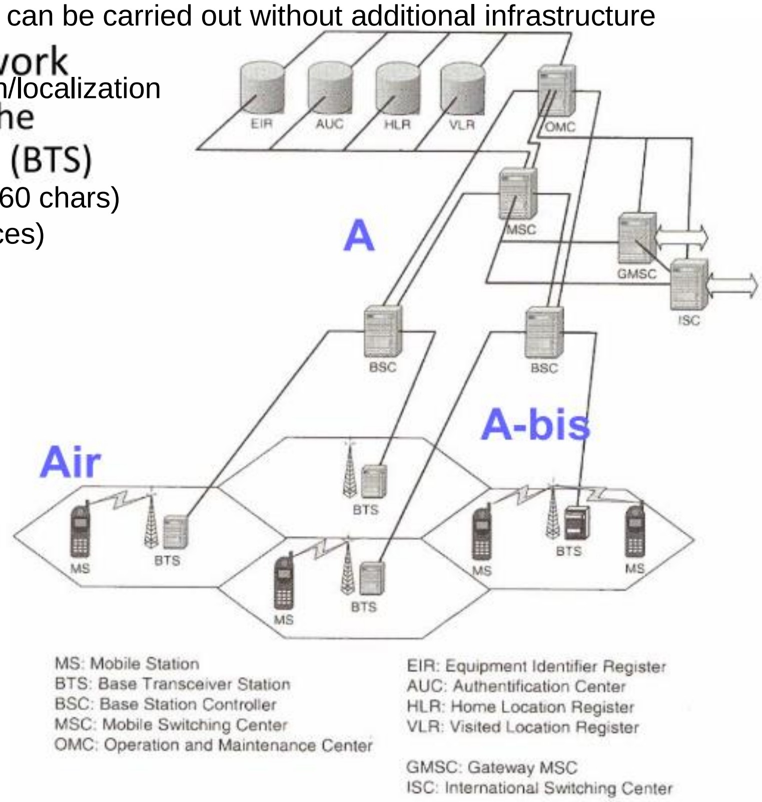
- **TMC (Traffic Message Channel) (1990)**
  Special RDS data for transmitting georeferenced traffic and travel information (weather situation)

- **DAB (Digital Audio Broadcast) (1998)**
  - ✓ Designed for mobile use (cars) using a simple rod antenna
  - ✓ TMC can be sent by DAB
  - ✓ Better quality than RDS and higher data rate: max 1.6 Mbit/s
  - ✓ Multi-path effects are used to improve receiving quality
  - ✓ Further development

  DAB+: upgrade including more efficient use of radio spectrum and lower transmission costs
  DMB → Digital Multimedia Broadcasting is a video and multimedia technology based on DAB.

- **GSM (Global System for Mobile Communications) (1993)**
  First international standard of mobile telephony
  Vehicle to Data Center data transmission can be carried out without additional infrastructure
  Characteristics
  - ✓ Subscriber and device authentication/localization
  - ✓ Data encoding
  - ✓ Transmission rate: 9,6 kBit/s
  - ✓ SMS: short message service (max 160 chars)
  - ✓ GPRS (General Packet Radio Services)
  - ✓ Rate: >50 kBit/s

  GSM architecture: 3 subsystem
  - ✓ Base Station Subsystem
  - ✓ Network and Switching Subsystem



- **UMTS (Universal Mobile Telecommunication System)**
  - ✓ CDMA protocol (Code-Division-Multiple-Access)
  - ✓ Higher speed and support for more users
  - ✓ Parallel transmission and receiving of several data streams
  - ✓ Data transfer rate: max. 2 Mbit/s — Standard 144 kbit/s
  - ✓ Communication, news services, information dissemination, localization, mass service

- **Satellite-based communication systems**
  - ✓ Global systems
  - ✓ Cannot be operated cost covering
  - ✓ Operation stopped in some cases
  - ✓ Generally speaking, irrelevant for ITS
  - ✓ Examples: Iridium (66 sat + 6 substitute sat), Globalstar (48 sat + 8 LowEarthOrbit), Teledesic (840 LEO sat, out of business)

- **Private Mobile Radio**
  - ✓ Radio network comprised by radio installations with appended mobile radio sets
  - ✓ Non-public mobile land broadcasting
  - ✓ Range: 10 – 20 km
  - ✓ Subdivided by several application areas according with user's needs.

- **Trunking -Trunked Radio**
  - ✓ Voice and data parallel transmission
  - ✓ Data transfer rate: 19.2 kbit/s
  - ✓ Subscriber administration carried out by central office
  - ✓ Cells up to 50 km radius

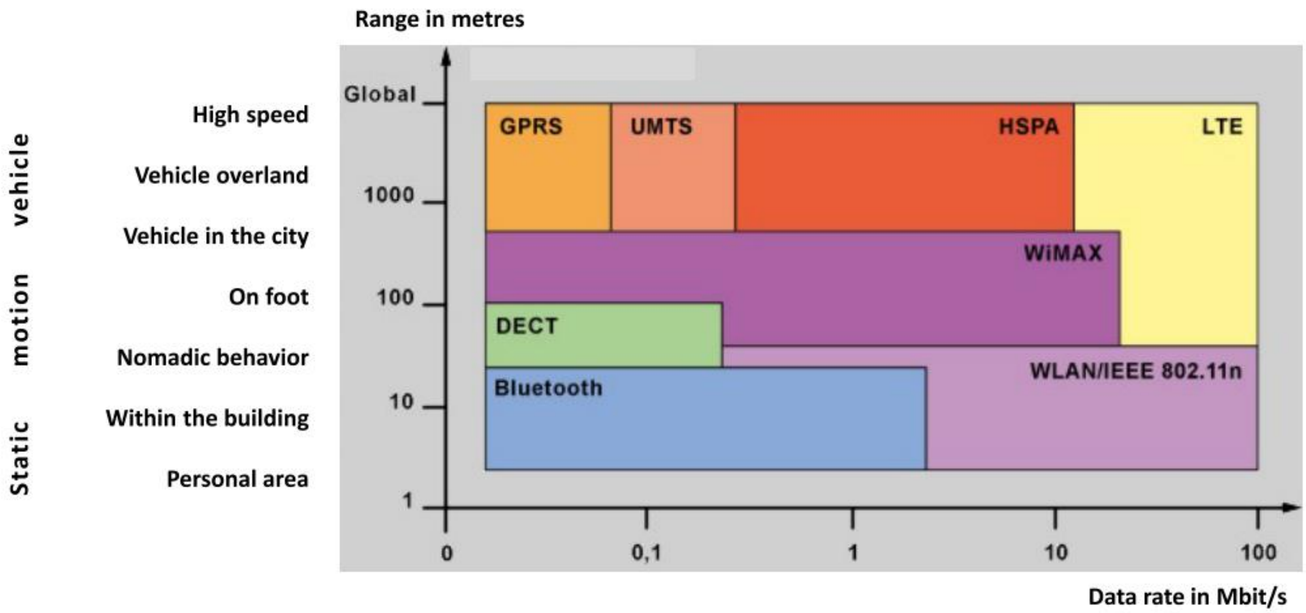
3. Short range systems

- **DSCR (Dedicated Short Range Communication)**
  - ✓ Range from 5 to 100 m
  - ✓ Infrared 5.8 GHz
  - ✓ Data rate: 32 kbit/s to 1Mbit/s
  - ✓ Simple onboard systems
  - ✓ Local real time information
  - ✓ Combination of localization and communication

