

A Fleet Monitoring System for Advanced Tracking of Commercial Vehicles

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Abstract—Many commercial off-the-shelf fleet telematics systems can provide basic tracking & tracing functionalities for vehicle fleets. These systems, however, require that dispatchers manually identify any discrepancies between the actual data available in the fleet telematics system and the planned data in the logistics system. Furthermore, actual data such as arrival and departure times at customer locations must be transferred manually between the fleet telematics system and the logistics system. In this paper we present a Fleet Monitoring System which can be used for advanced tracking of commercial vehicles. The Fleet Monitoring System can analyse messages sent from the vehicles in order to identify discrepancies between actual and planned data. Furthermore, it can be used to revise the planned data and to update the database of the logistics system, e.g. to store exact arrival and departure times at customer locations. As unexpected incidents and ambiguities are automatically detected, dispatchers do not need to manually analyse all messages sent by the vehicles and can quickly react on possible disturbances in the transportation processes.

I. INTRODUCTION

Due to globalisation, liberalisation of markets, deregulation in the transport sector, and the increasing commitment to the just-in-time philosophy, competition between motor carriers and expectations on punctuality, reliability, flexibility and quality of transportation services have increased significantly and will increase even more in the future. Rapid development of mobile communication and information technology allows the use of telematics to cope with those challenges and to increase the efficiency of commercial vehicle operations. Vehicles can be equipped with on-board units which can communicate with a stationary system in the dispatching office. These systems can significantly help in closing the gap between what is known to the drivers and what is known to the dispatchers in the dispatching office.

The major potentials of fleet telematics systems arise in the fields of information exchange between dispatchers and drivers, tracking & tracing, fleet management, and planning of handling activities. Vendors of fleet telematics systems promise that their systems can be used to exploit the various potentials. In order to exploit the full potential of fleet telematics systems, however, the actual data available in the fleet telematics system must be compared with the planned data in the logistics system. This is required to identify any disturbances in the transportation processes and to identify data such as exact arrival and departure times at customer

locations. These data can automatically be stored in the logistics system without the need to manually transfer it. As a result, the information flow is improved and the risk of typing errors is avoided.

In this paper we present the Fleet Monitoring System (FMS) we have developed for Georgi Transporte GmbH, a German motor carrier specialised in the road transport of so-called air cargo. The Fleet Monitoring System can analyse messages sent from the vehicles in order to identify discrepancies between actual and planned data. Furthermore, it can be used to revise the planned data and to update the database of the logistics system. As it can automatically detect unexpected incidents and ambiguities, dispatchers do not need to manually analyse all messages sent by the vehicles. Furthermore, the Fleet Monitoring System supports the dispatchers in reacting quickly to possible disturbances in the transportation processes. Although the Fleet Monitoring System was developed to build the bridge between a commercial off-the-shelf fleet telematics system and a proprietary logistics system, the conceptual framework is generic and can be applied to different system architectures if the required interfaces are provided.

The remainder of this paper is organised as follows. First, we give a short overview over related work before we describe the architecture of the telematics-enabled information system. Then, we describe the Fleet Monitoring System and its functions in more detail. Eventually, we present some practical experiences.

II. RELATED WORK

The potentials of commercial vehicle telematics have been studied by [1] and one of the major potentials identified is tracking & tracing. Following [2] the term *tracking* signifies the gathering of information related to the current location and state of moving objects, whereas *tracing* relates to storing and retaining the history of information related to the movements of the objects. According to [3] tracking of vehicles and shipments is needed in order to provide the link between the information systems and the physical reality (the material flow). Presumably due to the formerly lack of affordable in-vehicle telematics systems, the functionality of tracking systems described in the literature is often restricted to tracking of shipments at transshipment points, and the actual movement in the vehicle is not regarded, see e.g. [4].

Today, fleet telematics systems allow to track vehicles while they are travelling between the transshipment points and can, according to [5], provide the necessary information

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required to achieve real-time computer-based decision support. However, only few decision support tools can be found that use real-time information sent by the vehicles. So far no universal solution exists that is suitable for any motor carrier, and many of the systems available today still require that the data is manually transferred between the fleet telematics system and the logistics system - a time consuming and error prone task.

