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RELIABILITY THEORETICAL APPROACHES FOR ORGANIZATION OF RESOURCE-LIMITED INFRASTRUCTURE LOADS

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ABSTRACT: The management of mobile systems is essential for optimal management of transport systems to ensure even with the increasing complexity the transportation services in freight transport and passenger transport in terms mobility and safety of traffic flows.
Through the use of mobile devices as a source of traffic data today all the technical possibilities are available to control traffic chaos with the use of LBS and GIS technologies. Actually, it's all about avoiding the chaos from the start.
KEYWORDS: reliability, transport systems, management, mathematical modelling

INTRODUCTION

The current level of traffic telematics solutions brings the following problems that are to be solved:

- Through the active and unconditional use of navigation systems - i.e. the driver uses the navigation system and adheres strictly to its recommended route - a growing number of road users may get the effect that they use together with other road users the same bypass, creating a new traffic jam on this bypass route, especially if the navigation systems use the same or similar routing algorithms and use the same current traffic condition data
- At the current time existing traffic restrictions will be considered even if these on the optimal route, but are at a great distance from the current location are, and thus it is not certain whether this limitation is still present upon arrival of the vehicle,
- Traffic forecasting models, that consider future transport density on the optimum route or at sub-optimal alternative routes are still lacking, its use however promise to optimize traffic flows especially in overload situations,
- The stationary traffic control systems can indeed take with its dynamic signposting the current traffic situation into account and to bypass the traffic around the obstacles encountered, but does not allow individual route to a better utilization of several diversion alternatives
- To monitor the traffic condition traditionally stationary detectors are used: induction loops, video based or infrared technology. These systems are supplemented particularly in city traffic with floating car data systems, the use of the results from this point measurements for prediction of traffic on the road network are possible only with restrictions.

The management of mobile systems is essential for optimal management of transport systems to ensure even with the increasing complexity the transportation services in freight transport and passenger transport in terms mobility and safety of traffic flows [1], [2].

A task of transport telematics is to optimize the path that traffic objects or subjects of traffic through a transport network under given conditions and by setting an objective function. Starting point for such considerations can be the dynamic routing strategies of conventional telecommunications networks. Through the use of mobile devices as a source of traffic data today all the technical possibilities are available to control traffic chaos with the use of LBS and GIS technologies [1]. Actually, it's all about avoiding the chaos from the start.

To be able to solve the above problems the following theses will be set:

1. The target function for the optimization of traffic flow is to minimize the sum of the lives of travel time of all travel subjets rather than minimizing the travel time of an individual subject's movement, because it does not lead to a global minimum. The following relationship has to be used
$$\left(\sum_i T_{Tr_{i}\,i}\right) \rightarrow \min \neq \sum_i \left(T_{Tr_i} \rightarrow \min\right) \tag{1}$$
2. The routing decisions are made so that the travel time for traffic subject reached a local minimum and the network load is too large by the selected route. That means, that not already heavily loaded edges of the network traffic should be driven, even if this means that the travel time for a single subject will be longer.
3. The routing decisions for each transport subjects have to be taken with cooperation of a traffic control centre. An appropriate model for this was presented in [3].
4. For the organization of the transport process, the transportation network is divided in some intervals, the observed surface with a very large number of direct traffic sources (such as a household or a company with a number of vehicles) is divided in clusters, this is according to [4] based on postcode areas proposed and the streets are divided according to [3] in cells of the size of 100 meters. Furthermore, it is carried out according to the calculation of the rush hour for a time clock in 15-minute period.

❖ MATHEMATICAL MODEL. BASIC APPROACH

The starting point of mathematical modelling is the definition of process reliability $Z_{\Pi}(t)$ according to [1], which is split into the following reliabilities:

$Z_{Tr}(t)$ - Transport reliability

$Z_V(t)$ - Traffic reliability

$Z_{Sy\,\eta}(t)$ - System reliability of the operator,

$Z_{Sy_v}(t)$ - System reliability of transport vehicles and

$Z_{Sy_t}(t)$ - System reliability of transport routes (infrastructure reliability).