- **5.8 GHz Radio System**
  - ✓ Two-ways communication with short range
  - ✓ Range from 5 to 20 m
  - ✓ Data rate: 500 kbit/s
  - ✓ Onboard device

- **Bluetooth**
  - ✓ Wireless voice and data short range communication (10 – 100 m)
  - ✓ Data rate: ~500 kbit/s
  - ✓ P2P or P2MultiP connections.
  - ✓ Scope: Inside vehicles.

- **Wireless LAN (WLAN)**
  - ✓ Data rate: ~20 Mbit/s
  - ✓ Scope: inside buildings
  - ✓ Distance, users, objects inbetween



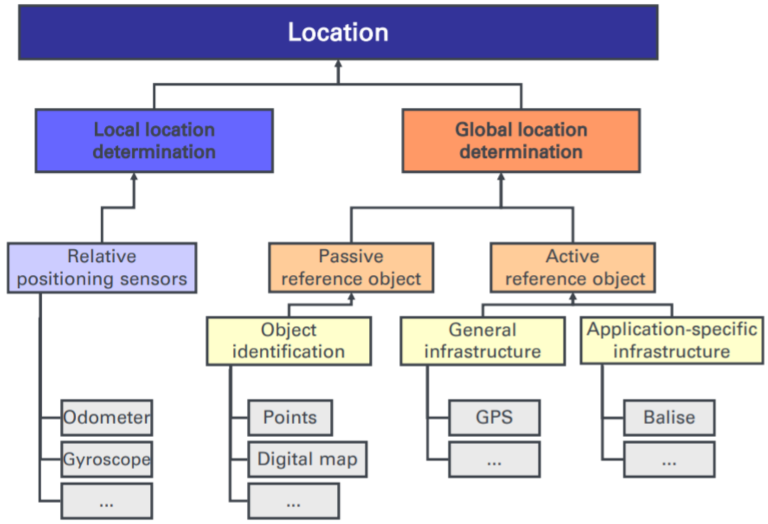
4. Communication inside vehicle

CAN BUS (Controller Area Network)

- Networking of control units in cars
- All devices simultaneously connected: *ready for transmission *conflict resolution of parallel transmission
- Transfer rate depends on bus length and version
- CAN-B
  - ✓ Support of intelligent sensors
  - ✓ Max. 10 stations
  - ✓ Low data rate
- CAN-C
  - ✓ For drive and chassis electronics
  - ✓ Max. 24 stations
  - ✓ High data rate

8. Positioning and navigation

1. Classification of location methods



Global	Local
Global reference No previous information necessary Measurement of absolute position	Measurement of position changes Lack of absolute position can be compensated for short periods (dead-reckoning)

Self-positioning	Remote-positioning
Positioning is realized by mobile object itself	Realized by a reference system (Data privacy must be considered)

Coordinate system (n-D)	Traffic network wrt road (1-D)	Predefined objects
Positioning related to a coordinate system, e.g. WGS84	Positioning related to a line	Area or point-related - for specific location - accuracy depends on container's size

2. Terms

- **Positioning**
  Determination of current geometric position.

- **Location**
  Determination of current position related to an element of a digital map, e.g. node on a graph, traffic network.

- **Map-matching**
  Allocation of the current geometric position or trajectory (sequence of positions) to the traffic network represented as digital map.

- **Route calculation**
  Determination of the optimum path between two or more places within the traffic network (concerning given optimization criteria)

- **Navigation / positioning and guidance**
  Positioning + Location + Route calculation between current location and target.
  Guidance to reach target
  Dynamic navigation: +rerouting (deviations/incidents)

3. Sensors (typical errors)

- **GPS – DGPS → Coordinates (Global position)**
  - ✓ Limited availability due to shadowing, Urban area coverage 90% ~ 95%
  - ✓ Jumps due to changes of satellite constellation and multi-path effects

  Jumps and deviations:
  - ✓ loss of correction signal
  - ✓ shadowing and reflections
  - ✓ change and faulty in satellite configuration
  - ✓ areas without GPS have to be bridged
  - ✓ GPS raw signal not directly usable → Filters necessary

  Dead reckoning: process of calculating current position by using a previously determined/fixed position and advancing that position based upon known or estimated speeds over elapsed time and course. Accuracy depends on shape of the track, number of measurements and accuracy of measurements.

- **Gyroscope → *Changes in direction***
  Zero point error and scale error

- **Odometer → *Distance increments and changes in direction***
  Scale and slip (= temporal scale)

- **Compass → *Azimuth and changes in direction***
  Zero point error
  Magnetic field influences

- **Speedometer → *Speed***
  Scale and slip (temporal scale)

- **Optical speed and distance sensor → *Speed and distance increments***

4. Map Matching

- **Characteristics**
  - ✓ Transformation of local positioning into global positioning info for georeferencing.
  - ✓ Realization of logical connection between vehicle position and map road network.
    - ➔ Logical connection enables access to further route-related data from map
  - ✓ Compensation of measurement errors.