Yet, some techniques to use real-time information to support the management of motor carrier operations have been developed. For example, [6] propose a concept for managing a truck fleet through cell-phones and the internet. [7] have proposed a mobile communication system, which focuses on the driver/dispatcher interaction and the integration with logistics software.

III. SYSTEM ARCHITECTURE

The Fleet Monitoring System (FMS) builds a bridge between the Logistics System (LS) and the Fleet Telematics System (FTS) as illustrated in figure 1. Furthermore, travel time estimates based on actual traffic conditions may be obtained from a Traffic & Travel Information System (TTIS). Due to the heterogeneity in the road transport sector, motor carriers usually operate different LS with different subsystems and functionality. In this paper, however, it is assumed that all information regarding planned trips and planned handling activities can be accessed via appropriate interfaces of the LS.

The FMS retrieves planned data from the LS and actual data from the FTS and TTIS. These data are analysed and

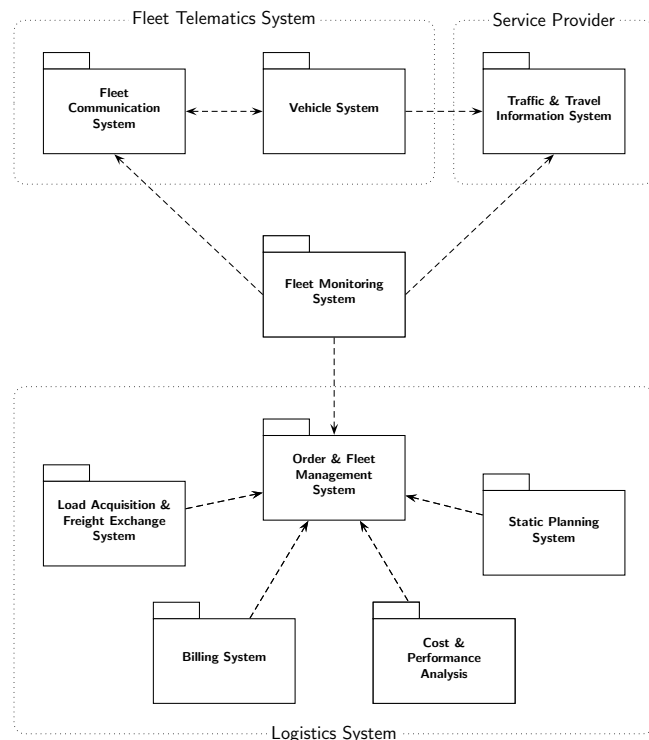


Fig. 1. Telematics-enabled information system

compared in order to monitor transportation processes and to identify disturbances or unexpected incidents. Furthermore, actual data such as arrival and departure times at customer locations are stored in the LS and the planned data stored in the LS is revised in order to consider the actual state of the transportation system.

IV. THE FLEET MONITORING SYSTEM

This section presents the FMS which is used to monitor transportation processes. The FMS analyses incoming messages, determines actual data and compares it with the planned data. Furthermore, it monitors whether all planned events occur as expected. This section presents the static structure of the FMS, describes how incoming messages are analysed, and describes how planned events are monitored.

A. Static structure

The information required to compare actual and planned data and to monitor whether all events occur as expected has to be obtained from the LS, the FTS, and the TTIS. The class diagram illustrated in figure 2 gives an overview of the information required by the FMS.

Detail: An instance of this class corresponds to any information detail which may be included in a `Message`. Details are characterised by a key-value pair. This information may be added to the message by driver input or sensor data. An example of details added by driver input is the driver identification (key: "PIN", value: "1234"). An example of details added by sensor data is the opening of the rear door (key: "Rear door", value: "opened").

