

Traffic State Detection with Floating Car Data in Road Networks

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Abstract—A method for a reporting behavior at optimal costs of single vehicles (FCD: Floating Car Data) in road networks with the aim of a high quality of traffic state recognition is presented. It is shown that based on minimum two FCD messages the substantial information of a typical traffic incident in a traffic center can be recognized. The two relevant periods of such an obstruction of traffic in road networks are the periods, in which either a travel time increase takes place due to congestion emergence or a travel time decrease because of congestion dissolution. A statistic analysis already shows the high quality of the reconstruction of the actual travel times in the net with 1.5% equipped FCD vehicles and a reduction of the FCD message sending of the vehicles by suppression of redundant incident information. Incidents with at least 20 min duration can be recognized with a probability of 65% with an penetration rate of 1.5% FCD vehicles within the whole amount of vehicles, whereby the FCD vehicles send only in each incident case two messages per event.

I. INTRODUCTION

Vehicle traffic is a very complex dynamic process in which diverse spatiotemporal congested traffic patterns are observed (see e.g., references in the recent book [1]). Recognition of traffic congestion is important for vehicle navigation, traffic control and management, as well as for many other intelligent transport systems in traffic. One of the efficient methods for congested traffic pattern recognition is the method of floating car data (FCD) (e.g., [1-15]). In this method, a FCD vehicle measures a travel time on a traffic network segment and sends it to a traffic center. The traffic center collects all travel times that different FCD vehicles have sent and uses this information for traffic pattern recognition.

There is a multiplicity of different methods for the production, processing and messaging of vehicle data (FCD), by which some were developed also up until the introduction to the market. In [2-15], for example technical solutions are suggested, which regard many aspects of a FCD process from the FCD vehicle behavior, FCD algorithms and aspects of communication up to a FCD traffic center. One of the problems for a higher market penetration of FCD are the high costs of FCD application because of the quantity of redundant messages: the same information about travel times

on congested network segments is sent by several FCD vehicles to the traffic center. Another problem is that one needs a relative high percentage of FCD vehicles, in order to have the possibility of a reliable reconstruction of the actual travel times on road segments in transportation networks.

During a FCD process, a FCD vehicle measures the travel time on a traffic network segment “k”. For example, in a city network with light signals the FCD vehicle moves through a road segment with a vehicle queue at the light signal (Fig. 1). In this case, the vehicle travel time $R_k^{(v)}$ is the difference between the time t_{in} when the vehicle enters the segment and the time t_{out} when the vehicle leaves the queue (Fig. 1).

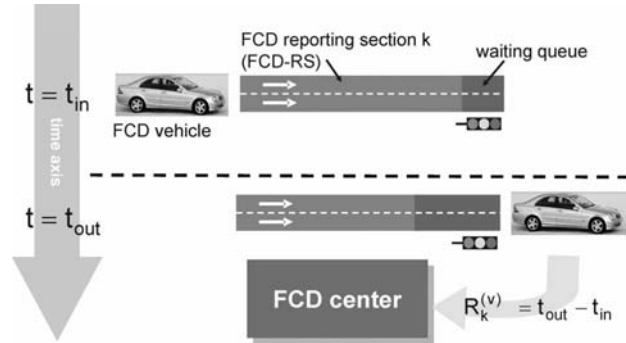


Fig. 1. Sketch of the standard FCD process [2-15]

After the FCD vehicle has left the segment, the vehicle makes the decision whether this travel time should be sent to the traffic center (Figs. 1 and 2). This decision is based on available information about the earlier travel time on this road segment $R_k^{(c)}$ already stored in the vehicle and on the measured current travel time $R_k^{(v)}$. If the difference between $R_k^{(v)}$ and $R_k^{(c)}$ is greater than a threshold $\Delta R_k^{(c)}$, specifically if [11]

$$|R_k^{(v)} - R_k^{(c)}| > \Delta R_k^{(c)}, \quad (1)$$

then the travel time $R_k^{(v)}$ is sent to the traffic center. The values $R_k^{(c)}$ and $\Delta R_k^{(c)}$ in (1) are sent to the FCD vehicle by the traffic center. This can be done over broadcast communication (Fig. 2) [11].