- **Principle:**
  - ✓ Geometric map matching algorithm (point to point matching, point to curve matching, curve to curve matching)
  - ✓ Topological map matching algorithm
  - ✓ Probabilistic map matching algorithm
  - ✓ Advanced map matching algorithm

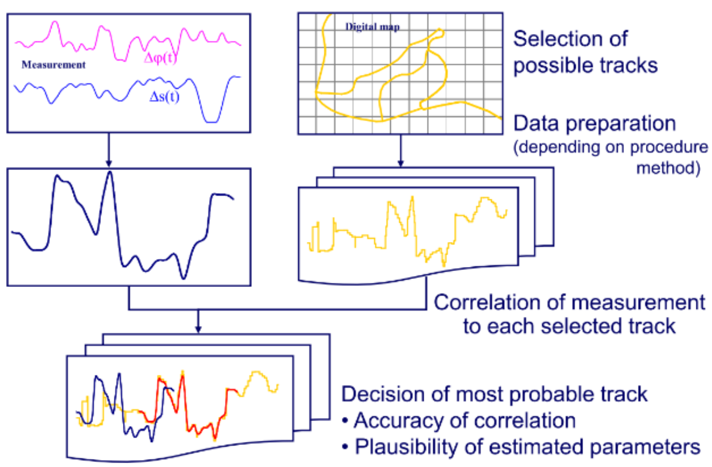
	Speed of algorithm	Accuracy
Geometrical	Fast	Low accuracy
Topological	Fast	Good
Probabilistic	Slow-medium	Very good
Advanced	Slow-medium	Very good

- **Types**
  Evaluation procedure depends on used sensors and application field.

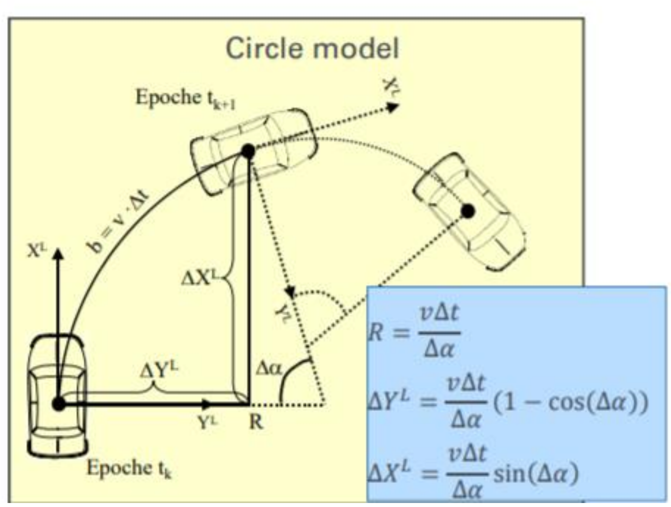
  Based on coordinates
  - ✓ Translation (2 parameters)
    Possible useable for DGPS
  - ✓ Similarity transformation (4 parameters)
    Translation and rotation, determination of initial values for dead reckoning
  - ✓ Affine transformation (6 parameters) → *Most precise*
    Translation, rotation, shearing and reflection

  Map matching with azimuths or curvatures
  - ✓ Adjustment based on offset and scale of elements

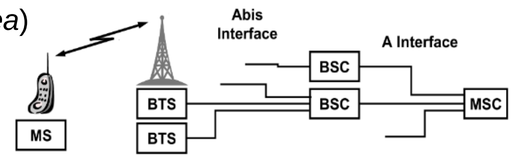
- **Procedure**
  - ✓ Selection of possible tracks
  - ✓ Data preparation (depending on method)
  - ✓ Correlation measurement vs. selected track
  - ✓ Decision: accuracy of correlation / plausibility of estimated parameters



- **Kalman filter: trajectory approach**
  - ✓ Parametrization of vehicle movements: (arc length, curvature/ radius)
  - ✓ Vehicle model: kinematic approach → uniform motion on a circle with constant speed.
  - ✓ Condition vector:
    - (X,Y)
    - Speed v
    - Orientation of vehicle
  - ✓ Measurement:
    - Absolute GPS (X,Y)
    - Odometer
    - Gyro



- **Positioning with GSM →** Structure of GSM network
  - ✓ MS: Mobile station
  - ✓ BTS: Base Transceiver Station (Antenna), controls one antenna respectively cell
  - ✓ BSC: Base Station Controller, controls several BTS
  - ✓ MSC: Mobile Switching Center, controls several BSC in *Location Area*)



- **Signal dispersion**

Wireless signals spread evenly in a vacuum in all directions of the room.
The signal strength decreases as the square of the distance.
Possible signal dispersion due to:

  - ✓ Shading, large objects attenuate the signal there is no reception behind
  - ✓ Reflection, after reflection the absorption of the signal strength is reduced
  - ✓ Scattering, one signal is split into several weaker signals which proceed in different directions
  - ✓ Diffraction, signals are diffracted on edges from the original spreading direction

- **Usable measurements for positioning in GSM**
  - ✓ **Cell ID:** unique ID of antenna's (BTS) cell
  - ✓ **Handover:** point of time when mobile changes cell
  - ✓ **Location Area Update:** point of time when mobile changes Location Area
  - ✓ **Timing advance value:** approx. distance between mobile and BTS
  - ✓ **Received Signal Strength (RXLEV):** signal attenuation between mobile and up to 7 antennas.

- **Positioning Methods:**

Method	Description	Costs	Precision (2D)
Cell location (COO)	Cell size defines precision	-	**100 m - 20 km**
Timing Advance (TA)	Circle cuts, at least 3 network stations required Technique: TOA	Synchronisation of the network stations and the mobile phone	**200 - 500 m**
Multipath pattern recognition	Comparison of an actual frequency and multipath pattern with a target pattern	Central for the pattern matching, creation of the target pattern	**50 - 100 m**
Observed Time Difference (OTD)	Hyperbola cuts, at least 3 network stations required Technique: TDOA	Synchronisation of network stations required	**50 - 300 m**
Enhanced Observed Time Difference (E-OTD)	Hyperbola cuts, at least 3 network stations required Technique: TDOA	Central on known points required for the synchronisation MS: Software upload	**50 - 400 m**
Observed Time-Difference-of-Arrival (OTDOA)	Like E-OTD but for UMTS networks, less multipath effects	Like E-OTD	**20 - 30 m**
Reference data procedure	Comparison of measured radio network data with reference data	Provision of reference data	**100 m – 1 km**

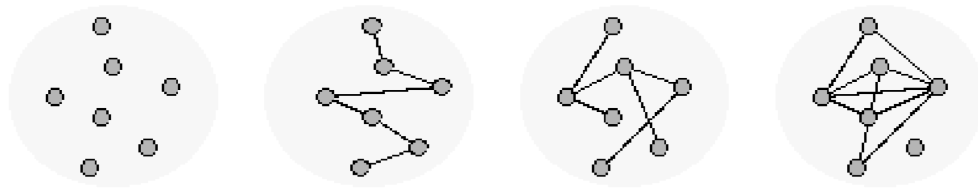
9. Routing

- **Purpose**
  Identify the best route between different locations within a given transport network (with specific requirements).

- **Application**
  Traffic, Navigation Systems, Fleet management/ Route planning

1. Graph theory

- **Definition:** A graph is a set of elements with the same properties having a specific structure.
  The structure is described by relationships between different elements.