DriverActivity: In order to calculate total travel times, considering regulations regarding drivers' working hours, it is necessary to know what activities a driver has been conducting for how long. Each of these activities can be categorised as DRIVING, WORK, BREAK, or REST.

Message: Each incoming message is analysed by the FMS. Besides of the vehicle and the time, the message may contain the position of the vehicle and a set of details.

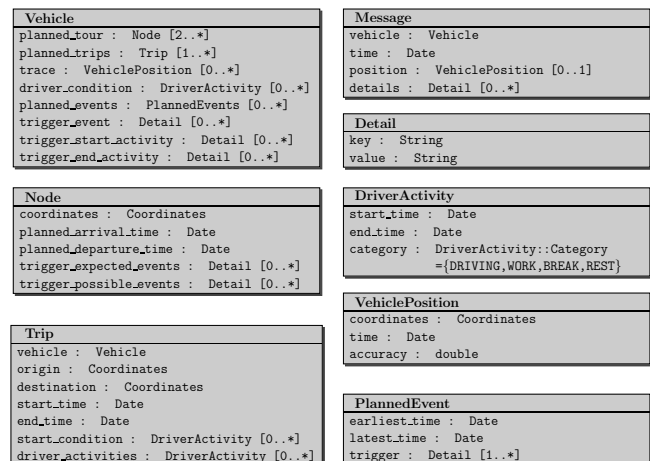


Fig. 2. Information required by the FMS

Node: Each point in the tour of a vehicle is represented by an instance of the class `Node`. A node is represented by the coordinates of the corresponding geographical location and its planned arrival and departure time. Different events can occur at different nodes. Some of them are expected to occur there and some can occasionally occur there. Events are identified if an incoming message contains respective details. An example of a detail indicating such an event is the start of handling activities (key: “Loading”, value: “begun”).

PlannedEvent: Some events are planned to occur within a certain time window. An example of such a planned event is the confirmation that a certain message has been read by the driver (key: “Message read”, value: “1234”).

Trip: The time required for a vehicle to travel from one point to another may depend on the vehicle, the start time and the activities the driver has conducted before starting the trip. During the trip further activities are conducted by the driver, which need to be known in order to calculate the duration of subsequent trips.

Vehicle: In order to monitor all transportation processes the planned tour and trips have to be known. The vehicle’s trace is used to improve the accuracy of determining the actual state of transportation processes. The activities already conducted by the driver are required to determine the duration of future trips. Some events are planned to occur within a certain time window. Other events are not planned and may occur at any time. An example of such an event is the transmission of odometer information (key: “Odometer”, value: “100000”). Furthermore, the start and end of some local activities may be detected if messages contain the corresponding detail information. An example of such a local activity is the start and end of a rest period (key: “Rest period”, value: “begun” and key: “Rest period”, value: “end”).

VehiclePosition: If the vehicle is equipped with a positioning system the current vehicle position can be added to messages sent to the dispatching office. Depending on the positioning system the vehicle position may have different accuracy which has to be considered when analysing messages.

If the FMS is supplied with all necessary data it can analyse incoming messages, determine actual data, compare it with the planned data, and can monitor whether all planned events occur as expected. For this purpose it detects information which can be represented by the classes illustrated in figure 3.

Activity: If a vehicle is not moving it can conduct a local activity. The start and the end of the local activity are usually identified by the start event and the end event. The duration of the activity can be estimated if the start event is detected. For example, if the begin of handling activities is detected by the details (key: “Loading”, value: “begun”) the estimated duration can be looked up in the database.

Event: An event is a singular occurrence which has triggered the transmission of a specific key-value pair.

MatchedPosition: The matched position is the vehicle’s

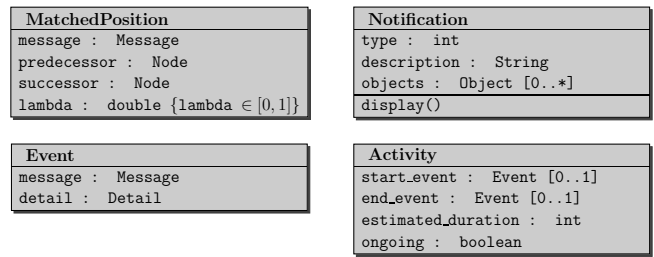


Fig. 3. Information detected by the FMS

position with respect to the planned tour of the vehicle and can be described by two succeeding nodes in the planned tour and a value $\lambda \in [0, 1]$ indicating the relative position between the nodes.