The transport reliability $Z_{Tr}(t)$ defined as the probability that a transport entity travels in time *t* from *i* to *j* can be characterized by the undisturbed transport process, the transport reliability $Z_V(t) = f(X_q(\tau, w_q), Z_{Tr}(t))$ is considered with the temporal and quantitative stochastic of the arrival process of traffic entities *X* in the traffic sources w_q, while the other components of the process reliability are accessible of the failure and recovery processes. The process reliability is calculated as
$$Z_{\Pi}(t) = Z_V(t) \cdot Z_{Sy_\eta}(t) \cdot Z_{Sy_v}(t) \cdot Z_{Sy_t}(t) \tag{2}$$
The following sections describe some fundamental approaches of the individual part reliabilities.

❖ MODELING OF SYSTEM RELIABILITY

The system reliability $Z_{Sy}(t)$ is according formula (2) will be distinguished as the equipment reliability - transport vehicle reliability - the operator reliability $Z_{Sy_\mu}(t)$ and infrastructure reliability $Z_{Sy_t}(t)$. Infrastructure reliability is influenced by the following events:

- ❖ Accidents
- ❖ Breakdown of vehicles
- ❖ Construction sites,
- ❖ Blocking of traffic lanes for any reason

The operating areas for modelling the infrastructure reliability can be characterized as follows:

- ❖ Nominal operation: all lanes are available to the currently available speed limit, which refers to the current state and the state it will be like when the subject travelling through this area, i.e. construction sites that are present with probability $Z_{Sy_t}(t) = 1$ be regarded as nominal operation)
- ❖ Downgraded operation: there are either fewer lanes available and / or the currently permitted maximum speed is temporarily limited, the probabilities should be calculated with the probability of these speeds. Because of the given range of speeds only various speed limits are considered.
- ❖ Collapse: there is no lane by accident, breakdown, weather, etc. available

For accident-related restrictions stationary models can not be used because the probability is of interest to a restriction at the time when the subject's moving in that cluster. One issue is for example "How likely is in the cluster *i* at time *t* a traffic jam if at time *t = 0* their was no traffic jam or if at time *t = 0* there was a traffic jam."

The infrastructure reliability can be calculated analytically with transient reliability models. The procedure is demonstrated in the following simplified example. There is a lane with the following speed limit areas:

- Free traffic = State $z_{\kappa=0} = z_{Sy}^{[nenn]}$ = Nominal Operation
- Limited Traffic = State $z_{\kappa=1} = z_{Sy}^{[stör]}$ = Downgraded operation
- Stationary traffic (v = 0), i.e. blocking of lane = State $z_{\kappa=2} = z^{[koll]}$ = Collapse

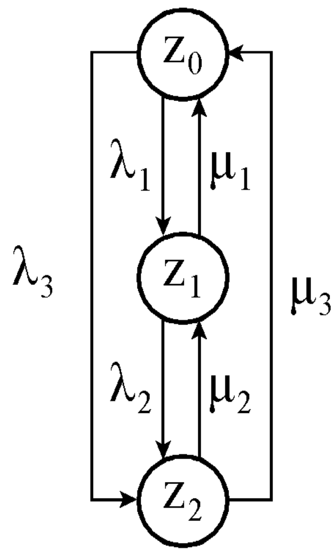

Figure1.: System reliability for a cell of a single track road

The following figure represents the system reliability (Fig.1). The mathematical model for a cell of a single-lane road has been described by [3] closer. In the second approximation is the route, i.e. the first edge e_{ij}, regardless of the real net structure in $\hat{\xi}$ into equal-sized cells divided. In calculating the system reliability of a cell $z_{Sy_{t_\xi}}^{[\kappa]}(\tilde{x},\tilde{t})$, the failure rate λ_ξ refers to this area. The parameter $\tilde{x}$ characterizes the (discrete) place and $\tilde{t}$ the discrete time when the vehicle is in (the centre) of the cell. A vehicle must go through all the cells $\xi \in [1,\hat{\xi}]$ of the edge. In reliability-theoretic sense, this can be modelled by a series circuit. To calculate the non-stationary reliability $z_{Sy_{t_\xi}}^{[\kappa]}(\tilde{x},\tilde{t})$ the system state of all cells $z_{Sy_{t_\xi}}^{[\kappa]}(\tilde{x},0)$ at the time $\tilde{t}=0$ will be determined. The variation of time in the calculation is performed in discrete steps determined by the width of a cell Δx and the average velocity $v_m(\rho_m)$. Density-dependent fluctuations should not be considered first. For the nominal operation:

$$z_{Sy_t}^{[nenn]}(\xi) = \prod_{\xi=1}^{\hat{\xi}} z_{Sy_{t_\xi}}^{[nenn]}\left(\xi\cdot\Delta x, \frac{\xi\cdot\Delta x}{v_m(\rho_m)}\right)\Big|_{z_{Sy_{t_\xi}}^{[\kappa]}(\xi\cdot\Delta x,\,0)} \quad \kappa \in [nenn \vee stör \vee koll] \tag{3}$$

This is the probability that all cells are passed in nominal operation, under the condition of the current operating range k, $k \in [1,\hat{\xi}]$ at time t = 0 (starting time) of each cell $\xi \in [1,\hat{\xi}]$.

For downgraded operation:

$$z_{Sy_t}^{[stör]}(\xi) = \prod_{\xi=1}^{\hat{\xi}} z_{Sy_{t_\xi}}^{[stör]}\left(\xi\cdot\Delta x, \frac{\xi\cdot\Delta x}{v_m(\rho_m)}\right)\Big|_{z_{Sy_{t_\xi}}^{[\kappa]}(\xi\cdot\Delta x,\,0)} \quad \kappa \in [nenn \vee stör \vee koll]$$

This is the probability that all cells are passed in downgraded operation, under the condition of the current operating range k, $k \in [1,\hat{\xi}]$ at time t = 0 (starting time) of each cell $\xi \in [1,\hat{\xi}]$. For simplification a valid speed must be defined for all cells.

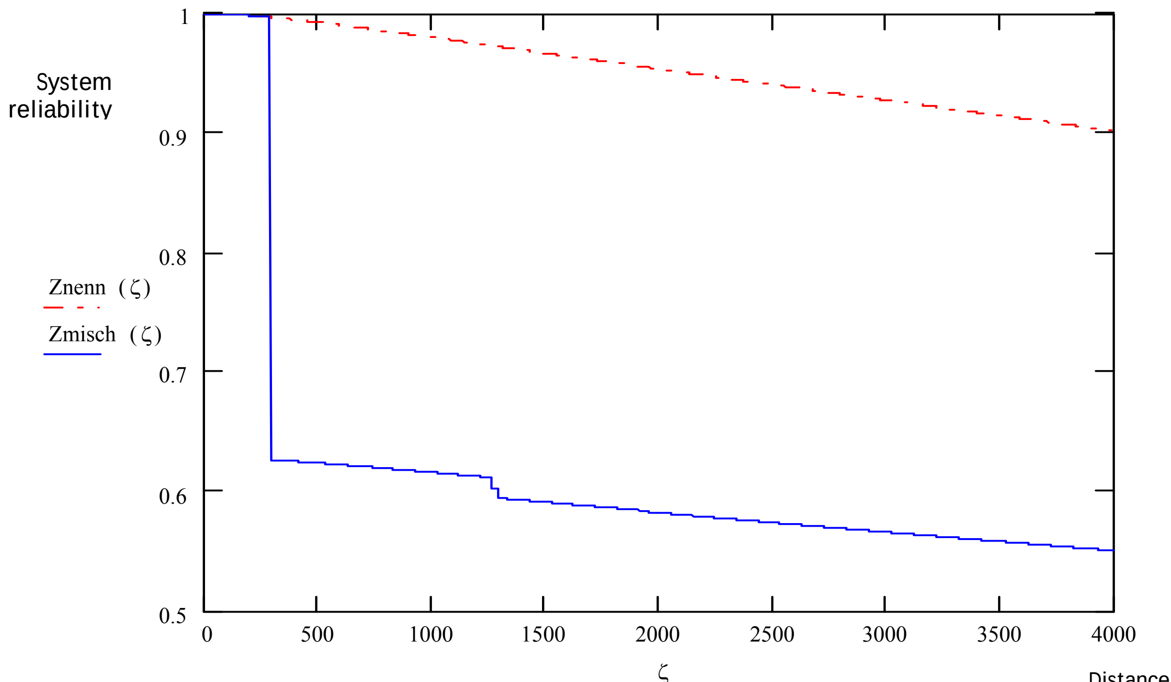

Figure 2.: System reliability - different initial states

The calculation of the probability that all cells are passed in collapse state makes no sense and leads to no useful result. An example calculation indicates that (Fig.2).