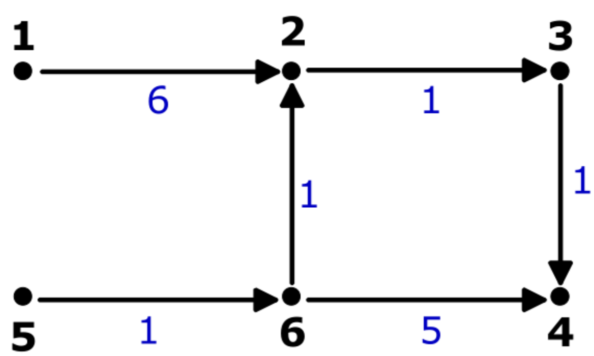


Unstructured data set **Sequence** **Tree** **General Tree**

- **Adjacency:** relation between node and node
  Incidence: relation between node and edge

- **Representation** of graphs: graphical, matrix, list

- **Distance matrix**



$$D = \begin{bmatrix} \infty & 6 & \infty & \infty & \infty & \infty \\ \infty & \infty & 1 & \infty & \infty & \infty \\ \infty & \infty & \infty & 1 & \infty & \infty \\ \infty & \infty & \infty & \infty & \infty & \infty \\ \infty & \infty & \infty & \infty & \infty & 1 \\ \infty & 1 & \infty & 5 & \infty & \infty \end{bmatrix}$$

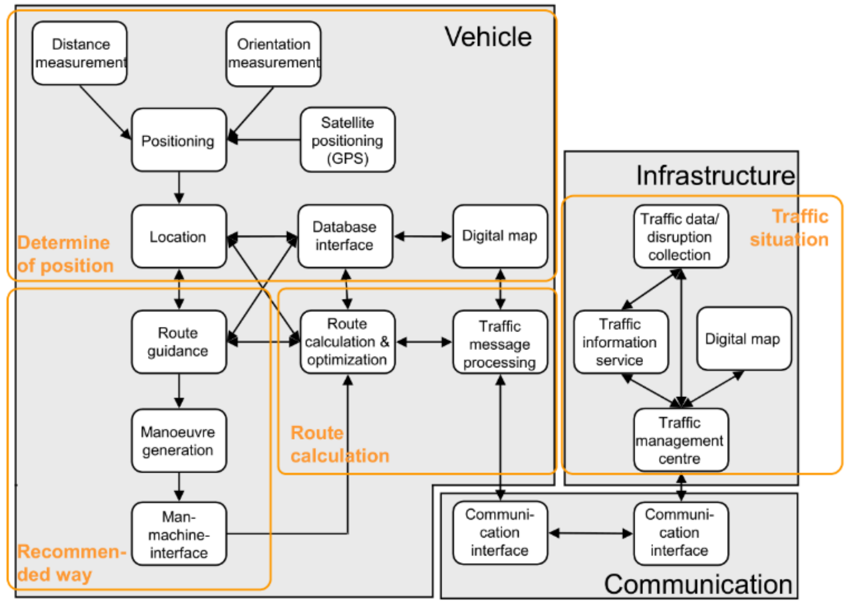
The search for the shortest path is always a search for the best node-edge sequence.

- **Shortest path algorithms**
  - ✓ Moore
  - ✓ Dijkstra

- **Tour planning**
  - ✓ Travelling salesman problem (TSP): connect several destinations using the shortest path forming a closed tour.
  - ✓ Solution:
    Nearest-Neighbor-Approach
    Christophides' algorithm: construction of a minimal-spanning tree via all points, minimum-matching for all nodes with uneven degree, find an Euler Path, create a Hamilton Path

2. Navigation systems

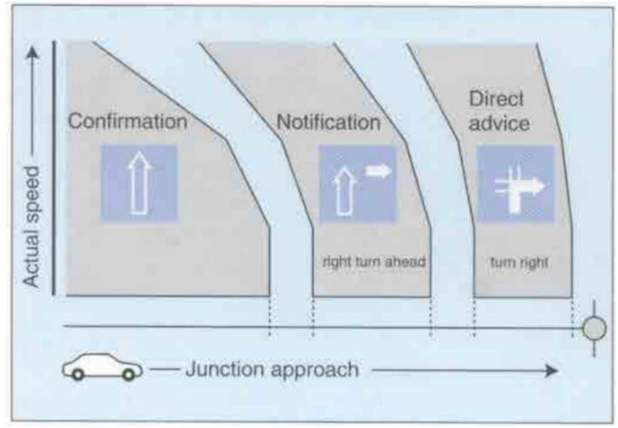
- Functional architecture of navigation system



- **Kinds of navigation systems**
  - ✓ Mobile systems
    - PDA, smartphones
    - GPS-based only (usually)
    - Map representation (some devices include TMC/RDS)
  - ✓ Radio-integrated systems
    - Integrated in the radio bay
    - GPS, TMC/RDS capable
    - Pictogram representation
  - ✓ Stand-alone systems
    - External monitor
    - GPS, gyro, odometer
    - Map representation

- **Examples**
  - ✓ ALI (Bosch – 1978)
    - Driver guidance and information system
    - Acquisition of traffic situation
    - Evaluation of traffic situation
    - Determination of recommended paths
  - ✓ EVA (Bosch – 1984)
    - Electronic traffic pilot
    - Dead reckoning and map matching
    - Accuracy 15 m
  - ✓ CITYPILOT (VDO 1985)
    - Dead reckoning to support the positioning
    - Input of destination via light pen and bar-coded city map using a grid
  - ✓ ALI-SCOUT (Bosch/Siemens – 1988)
    - Vehicle positioning using beacons and dead reckoning
  - ✓ TravelPilot (Blaupunkt/Bosch – 1994)
    - Guidance system including Route search and voice output
  - ✓ CARIN (Phillips/VDO – 1994)
    - Positioning combined with map-matching
    - Graphical output/display and voice output

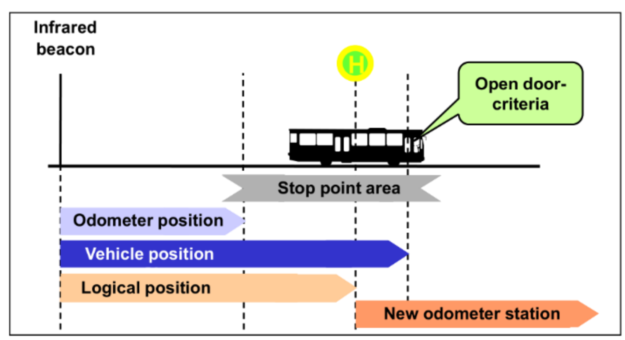
- **User Interface – Man Machine Interface (MMI)**
  - ✓ Tasks/Requirements
    - Menu-based handling
    - Input of several destinations
    - Calibration and service options
    - Graphical guidance
    - Acoustic guidance
    - Simple handling
    - No distractions for the driver → voice output