Notification: Any obscurity related to data which cannot be interpreted unambiguously or any irregularity which is detected result in a notification which is displayed to the dispatchers. The notification may be related to other objects, e.g. a vehicle, a message, etc..

The information detected by the FMS is stored in its database and used to adjust the data in the LS. For example, if the database of the LS contains a field for the actual arrival time at a customer location, and the vehicle’s position is matched to a customer location, the arrival time at this location can be automatically set by the FMS.

B. Message processing

The processing of incoming messages is realised as illustrated in figure 4. The FMS receives an incoming message from the FTS and analyses it. All relevant data is stored in the LS depending on matched position, detected events and activities, and notifications. In certain cases, a dispatcher may have modified the tour of a vehicle while the FMS analysed the message. In this case, the analysis of the message has to be repeated by the FMS. Eventually, notifications are displayed to the dispatchers who can initiate countermeasures if necessary. As a result, dispatchers do not need to read and analyse all incoming messages and thus, can concentrate on those messages which cannot be interpreted automatically or where unexpected incidents are identified.

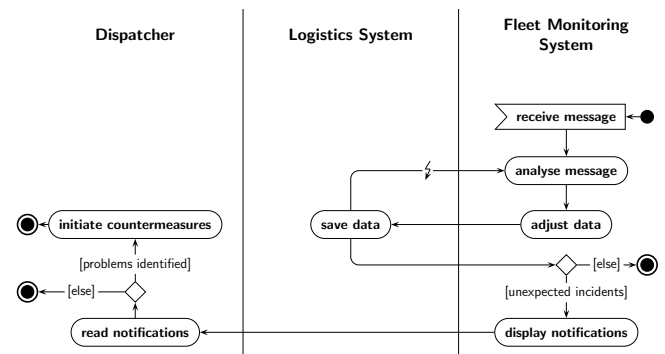


Fig. 4. Process message

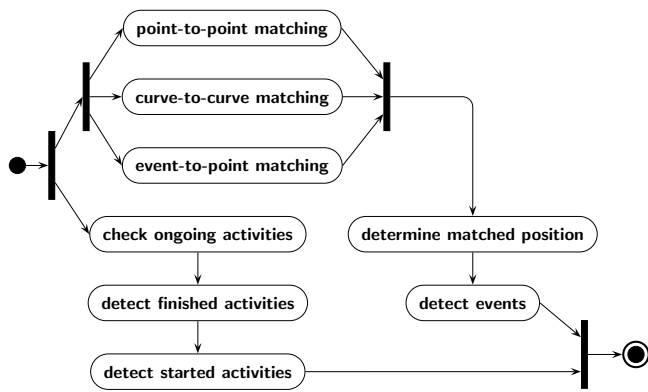


Fig. 5. Analyse message

Analysing messages is a non-trivial task due to fact that potential discrepancies between planned and actually used route, between planned and actual arrival and departure times, and between expected messages and actually received messages must be considered. Furthermore, inaccuracies of the positioning system, inaccurate planning data, and faulty driver input can increase the complexity of automatic analysis. In figure 5 it is illustrated how the FMS analyses incoming messages. The FMS determines the vehicle's position with respect to the planned tour. If the message contains a valid position, the coordinates are matched to all nodes in the planned tour which are reasonably "close" regarding planned arrival and departure times. This point-to-point matching is only successful if the vehicle is within vicinity of one of the nodes in the planned tour and if the accuracy of the position is sufficiently good.