Travel times received from all FCD vehicles are used in the traffic center to produce a travel time set related to the network. In particular, on the basis of the measured travel

Manuscript received December 16, 2004.

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time $R_k^{(v)}$ the traffic center decides whether there is a travel time increase or decrease on the road segment. The two periods of the emergence or dissolution of the related traffic congestion are those, within the travel time strongly increase and/or decrease.

The traffic center can send the travel time set for application in all vehicles moving in the traffic network. These travel times can be used for dynamic vehicle navigation. Further concepts for such communication design of a vehicle and a service center are described for example in [2, 4, 5, 9-11], also with the purpose of a message optimization by the backward channel [9, 11].

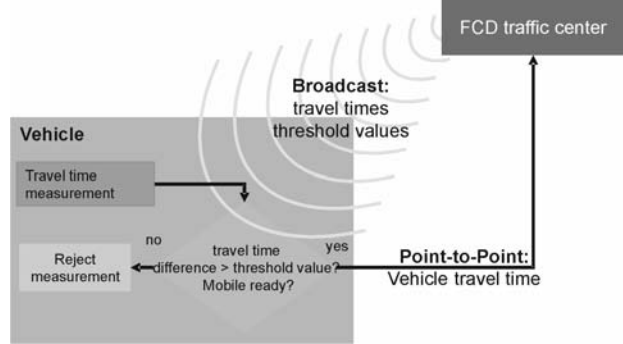


Fig. 2. Overview of the FCD process with broadcast and communication of point to point between vehicle and traffic center (e.g., [11])

The principal purpose of the FCD method represented in this article is a strong reduction of the amount of FCD messages with a small percentage of FCD vehicles. In addition, the method should nevertheless permit to obtain a high quality reconstruction of current travel times in the net. The study on basis of a microscopic traffic net simulation [1, 16, 17] includes a statistic analysis and modeling of the FCD process, requirements to the FCD software modules and to the traffic center as well as aspects of communication. The FCD method suppresses the irrelevant information to a low level of FCD costs and requires a shift of FCD travel times and its interpolation in the traffic center [18, 19]. In this paper first the FCD method with a processing in the traffic center is presented, before the measurement time intervals relevant for this method are described exactly. The results of a statistic analysis and some aspects of the entire FCD process such as characteristics of the FCD center and communication questions complete the paper.

II. FCD METHOD FOR TRAFFIC NETWORKS

A FCD method presented in this article is developed with the goal of the further cost minimizing of FCD communication with accompanying high quality of the traffic reconstruction [18, 19]. In this method, the traffic center makes a prediction for travel times, which is based on the

travel times $R_k^{(v)}$ received from FCD vehicles. The related predicted travel times $R_k^{(c)}$, $k=1, \dots$ are functions of the travel times measured by the FCD vehicles $R_k^{(v)}$, $k=1, \dots$, i.e., $R_k^{(c)} = f_p(R_k^{(v)})$. The predicted travel times $R_k^{(c)}$, $k=1, \dots$ are broadcasted afterwards to all vehicles as current travel times for the related traffic network segments (Fig. 3 and Fig. 4).

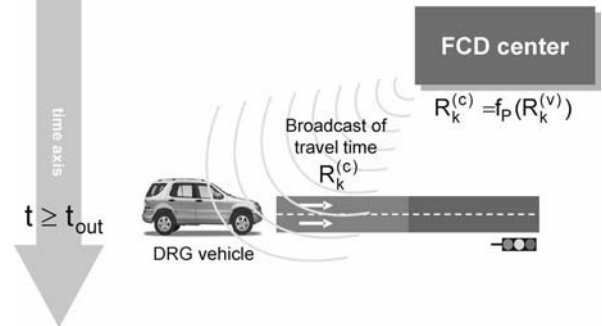


Fig. 3. Computation of predicted travel times in the traffic center and their broadcast communication.