- **Database within navigation system**
  Maps on different levels of detail

Detailed map	All road segments and junctions
High level 3	Motorways Interstate roads Country roads
High level 2	Motorways Interstate roads
High level 1	Motorways
Land use maps	Map generation and representation (water, railroads)
Points of interest	Symbols + additional textual info

- **Localization for regional public transportation**
  Why?
  Operation/ Disposition
  Passenger information
  Protection/ Security

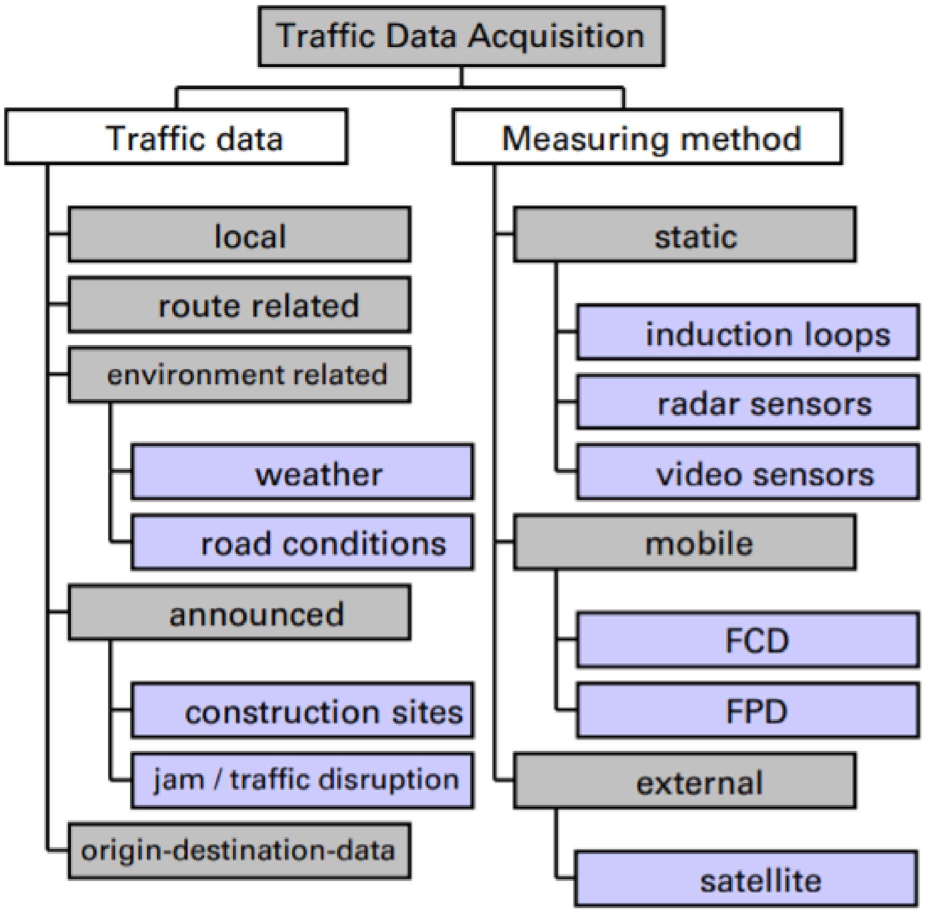


  - ✓ Logical localization (beacons)
    - Reliable but inflexible
    - Expensive: requires many devices along tracks
  - ✓ Localization by GPS
    - Independent from path, not 100% reliable
  - ✓ Localization using installed infrastructure
    - High installation costs – Expensive maintenance
    - Trains must keep largel distance to each other
    - Low comfort for passengers
  - ✓ Board-autonomous rail vehicle location
    - Determination of position by themselves
    - Position sent to central office →known position at any time
    - More flexibility regarding distance between trains
    - Better information of passengers about current traffic situation

10. Traffic data acquisition

1. Needs

- Information about traffic situation → basic data for traffic control
- Computation of route → By service center
- Dynamic routing → In vehicle
- Traffic prediction
- Refinement is necessary to generate traffic information
- Detection of parameters at discrete locations



2. Traffic parameters

- Presence/absence of car
- Traffic direction
- Velocity
- Vehicle class
  - Passenger car
  - Van
  - Bus
  - Motorbike, etc.
- Period of presence
- Time gap
- Traffic volume (traffic flow) [vehicles/h]
- Traffic density [vehicles/km]