Furthermore, the vehicle's trace including the current position is matched to the planned tour. This curve-to-curve matching is similar to the map matching techniques used in in-vehicle navigation systems, see [8] and [9]. In contrary to in-vehicle map matching, however, there is usually less information available to the FMS. On the other hand, less candidate curves have to be considered. If this curve-to-curve matching is not successful or the distance between the current position and the matched position is too high, the vehicle may have left the planned tour and the dispatchers have to be notified.

If the message contains additional information in form of key-value pairs, these message details are also analysed as certain key-value pairs may indicate events which can only occur at certain nodes in the planned tour. This event-to-point matching has to consider which events are expected at the nodes and which may occasionally occur there.

Obviously, multiple reasonable matches may be found in point-to-point, curve-to-curve, and event-to-point matching. Instead of independently determining the best matched position for each of these three types of matching, a "fitness" value is determined for each type and for each possible match. In the next step, the best matched position is determined by multi-objective optimisation. In the multi-objective optimisation the fitness value of all three types of matchings

must be considered. Only those matches can be accepted which are reasonably good for all cases. That is, if a match with a very good fitness value in one of the cases has a bad fitness value in one of the others, this match is unlikely to be a good choice. Dispatchers are notified if no reasonable match can be found. After determining the matched position, the FMS checks whether events have occurred. If a matched position has been found with $\lambda = 0$ or $\lambda = 1$, those events which are possible or expected to occur at the corresponding node can also be detected.

Parallel to the processes described above, the FMS checks all local activities whether they are still ongoing. As local activities are bound to a specific location, an activity cannot be ongoing if the vehicle's position has changed since the start of the activity. In this case, the dispatcher is notified that the activity is no longer ongoing and the end of it has not been detected before. In the next step, message details are analysed to determine whether an activity is finished. If no corresponding ongoing activity can be found, the dispatchers are notified, as an activity is finished which has not been ongoing. Eventually, the message details are used to detect activities which have just started.

C. Event monitoring

Just as an incoming message can give information about possible problems, the nonappearance of messages may indicate that some unexpected incident occurred. In order to store exact arrival and departure times a message is usually expected at each arrival at and departure from a customer location. If such a message is not received by the time it is expected, this may indicate some delay. If a driver does not confirm the receipt of an instruction sent to him, this may indicate that he has not received or read the instruction. Figure 6 illustrates the monitoring of such events.

The LS publishes all changed data and the FMS analyses these changes in order to determine whether they are associated to planned events. If the changed data is of no relevance to the planned events, nothing has to be done.

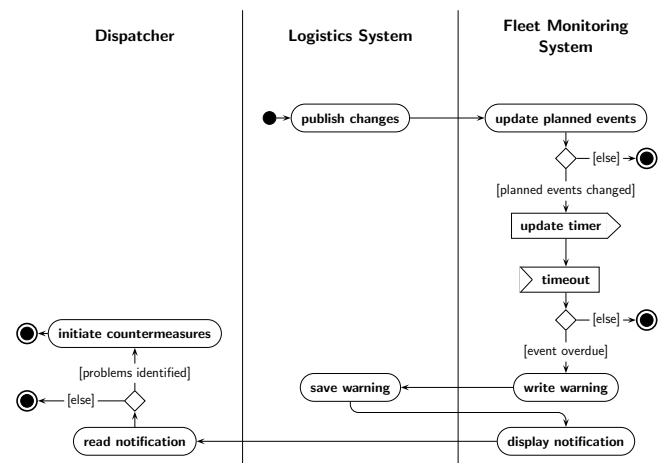


Fig. 6. Monitor events

Otherwise, the planned events and the corresponding timer are updated. When the updated timer sends a timeout signal, the FMS checks whether the event is overdue or whether it has occurred before. If an event is overdue, a warning message is generated and stored in the LS. Eventually, this warning is shown to the dispatchers who can initiate countermeasures if any problems are identified.