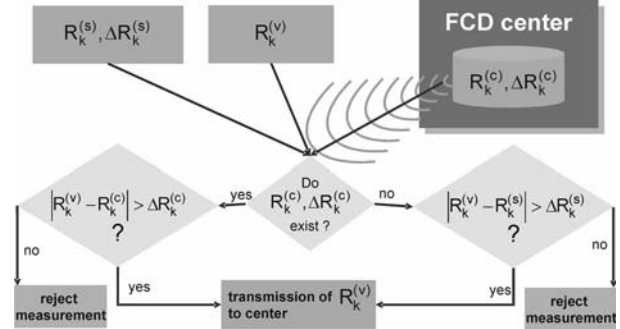


Fig. 4. Processing of the predicted travel times $R_k^{(c)}$ and threshold values $\Delta R_k^{(c)}$ in the FCD vehicles.

For the explanation of the necessity for calculation of the predicted travel times in the traffic center the congestion time periods relevant for a FCD process should be analyzed. Firstly, it must be taken into account that the entire period of traffic congestion can be marked by three intervals:

- (i) a travel time increase due to congestion emergence,
- (ii) a high travel time during congestion and
- (iii) a travel time decrease during congestion dissolution

(Fig. 5).

For a dynamic route guidance the periods of congestion emergence and dissolution are relevant, which are connected with an increase and a decrease in the travel time (light grey intervals in Fig. 5). The relevance of these periods is given thereby because in these periods the change in recommendations regarding the route choice should take place. The quality of a dynamic route guidance service is therefore dependent on the actuality and preciseness of the detection of the travel time increase/decrease on a road section.

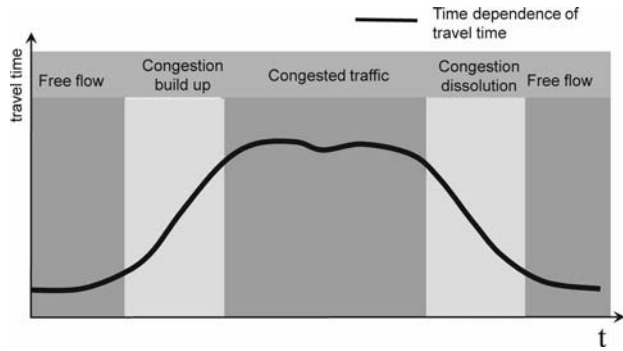


Fig. 5. Qualitative time dependence of the travel time on a road section in the network in case of a typical traffic incident. Light grey: relevant time intervals in the travel time of a road section (“congestion build-up” and “congestion dissolution”), which should be announced by FCD vehicles.

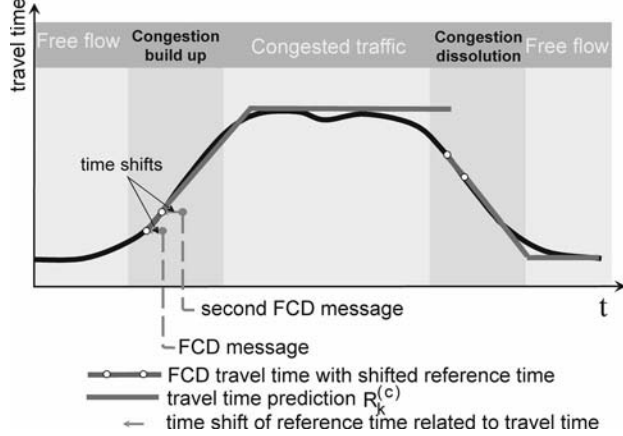


Fig. 6. Method for the recognition of the traffic incident with FCD vehicles: time shift of the reference time associated with the FCD travel time in the traffic center and interpolation of temporal development for a prediction of travel time development.