3. Analysis of acquired data

- **Fundamental parameters:**
  - Traffic volume
  - Traffic density

  Spatial-temporal description of traffic situation

- traffic volume

$$\Phi(l) = \frac{n}{t}$$

- traffic density

$$\rho = \frac{\sum_{i=1}^{n} t_i}{t \cdot l}$$

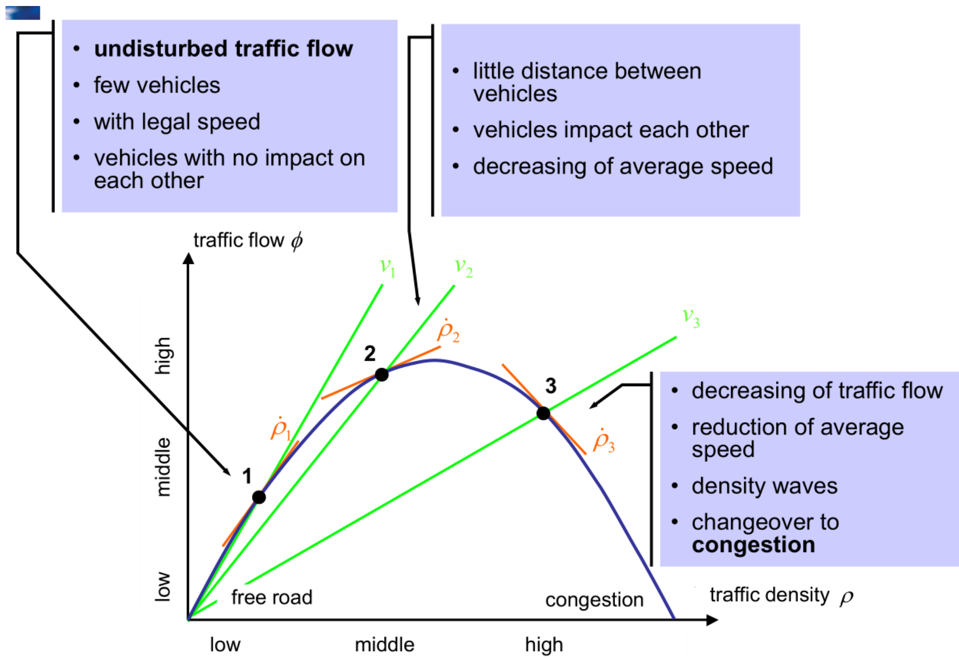
n: number of vehicle

t: given period

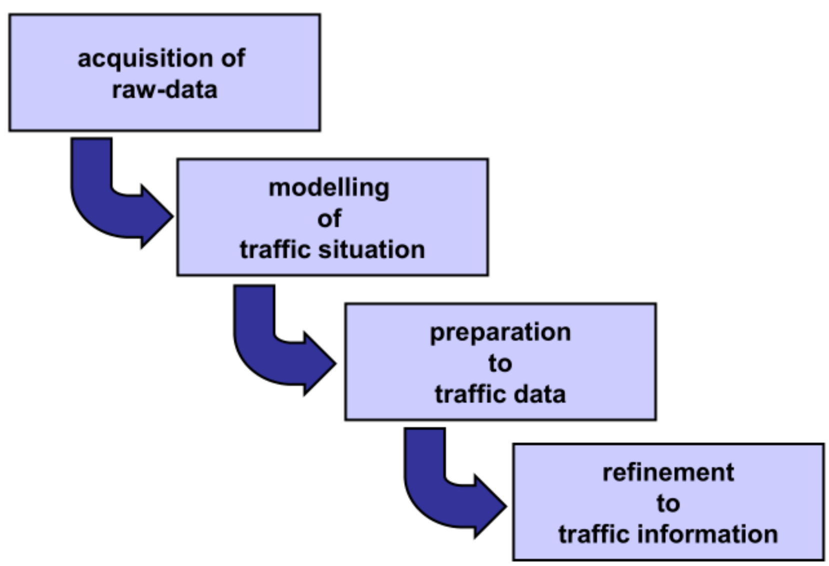
l: length of road section

t_i: time of travel of vehicle i

- **Fundamental chart**



- Sequence of traffic-data acquisition

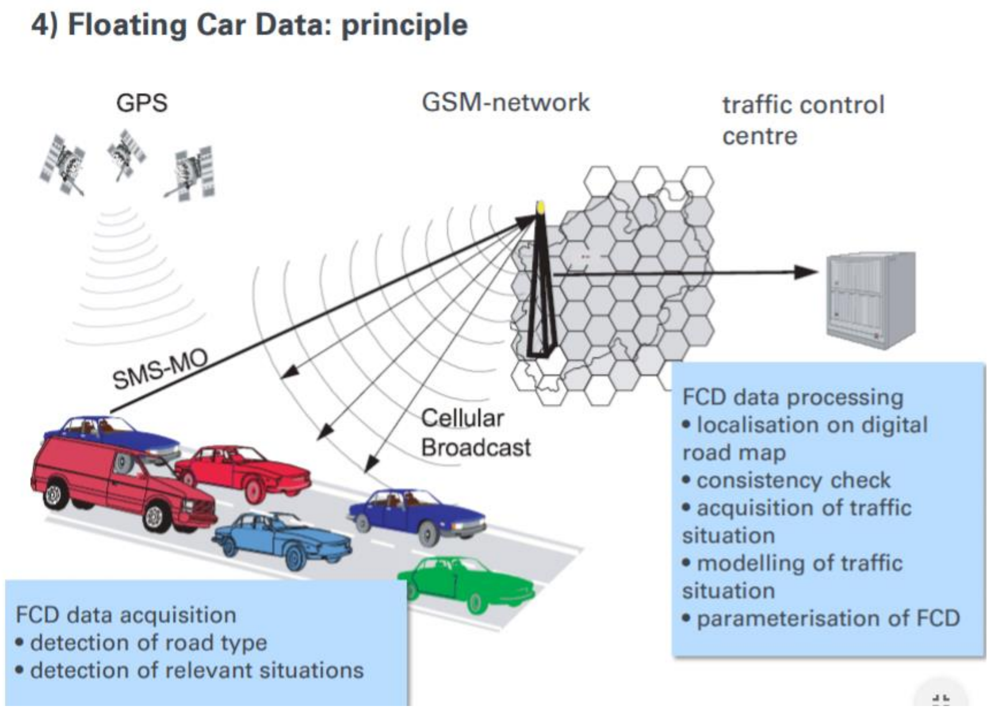


4. Acquisition methods

- **Methods**
  - ✓ Stationary acquisition methods
    - On fixed places along the route
    - Beacons, induction loops, video
  - ✓ Mobile acquisition methods
    - Monitoring of traffic situation with sensors mounted on vehicles
    - Floating car data (FCD)
    - Floating phone point (FPD)
  - ✓ External acquisition method
    - Monitoring of traffic situation out of an aircraft or satellite
- **Requirements on traffic information**
  - ✓ Updated info
  - ✓ Complete info
  - ✓ Full area coverage
  - ✓ Relevance
- **Requirements on control points**
  - ✓ High quality measurements
  - ✓ Profound information
  - ✓ Reproducibility
- **Stationary acquisition**
  - ✓ Manual traffic census
  - ✓ Automated
    - High installation and maintenance costs
    - High failure rate
    - **Induction loops**
      - Disturbance of magnetic field → measures absence/presence of vehicle
      - Can be used to measure driving direction, speed and classification of vehicles
      - Can be placed on traffic lights (10-30 m range) to register demands
  - ✓ Sensors on highways
    - Anonymous acquisition of velocity
    - Traffic flow at discrete positions: free flow – unstable flow -- congestion
    - Traffic detection → short message service SMS to central
    - **Radar sensor**
      - Used for velocity measures, seldom used for other traffic parameters
      - Principle: doppler frequency shift due to signal reflection on moving objects
    - **Passive infrared sensor**
      - Dimensioning of green phases and determination of deallocation periods
      - Principle: variations in temperature can be registered as variations in voltage
      - Only detects moving objects, insensible for snow and rain
      - Cheap and easy installation
    - **Other detectors**
      - Video detector
      - Supersonic detector
      - Beacon-based, etc.
      - Lidar: classification of vehicle along the road
      - Radar + microphone: noise, length, classification
      - Bluetooth Scanner → Journey time samples
      - Weight sensors
    - **Combined systems**
      - Video + Doppler radar + Infrared + Supersonic

