

EFFICIENT ORGANIZATION OF TRUCK PLATOONS BY MEANS OF DATA MINING

Application of the Data Mining Technique for the Planning and Organization of Electronically Coupled Trucks

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Abstract: One opportunity to manage the increase of freight transportation and to optimize utilization of motorway capacities is the concept of truck platoons. With the aid of Advanced Driver Assistance Systems, trucks are electronically coupled keeping very short gaps (approx. 10 meters) to form truck platoons on motorways. This contributes to a couple of advantages, such as a reduction of the inter-vehicle distance, which leads to an improved vehicle occupancy and gained road space, an optimization of traffic flow, the reduction of fuel consumption advantaged by slipstream driving, a relief for professional drivers and finally an increase in safety due to the longitudinal and lateral guidance. In this paper, a brief introduction into these truck platoons is given, which have been realized within the project KONVOI. The paper focuses on the calculations for an efficient planning and organizing of truck platoons, which could have been realized by means of the application of data-mining technique. Therefore, the efficiency criterion of electronically coupled truck platoons is discussed as well as the framework of the data-mining technique and the algorithm for the calculation of efficient truck platoons are presented. Finally, the experimental results of the application of the data-mining technique and their relevance for an efficient operation of truck platoons is presented.

1 INTRODUCTION

1.1 Initial Situation

The integration of the new European member countries is a challenging component for national traffic planning in the near future. Especially countries with a central geographic position within Europe, such as Germany, have to shoulder the majority of the future traffic emergence. Additionally, this traffic will predominantly encumber the road. Due to the increase of global freight transportation, the maximum road capacity in several countries worldwide is nearly reached (Economic and Social Commission for Asia and the Pacific, 2008). A modern national economy needs an efficient traffic system to face such a challenge successfully. Otherwise, today's even worse traffic situation will be pre-assigned to collapse.

The importance of this fact was emphasized by studies from the European Commission in 2006 (Commission of the European Communities, 2006). Between 1995 and 2004 a growth of 35% in road

freight transport was detected. Furthermore, between the years 2000 and 2020 an increase of 55% in road transportation is expected (Commission of the European Communities, 2006). In the year 2003, the European Commission stated that every day 7,500 kilometers of the European road system are being blocked by traffic jams (Commission of the European Communities, 2003). Environmental pollution, safety risks and a loss in efficiency for the economy are only some of the effects that result from these factors. Similar problems are known and discussed worldwide.

One possibility to face the rising traffic volume on the roads is the modal shift to other types of transportation (e.g. rail, shipping). Further potential has the optimization of the road-side traffic flow by driving assistance systems. Since the 90s, Advanced Driver Assistance Systems (ADAS) for trucks have been on offer, including pre-adjustment of speed and distance to the front vehicle. This is exerted automatically via computerized engine- and brake-management in connection with an automated transmission. The combination of an Adaptive Cruise

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Control (ACC) together with an Automatic Guidance (AG) leads to autonomous driving. The difference between platooning and autonomous driving makes the necessity of a leading vehicle. Following trucks can go far distances without any manual engagement by the driver as long as another ahead-driving vehicle exists. Nevertheless, each truck must be assigned with a truck driver at all times due to legal rules and regulations. Due to the platoons, smaller distances between the vehicles (up to 10 meters) can be realized. These truck platoons contribute to an optimization of traffic flow up to 9% and a reduction of fuel consumption due to slipstream driving (Savelsberg, 2005).

The development and evaluation of the practical use of truck platoons is the objective of the project KONVOI, which was funded by German's Federal Ministry of Economics and Technology. The Project KONVOI is an interdisciplinary research project with partners of RWTH Aachen University, industry and public institutions, which ended after a duration of 49 months with test runs on German highways at the end of May 2009 (Figure 1). With the assistance of virtual and practical driving tests by using experimental vehicles and a truck driving simulator, the consequences and effects on the human-, the organization- and the technology-dimension have been analyzed (Henning et al., 2007).



Figure 1: Test Run on German Motorways (March 2009).

1.2 Problem Definition

For planning and organization of such truck platoons, as well as evaluation and simulation purposes, it is necessary to implement an algorithm which searches for economic truck platoons within the planned or current driven routes of all participating trucks. In any case of organized platoon driving, it is essential to search for and group possible participants. In principle, the "common route" is one general search criterion, whereas other criteria (e.g. profit, waiting-time,

properties of the participating vehicles) can differ because of the focus.

In this paper, a data-mining technique is presented to solve the mentioned problem of searching for possible platoons which satisfy given specific criteria (in the case of truck platoons: economy). The scenario of driver organized truck platoons, on which KONVOI is based, is presented in section 2. Section 3 explains the operational and organizational structure of platoon systems. Before introducing the so called TPSpan-Algorithm and related work as well as the possibility to use this algorithm as a solution for the problem of planning and organizing truck platoons in section 5, the criterion of a efficient usage of electronically coupled trucks as well as the calculation basis for the efficiency of truck platoons are defined in section 4. Finally, in section 6 the experimental results of the application of the data-mining technique is presented.