The FCD method for incident detection presented is as follows:

(i) If congestion build-up and/or congestion dissolution is recognized in a network section k , the traffic center shifts the reference time t associated with the FCD travel time $R_k^{(v)}(t)$ to the past time. This shift δt of the reference time associated with the travel time is equal to $R_k^{(v)}$ (Fig. 6):

$$R_k^{(c)}(t - \delta t) = R_k^{(v)}(t), \quad \delta t = R_k^{(v)}. \quad (2)$$

This shift is necessary because the travel time $R_k^{(v)}$ received from the FCD vehicle is related to the time t when the FCD vehicle has already passed the section k . In contrast, the travel time $R_k^{(c)}$ (2) is approximately associated with the past time $t - R_k^{(v)}$ when the vehicle was at the beginning of the section k . This can be clear in the following example: the vehicle needs 15 min for passing a section k and sends this at the time 10:45h to the center, which shifts this FCD travel

time of 15 min to the reference time of 10:30h in the center and uses this further as $R_k^{(c)}$.

(ii) After the time shifting (2) has been made, the traffic center accomplishes a temporal interpolation of the travel time $R_k^{(c)}$ for the future time. This permits one to calculate a prediction of the temporal development of traffic congestion (Fig. 7).

(iii) Based on this prognosis of the travel time the traffic center calculates a predicted travel time $R_k^{(c)}$ as a function of time for the network road section k (Fig. 3).

(iv) The traffic center sends the predicted travel time $R_k^{(c)}$ associated with the current time to all vehicles moving in the network by broadcast communication, as if it would be a new current travel time (Fig. 4). In addition, the traffic center dispatches reporting threshold $\Delta R_k^{(c)}$.

(v) This “current” travel time $R_k^{(c)}$ is used in FCD vehicles for a decision over sending new measured travel times for this section k . That means, if further FCD vehicles come into the same congestion section k , these vehicles will not any longer send their travel times (“reject” in Fig. 4), if the travel time difference is smaller than the reporting threshold, i.e., $|R_k^{(v)} - R_k^{(c)}| < \Delta R_k^{(c)}$.

(vi) If there are no travel times $R_k^{(c)}$ and thresholds $\Delta R_k^{(c)}$ sent by the traffic center for some sections of the network, FCD vehicles use travel times $R_k^{(s)}$ and threshold values $\Delta R_k^{(s)}$ stored in the vehicles (Fig. 4). However, the values $R_k^{(c)}, \Delta R_k^{(c)}$ from broadcast communication have priority against the stored values $R_k^{(s)}, \Delta R_k^{(s)}$.

The treatment of the FCD travel times in the traffic center, i.e., the choice of the function $R_k^{(c)} = f_p(R_k^{(v)})$, is crucial for the success of the method. After the receipt of the FCD travel time $R_k^{(v)}$ a broadcast of the predicted travel time $R_k^{(c)}$ should take place via the center with as small as possible delay. The predicted travel times can be used in all vehicles with dynamic route guidance (DRG) (Fig. 3).

The interpolation and the associated travel time prognosis $R_k^{(c)}$ are accomplished for both time intervals of congestion built-up and congestion dissolution (Fig. 6). Using historical data about congestion emergence and dissolution on the section, these time intervals could be determined with knowledge of the upward and downward gradients of the travel time with only one FCD message in each of the intervals. However, for a more precise determination of each of these time intervals the travel time interpolation should be made based on travel times measured by two FCD vehicles (Fig. 6). These two FCD travel times can be related to

shorter time intervals than time intervals of congestion emergence and congestion dissolution (Fig. 7).

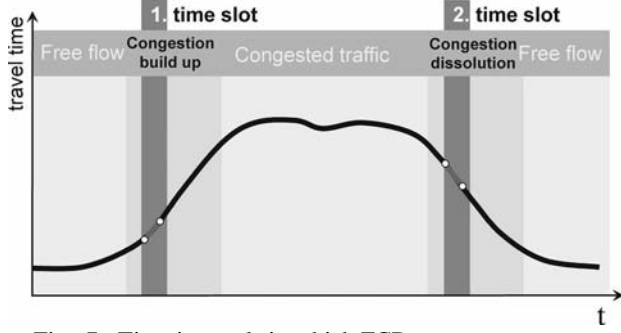


Fig. 7. Time intervals in which FCD messages are sent.