- **Mobile acquisition**
  - ✓ Floating car data (FCD)
    - Monitoring of location, driving direction, speed
    - Equipped with positioning module
    - Incident-based communication via GSM-mobile network (anonymization)
    - Used by police
    - High accuracy and up-to-datedness

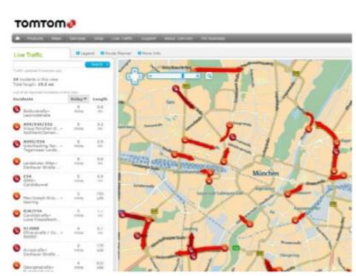
  Pro and contra:
    - High up-to-dateness
    - High position accuracy
    - Nontrivial analysis necessary to identify relevant events
    - Distinction between intended stops and congestions is nontrivial
    - Low penetration



  - ✓ Floating phone data (FPD)
    - Detect moving phones
    - Disregard moving phones on railways
    - Positioning of phones using triangulation
    - Derivation of traffic info
    - NO additional infrastructure needed
    - Position of less accuracy → lots of devices have to be tracked and evaluated
  - ✓ Google

Google acquired the movements of vehicles with Android smartphones or Android tablets inside.
→ Android devices have to enabled GPS, have to use Google Maps, have to show their location on Google Maps and forward this position data to Google

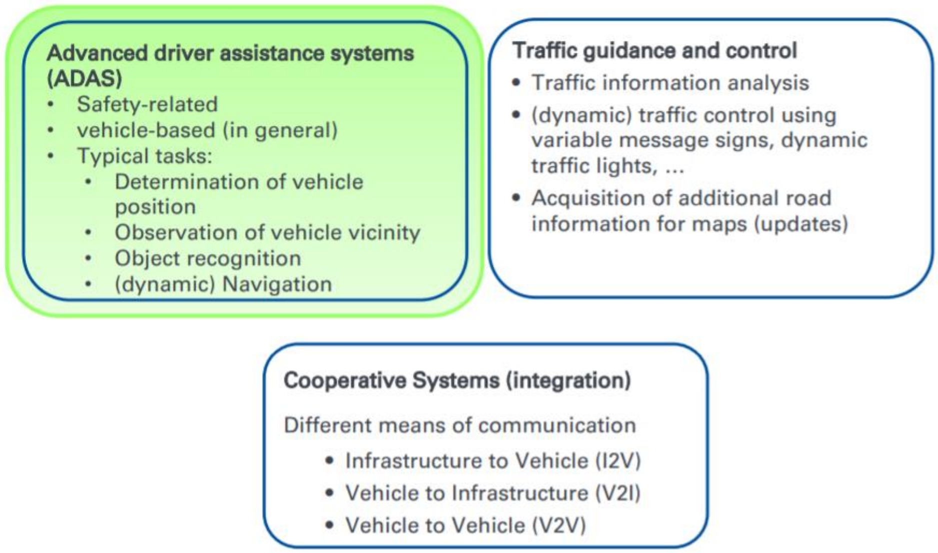
TomTom



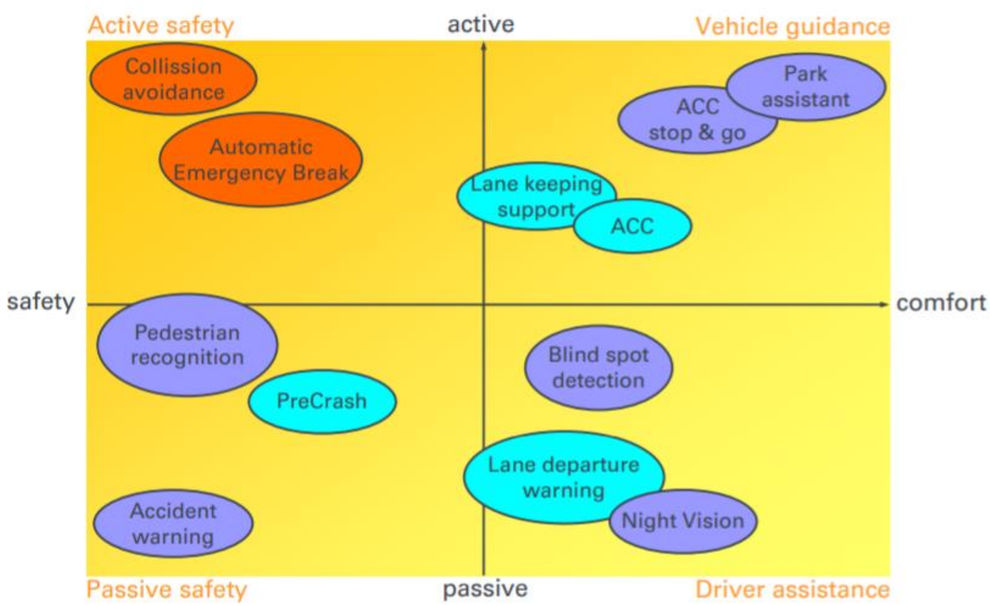
- Built-in data from vehicles with TomTom navigation devices and Connected live services
- TomTom apps from iPhone or Android smartphone send their real-time traffic data
- anonymous transaction data of smartphones that do not have the TomTom apps installed (mobile service provider, Vodafone here)
- Tracking data from vehicle fleets (Floating Car Data) TomTom and third-party
- In addition, information from road sensors and TMC Data of traffic clubs and the police

11. Applications of Transport Telematics

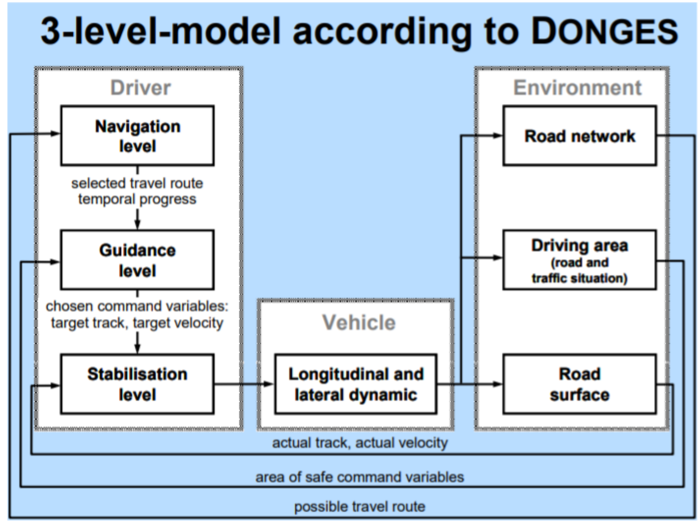
1. Advance driver assistance system (ADAS)