V. PRACTICAL EXPERIENCES

Georgi Transporte GmbH is a German motor carrier specialised in the road transport of so-called air-cargo between European airports. The carrier operates 140 vehicles equipped with mobile *fleetec III* systems which communicate with the stationary *DATAfleet* system [10]. The *fleetec III* systems consist of a display, configurable status buttons, and a GPS receiver. The communication is realised by using the Short Message Service (SMS) provided by the Global System for Mobile Communications (GSM). We developed the FMS to integrate the *DATAfleet* system into the existing LS. The main goals were to:

- quickly detect significant discrepancies between actual and planned data, e.g. delays
- reduce operational costs, e.g. when vehicles are standing unnecessarily
- determine actual arrival and departure times
- monitor the communication

All messages with valid GPS data are used by the FMS to compare actual and planned route. The FMS notifies dispatchers in case of significant discrepancies. The arrival at and departure from customer locations is detected by using GPS data and additional information supplied by the drivers pushing status buttons. Furthermore, drivers can push buttons indicating the start and end of handling activities. This information is e.g. required in order to prepare the invoices.

As drivers' working hours are regulated by EU social legislation all driving, working and rest periods have to be known to be able to estimate total travel times, including the pure driving time and the time needed for obligatory breaks and rest periods. The *fleetec III* systems are configured to automatically send messages when the vehicle has stopped or resumed driving. Additionally, drivers can push status buttons to indicate that they have started or finished a rest period. The FMS detects these changes in the driving state and uses the information to calculate arrival time estimates. One of the requirements was to monitor the daily rest periods of drivers as, especially in hot summer months, sometimes drivers overslept in their sleeper berths. We dissolved the problem by detecting all daily rest periods as described above. If the daily rest period is not finished by the time it is expected the dispatchers are notified and can call on the driver to continue his tour.

All matched positions, detected events and activities, and notifications are stored in a database and are used, for example, for cost and performance analysis or for preparing invoices. The FMS is configurable and allows that additional events and activities can be defined in a lookup table. As the

fleetec III systems have configurable status buttons, new or extended monitoring functionalities can be realised without modifying the FMS.

After the FMS was running for more than one year we questioned Georgi Transporte GmbH about their experiences with the FMS. They reported that there was a significant increase in the quality of transportation services and the level of fulfilment of customer requirements. The support of the communication process brought a significant relief to dispatchers and drivers, misunderstandings were avoided, and the information flow was improved. A proof of delivery and the identification of responsibilities of costs were simplified. There were also enhances in avoiding unnecessary times where vehicles were not moving. Unfortunately, no information about a possible reduction of empty mileage and costs resulting from better decisions accompanied with the improved information supply was given to us.

VI. CONCLUSIONS

In this paper we have presented a Fleet Monitoring System which can compare actual data, retrieved from the Fleet Telematics System and the Traffic & Travel Information System, with the planned data stored in the Logistics System. The FMS can identify data, such as exact arrival and departure times, as well as discrepancies between actual and planned data.

Motor carriers benefit as the automatic monitoring of events and analysing of messages improve the information flow as well as the reliability and usability of the information available. As a result, countermeasures can be initiated faster and, in some cases, even before irregularities have resulted in unnecessary costs. Dispatchers benefit as they are supported in monitoring transportation processes. They can concentrate on work which cannot be automatized and which requires human decisions. Drivers benefit as the information gap between dispatchers and drivers is reduced. The decisions of dispatchers, therefore, are less likely to be in conflict with practical or legal requirements, e.g. regarding drivers' working hours. Shippers benefit as they can be informed about the progress of transportation processes and estimated arrival times and thus, can better plan handling activities and optimise succeeding processes.

The lack of information used to be a major problem for successful deployment of dynamic planning systems, see [11]. As information is analysed automatically, the prerequisites for dynamic planning are provided. A framework for dynamic planning is presented by [12] and algorithms capable of handling dynamic changes in the input data have been proposed by [13] and [14]. Such dynamic planning systems can be used to further improve the efficiency of commercial vehicle operations.

An interesting question for future research is to analyse the monetary effects of using the FMS. This, however, requires to be able to distinguish between internal effects caused by using the FMS, and external effects due to seasonal and cyclical changes.

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