III. STATISTIC ANALYSIS OF THE FCD METHOD

Let us consider an example of two alternative routes in a traffic network (Fig. 8). In free flow, the average travel time on the main route is about 6 min and on the alternative route is about 10 min (Fig. 8).

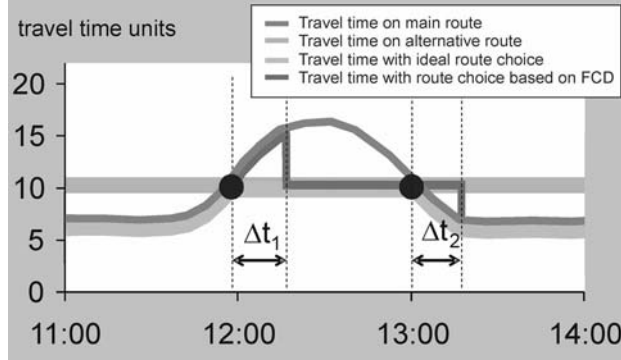


Fig. 8. Time delays and a FCD based route guidance in the comparison with ideal dynamic route guidance.

During congestion emergence on the main route the travel time increases, then it remains on a high level during congestion and finally it reduces during congestion dissolution. Thus, the quickest route changes to the alternative route at about 12:00 and back to the main route at about 13:00 (black points in Fig. 8): between 12:00 and 13:00 the travel time on the main route exceeds those on the alternative route. This route change would be related to some ideal dynamic route guidance. However, because FCD vehicles send travel times after they passed the related network section, there are always time delays Δt_1 , Δt_2 for the real dynamic route guidance ("dark grey") based on FCD travel times.

The FCD method has the goal of minimizing the time delays Δt_1 and Δt_2 (Fig. 8) at the same low percentages of FCD vehicles. To estimate Δt_1 and Δt_2 , a statistic analysis of the FCD method (Figs. 9 and 10) has been made, which is based on a numeric simulation with a model for city networks UTA (Urban Traffic Analysis) [1, 16, 17]. For

simulation results it is assumed that the FCD vehicles send correct and valid travel times. The results are a kind of best-case simulation for an FCD process.

Duration and variance of times with incorrect routing advice (Δt_1 and Δt_2) in comparison with optimal situation of dynamic route guidance (DRG) for 2/3 or 1/3 active DRG systems in FCD vehicles for 200 simulation realisations

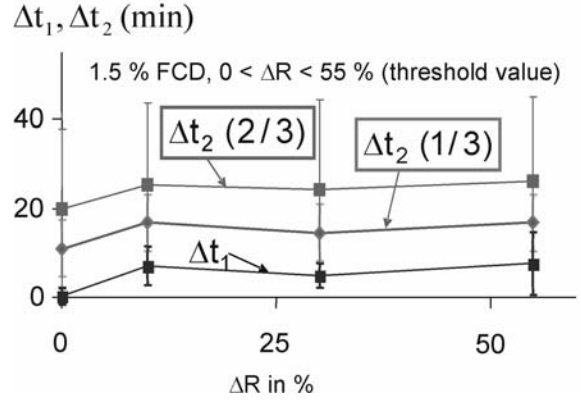


Fig. 9. Errors Δt_1 and Δt_2 (Fig. 8) as a function of the threshold for FCD message generation $\Delta R = \Delta R_k^{(c)} / R_k^{(c)}$ and different portions of activated route guidance in FCD vehicles.

The statistic analysis estimates errors, i.e., the mean time delays Δt_1 and Δt_2 in the real route choice in comparison with ideal route choice. The statistical analysis of 200 simulation realizations shows that at 1.5 % of FCD vehicles the mean time delays Δt_1 and Δt_2 are almost independent of the threshold for FCD message generation (Fig. 9). The simulation includes a stochastic FCD process: 1.5 % FCD vehicles mean the average percentage of the total vehicle flow on a section in a stochastic FCD simulation. It has been found that with one third FCD vehicles with active DRG the time delay Δt_2 is about 15 minutes, whereas with two thirds FCD vehicles with active DRG Δt_2 is about 25 minutes.