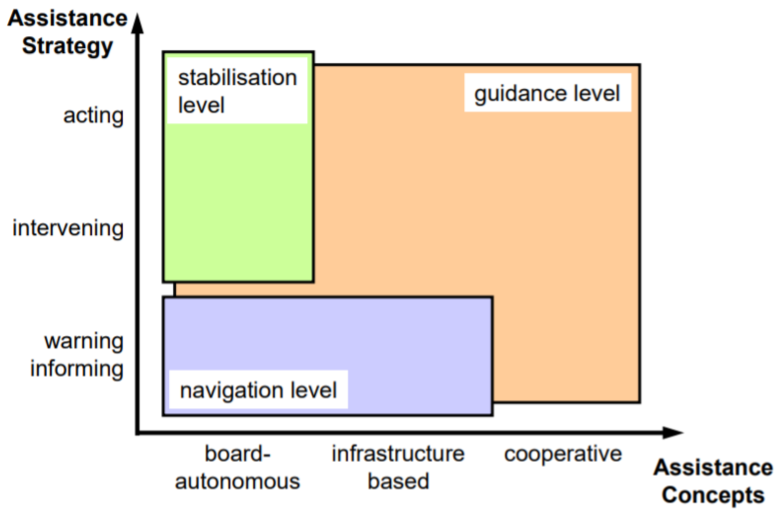


- **Classification of Driver Assistance System**



- ✓ Assistance Levels
  - Navigation level
  - Guidance level
  - Stabilization level
- ✓ Assistance Strategies
  - Informing and warning
  - Intervening
  - Acting
- ✓ Assistance Concepts
  - Board-autonomous
  - Infrastructure-based
  - Cooperative
- ✓ Conclusions



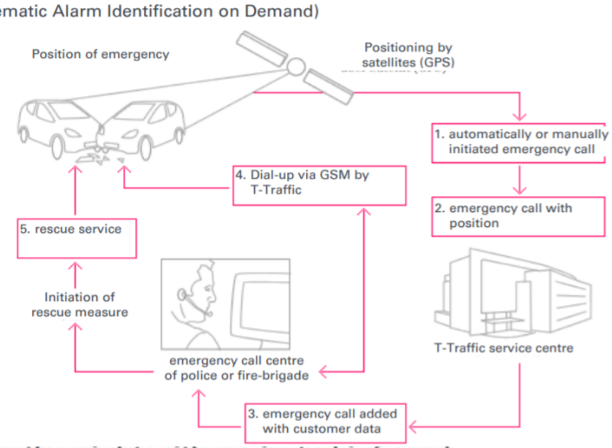


- **Adaptive Cruise Control**

  ➔ Active and predictive driver assistance system

  - ✓ Basic functionality:
    - No other vehicles ahead: normal cruise control mode
    - Following other vehicles ahead: adjustment control of relative vehicle velocity and distance
    - Automatic adaption in case of changing scenarios
- **Automatic Emergency Brake**
- **Forward Collision Warning (FCW)**
- **Emergency Call System**
- **Lane Departure Warning (LDW)**
- **Lane keeping support**
- **Curve Speed Warning (CSW)**
- **Blind-spot detection**
- **Parking Aid**
- **Adaptive Light Control**
- **Night Vision**

TELEAID (Mercedes Benz, T-Traffic)
(Telematic Alarm Identification on Demand)



- active system or near-IR system → illuminates the night with projected infrared light, much like optics found in military-issue night-vision goggles
- passive system → uses far-IR or FIR technology in its onboard night-vision systems

2. ROSATTE

- Road databases incl. safety attributes (e.g. traffic signs) are maintained by
  - Motorway Agencies
  - District offices
  - Cities and communes / boroughs
- No common data management at local authorities
  - Fully automated and digital
  - (semi) automated
  - Analogue (paper-based)
- The position / extend of the traffic sign is described as
  - Point information (locations of the traffic signs)
  - Linear features (linear extend of the traffic regulations)
- Location / linear extend of the safety attribute (speed limit) must be described in a way that European customers can interpret

  → **standardized data exchange format**

3. Exchange of georeferenced information

- Big variety of information to be exchanged
  - **Infrastructure to vehicle**
    - Map updates
    - Traffic information
    - Road safety feature updates
  - **Vehicle-to-vehicle**
    - Problems with own vehicle
    - Detected problems on the road
    - Information from other vehicles (hand-on)
  - **Vehicle-to-Infrastructure**
    - Accident information
    - Detected traffic jams
- All this information is referenced on **digital road maps**
- Each vehicle matches its position on the map (map matching)
- But there is no „one" road map; different maps of different suppliers are available
  - TomTom
  - HereMaps
  - OpenStreetMap
  - ...

  → Need for map-based but map-independent „Location Referencing"
- 2 realizations:
  - Pre-coded location references (e.g. TMC)
  - Dynamic location references (e.g. ISO 17572-3 [AGORA], OpenLR®)

4. Project examples: CVIS (cooperative vehicle-infrastructure system)

- Definition:
  - continuous and transparent communication between vehicles and infrastructure
  - to enable cooperative services in the vehicle and roadside equipment
  - to define an architecture and common core components for a number of cooperative system applications
- Expected CVIS results
  - a communication terminal using cellular, mobile Wi-Fi networks, infra-red or short-range microwave technology
  - an open architecture connecting in-vehicle and traffic management systems and telematics services at the roadside
  - techniques for enhanced vehicle positioning and the creation of local dynamic maps
  - Protocols to allow vehicles to share their data with other vehicles or infrastructure nearby
- Application
  - cooperative urban network management, cooperative area destination-based control, cooperative acceleration/deceleration and dynamic bus lanes;
  - enhanced driver awareness and cooperative traveler assistance on inter-urban highways;
  - commercial vehicle parking and loading zones booking and management, monitoring and guidance of hazardous goods and vehicle access control to sensitive areas.

5. Project examples: SAFESPOT

- **SAFESPOT aims to:**
- Use the infrastructure and the vehicles as sources and destinations of safety-related information
- develop an open, flexible and modular architecture and communication platform using ad-hoc dynamic networks, accurate relative localization and dynamic local traffic maps.

The SAFESPOT co-operative system is composed by the following communicating elements:

- Intelligent vehicles equipped with on board co-operative systems.
- Intelligent infrastructure including road side units
- Safety centre(s) and/or Traffic centre(s) that are able to centralize or forward safety information coming from the intelligent vehicle and/or the intelligent infrastructure.