For the red curve, all cells are in the initial state in the nominal operating range, the blue curves are two cells in the initial state not in nominal operation. This can be clearly seen at the two jumps, the impact on the overall reliability decreases with distance.

The consideration of equipment reliability $Z_{Sy_v}(t)$ here the reliability of transport vehicle should be for example the charging the battery of an electric car. As a model, the maintenance theory of planned preventive maintenance to age-related cycle (period t_p) can be used to complete repairs by interference (time t_s) [5]. Preventive maintenance is the scheduled charging of the battery or the exchange of the battery. Disruption maintenance is regarded as the stopping of the vehicle when the battery is depleted. The maximum availability is

$$V_{Sy}^{[nenn]}(\tau_0) = \frac{1}{1+\lambda(\tau_0)(t_s - t_p)} \tag{5}$$

The operator reliability, i.e. the probability of the driver's failure during the time t is neglected.

❖ MODELING OF TRANSPORT RELIABILITY

Due to the complexity of the transport process for its modeling a multi-stage calculation method is used to the abundance of the factors considered separately. First, the transport reliability is calculated independently of the arrival process.

The transport reliability is the distribution function of the transport time T_{Tr} without consideration of the influence of traffic density, i.e. it is considered the speed of free traffic v_f . This is dependent on many factors, e.g.

- Legally fixed limits,
- Road conditions
- Traffic conditions
- use of the utility weight,
- Specific drive performance,
- Behaviour of drivers.

The transport reliability is calculated for each cell of the transport network in time interval. In [6] for modelling the transport time, normal distribution was used. Using a deterministic transport path by forming a function of stochastic variables according to Richter [7] to estimate the distribution function of the duration of transport can be achieved. It is

$$T_{Tr} \in N\left(\frac{s}{\mu_v}, \frac{\sigma_v^2 s^2}{\mu_v^4}\right) \tag{6}$$

This distribution function corresponds to the transport reliability $Z_{Tr}(t)$. For the assessment of reliability of traffic is $\rho(\Delta\xi, \Delta\tau)$ used. From the density of traffic, the transport speed is through an approach of Kuehne [8] calculated.

$$v(\rho) = v_f\left[1 - \left(\frac{\rho}{\hat{\rho}}\right)^a\right]^b \tag{7}$$

The transport rate is a function of:

- Road-specific empirical parameters a and b,
- Assignment of the road (traffic density) ρ
- Maximum occupancy of the road $\hat{\rho}$ and
- The speed of free traffic v_f .

Reliability for the traffic is according to [3]:

$$Z_V(t) = \frac{v(\rho(\Delta\xi, \Delta\tau))}{v(0)} = \frac{v(\rho(\Delta\xi, \Delta\tau))}{v_f} = \left[1 - \left(\frac{\rho(\Delta\xi, \Delta\tau)}{\hat{\rho}(\Delta\xi)}\right)^a\right]^b \tag{8}$$

This shows that the speed of free traffic has no effect on the ability to reliability. It is calculated from the ratio of the current to maximum traffic density of the route part (cell). With the help of macroscopic traffic models [8] the variation of traffic density and traffic speed can be - for a limited time horizon - calculated and numerically the time of transport can also be determined. One approach was presented in [3].

In this calculation the composition of the traffic density from the individual relationships $\rho(w_q, w_s)$ between the traffic source and traffic destination does not matter, however these factors should be considered now. Here the following question emerges:

- How many traffic subjets will be on the individual sections of the route, if that section is passed? Or to put it mathematically, the traffic density $\rho(\Delta\tau, \Delta\xi[\psi(w_q, w_s)])$ is sought.