The error Δt_1 is about 5 minutes for these both cases. The difference in the error Δt_2 can be explained as follows. The FCD vehicles with active DRG can avoid congested sections. When there are one thirds FCD vehicles with active DRG, then 1.0 % of the vehicles with FCD-device will drive on the congested sections (there are 1.5 % FCD vehicles in these simulations, Fig. 9). However, when there are two thirds FCD vehicles with active DRG, then only 0.5 % of the vehicles with FCD-device will drive on the congested sections. As a result, the error in the recognition of the time of congestion dissolution the greater is, the more FCD

vehicles use active DRG.

Simulations in which duration of congestion recognized by FCD vehicles as a function of the FCD vehicle percentage that have been studied show that 1.5% FCD vehicles (two thirds FCD vehicles with active DRG) can recognize congestion with 20 min duration with 65 % probability (Fig. 10). Thus, a route guidance service is well possible with 1.5% FCD penetration rate (a 4-min update interval of the traffic center has been chosen in simulations). This statement is supported by the empirical fact that typical congestions relevant for dynamic route guidance are lasting longer than 30 min. Therefore, a recognition probability of 65% or 85 % with 1.5-2% FCD vehicles for 20-30 min of congestion is in the right order of magnitude.

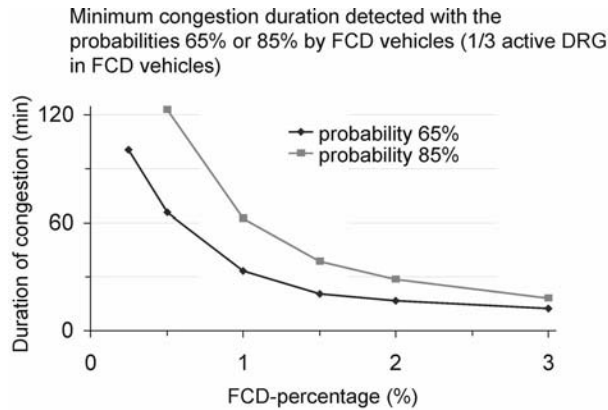


Fig. 10. Congestion duration recognition by FCD vehicles as function of the percentage of FCD vehicles with two different values of probability of congestion recognition and a third of active route guidance in the FCD vehicles.

IV. FCD PROCESS FOR TRANSPORTATION NETWORK: ASPECTS OF APPLICATION

A. Proceeding for investigation of FCD based route guidance service

A goal of a high-quality service must be the highest possible “travel time gain”, which can be offered for vehicles, presupposed information about current traffic, and traffic prediction. Additionally, a definition of a part of a traffic network area with at least one alternative route (a transportation network) must be defined, which is used for a simulation of traffic prediction and FCD message generation. In order to compute traffic prediction with the model UTA [1, 16, 17], the following steps are to be implemented: (i) historical traffic data is used for boundary conditions at nodes and for traffic flows at the edge of network, (ii) traffic prediction by a comparison and selection of the historical data and current measurements, (iii) the travel time calculated under the approximation that the current vehicle movement with its moving at traffic lights is replaced by a middle averaged movement with an effective speed. The possible information losses for a dynamic route choice

evaluated for different portions of FCD vehicles and intervals of dispatching. Restrictions of the FCD method are examined, i.e., the minimum percentage of FCD vehicles and the minimum transmission arising are looked for, with which the FCD method still can find useful information for the dynamic route choice. Different scenarios of the quality of the traffic prediction created through the FCD method are developed dependent on (i) the percentage of the FCD vehicles, (ii) different positions of sending locations in a network, (iii) the frequency of the message generation. An optimization of the sending locations in the network is accomplished with the goal of lowering the volume of FCD communications. Methods for controlling of amount of messages (changes of the positions, the activations and in the changes in the message frequencies) are analyzed dependent on the traffic conditions.

B. FCD service specification: navigation and traffic center

The recognition of relevant network sections in which congestion can occur and the bringing of received travel times together with the measured ones require a connection of the FCD processing unit and a navigation system in the vehicle: the travel times transferred by the traffic center should be integrated into the navigation system (Fig. 11).

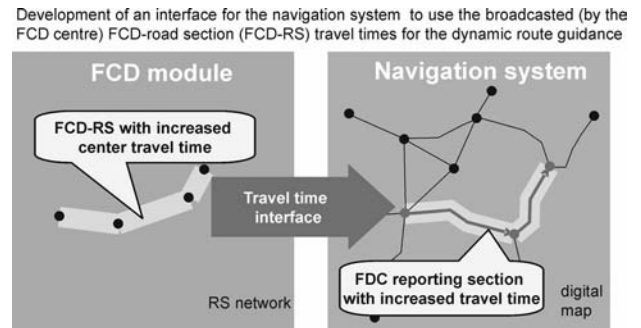


Fig. 11. FCD reporting section (FCD-RS) in navigation.

The recognition of the relevant FCD reporting sections (FCD-RS) and the combining of the travel times broadcasted by the traffic center require an interface of the FCD module and the on board digital map (mostly in the navigation system): travel times of the traffic center must be used in dynamic navigation for the route choice (Fig. 11).

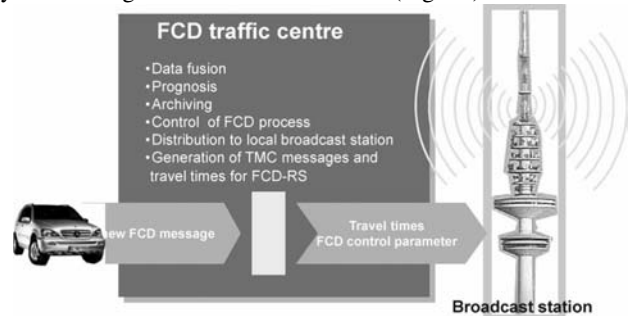


Fig. 12. Procedure and tasks in traffic center.

The traffic center has thereby the tasks, which are called in Fig. 12. Apart from the algorithmic tasks of the prognosis and the data fusion, which mean a fusion of the FCD information with other data sources, the center steers the FCD process and archives all relevant information. Additionally, it generates (in Fig. 12 in the form of TMC (Traffic Message Channel)) messages to the broadcasting of FCD travel times and FCD threshold values illustrated.

C. Communication channels for FCD method

Today possible communication channels are either point of point over SMS (Short Message Service) and GPRS (General Pack Radio Service) or broadcast with RDS (Radio Data System) and DAB (Digital Audio Broadcast).

V. CONCLUSIONS

The contribution permits finally the following statements:

(i) A process for the optimized production of FCD messages with a broadcast of travel times revised in a traffic center can reduce the necessary amount of information clearly.

(ii) The only important traffic information within a route guidance service is the time intervals of congestion emergence and dissolution on a road section: two FCD messages are necessary, in order to determine congestion completely.

(iii) The traffic center needs a procedure for the reference time shift associated with a FCD travel time (2) and for the following interpolation of the travel time, in order to predict the travel time sent by the center through the use of broadcast communication for all vehicles in the network.

(iv) FCD penetration rate of 1.5% and a 4-minutes-cycle of the traffic center give a sufficient service quality in optimal best case circumstances.

(v) Given 1.5% FCD vehicles traffic congestions with a duration of 20 minutes can be determined with 65% probability of recognition.

(vi) With 2% FCD vehicles 85% probability of congestion recognition longer than 30 minutes is possible.

(vii) The FCD process for transportation network requires and covers point to point and broadcast communication between traffic center and vehicle.

The barriers for realization of this kind of traffic state detection are the definition of a successful business case for traffic information and the practical installation in many vehicles: 2 % mean close to 1 million vehicles in Germany. To reach this, several car manufacturers have to follow a joint approach, which is a political issue.

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