To calculate this traffic, the following parameters could be used:

- Matrix of the traffic density from measured data of the past $\vec{P}(\Delta\tau)$
- Matrix of the objective factors from measured or estimated data of the past $\vec{F}(\Delta\tau)$
- Swelling of the subjects $X_{inp}(w_q(\Delta\tau))$ in the individual road traffic clusters, this data can be measured or estimated by different methods and data acquisition systems (Figure 3).

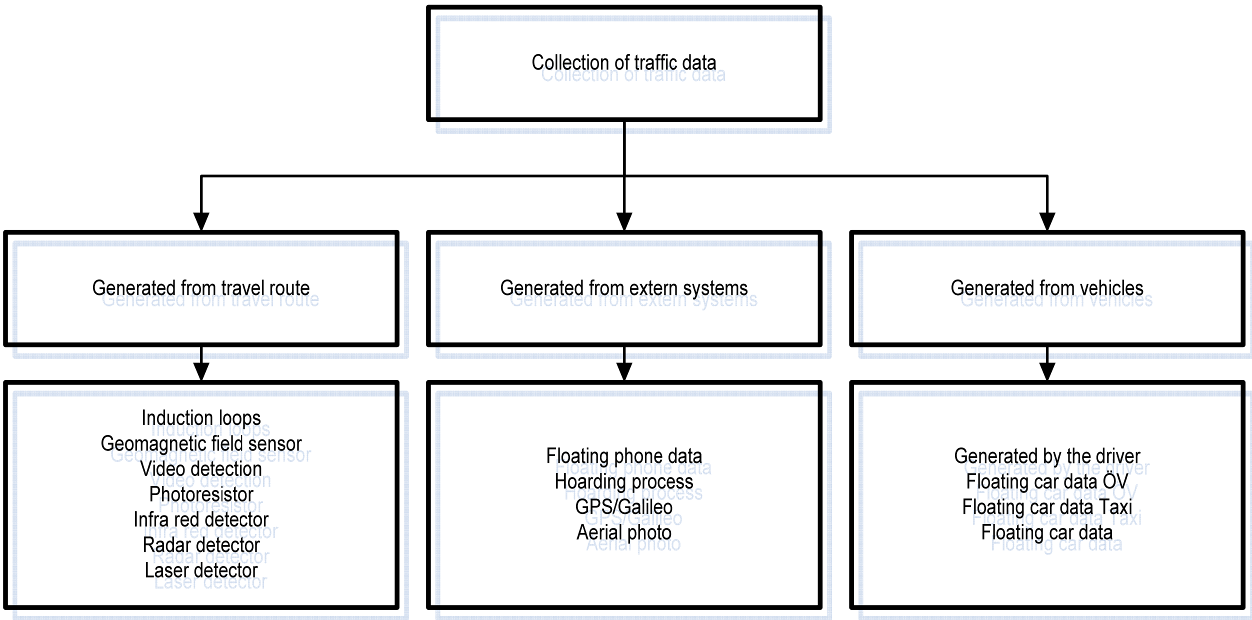

Figure 3.: Classification of traffic data collection

The data acquisition systems are usually suitable for recording the traffic density and speed. Traffic flows can be determined by a number of systems at the time of acquisition, but difficult is the detection of the target cluster w_s of all traffic entities at the time of acquisition. Suitable for this purpose are for example navigation systems with a communication session from the vehicle to a control centre. To estimate the density of traffic in the future forecasting models of the transport planning can also be used.

❖ CONCLUSION

If an edge or a node of the network is detected as a critical spot for trouble-free transaction processing in the whole network, so can this fit into a management model. Here, the inflow will be measured, directions of traffic selected, loads for a specific point forecasted, and constrained by the available capacity inflows to this point limited or amended by another traffic control. The detection of an overload condition of an associated site infrastructure at a future date allows an activation of defensive strategies by

- ❖ Inflow reduction,
- ❖ Alternative routing under time restrictions,
- ❖ Temporal effect as speed limits in the form of maximum or minimum speed etc.

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