2 THE SCENARIO "DRIVER ORGANIZED TRUCK PLATOONS"

The project KONVOI is based on the scenario "Driver Organized Truck Platoons" (Figure 2) which was developed in the project "Operation-Scenarios for Advanced Driving Assistance Systems in Freight Transportation and Their Validation" (EFAS) (Henning and Preuschoff, 2003). In the scenario "Driver Organized Truck Platoons", the platoons can operate on today's existing motorways without extending the infrastructure and the driver has the permanent control of the autonomous driving procedures (Henning and Preuschoff, 2003). The creation of a platoon depends on the initiating driver who delivers the necessary data about time and place of meeting, the destination, as well as the required truck telemetric data (loading weight, engine power etc.) with the help of a Driver Information System (DIS). The high flexibility of truck transportation is not lost, because scheduling, like in rail traffic, is dispensable. After activating the ADAS, a selection of the best matching platoons is automatically shown. The ADAS informs the driver and prepares the participation to the selected platoon. The DIS acts as a human machine interface of the platoon system and helps the truck driver to plan the route and guides the driver to the meeting point (Friedrichs et al., 2008).

The driver has to initialize and respectively confirm all of the platoon maneuvers in order to build and to dissolve the platoon. As soon as the final position in the platoon is reached, an automated longi-

Table 1: Reduction of Fuel Consumption based on Theory, Simulation and Test (Bonnet and Fritz, 2002).

	THEORETICAL	SIMULATION DAIMLER	MEASUREMENT DAIMLER
Fuel Consumption (1st vehicle)	2,17% (14t); 1,64% (28t)	2% (28t)	6% (14t)
Fuel Consumption (2nd vehicle)	38,06% (14t); 28,76% (28t)	19% (28t)	21% (28t)

Table 2: Reduction of Fuel Consumption due to Electronically Coupled Platoon Driving.

PLATOON STRUCTURE	FUEL REDUCTION
1st Platoon Vehicle (Leading Vehicle)	2%
2nd Platoon Vehicle (Following Vehicle)	11%
3rd Platoon Vehicle (Following Vehicle)	13%
Average Fuel Reduction, 2 Vehicles	6.50%
Average Fuel Reduction, 3 Vehicles	8.67%
Average Fuel Reduction, 4 Vehicles	9.75%
Average Fuel Reduction, 5 Vehicles	10.40%

meeting point or reduce speed until they got together. Another criterion for extra personnel costs is the platoon driving itself and the associated platoon maneuvers (e.g. a platoon has to be dissolved at a working area). It is also possible that a truck, which participates in a platoon, has to drive with reduced speed because of another, slower participant (e.g. uphill).

Due to the fact that the extra personnel costs caused by platoon maneuvers or speed reduction because of slow participants are unascertainable without accurate road and traffic information, therefore those influencing criteria will be ignored. The only criteria which take account of extra personnel costs will be the waiting time $Time_i(l)$ for each participating truck i and the wage rate k_{PK} .

$$Costs_i(l) = k_{PK} \cdot Time_i(l) \quad (6)$$

4.4.3 Boundaries of the Efficiency of Truck Platoons

To get a statement on the maximum of waiting time, equation 3 has to be transformed and complemented by equations 4 and 6. The efficient criterion of electronically coupled truck platoons is originated in equation 7.

$$u_i \cdot \frac{Length(l)}{100} \cdot \Delta B_{e,Size(l)} \cdot \frac{k_{KS}}{k_{PK}} > Time_i(l) \quad (7)$$

With this efficient criterion it can be easily proofed, if the benefit of the operation of electronically coupled truck platoons is bigger than their costs.

5 DATA MINING TECHNIQUE

5.1 Related Work

Discovering patterns in sequences is an important knowledge discovery and data-mining research area. There are many different interesting fields like discovering rules in so called events (Mannila et al., 1997) or finding text subsequences (Califano and Rigoutsos, 1993) that match a regular expression. In 1995, Agrawal and Srikant introduced the problem of mining sequential patterns (Agrawal and Srikant, 1995): "A database with customer transactions is given. Each transaction consists of the fields; customer-id, transaction-time and a set of items purchased in this transaction. Quantities of items purchased in a transaction are not considered. The problem of mining sequential patterns is to find all sequences that have a certain user-specified minimal support." This difficulty deals with the questions; "which items are bought in which order" or "which item will be bought next". Agrawal and Srikant presented three algorithms for solving the sequential pattern problem and many other algorithms have been proposed to speed up the mining process (e.g. (Zaki, 2001); (Pei et al., 2004)). In general, those algorithms are based on two different methods for mining sequential patterns: apriori-based methods and pattern-growth methods (Antunes and Oliveira, 2004).

The apriori-based methods are, as the name states, based on the so called apriori condition. This condition is used to generate larger candidates based on smaller frequent sequences in the so called join-step. Each generated candidate is then validated in the following so called prune-step. These two steps are repeated until there are no more frequent sequences found. The pattern-growth methods deduce from a smaller frequent sequence, a longer sequence. Instead of generating candidates, these methods directly look for frequent sequence.

In 2003, Yan et al. introduced the problem of mining closed sequential patterns which means that in-

stead of finding all frequent sequences, only the "most supported" sequences are searched for (Yan et al., 2003). They presented a new algorithm to find closed sequential pattern, called CloSpan, which is based on a pattern-growth method introduced in 2001 by Pei et al. Figure 6 illustrates the main idea of the approach. The items are nodes in a lexicographical sequence tree. Each path of the tree is a frequent sequence found in the database. So called projected databases are stored for each node of the tree. If the projected databases of two different paths are equal to each other, the mining for more frequent sequences can be eventually stopped. In figure 6, the mining for further frequent sequences can be stopped at node *B* in the path *B* because the projected database of this node is equal to the projected database of node *B* in the path *A, B*.

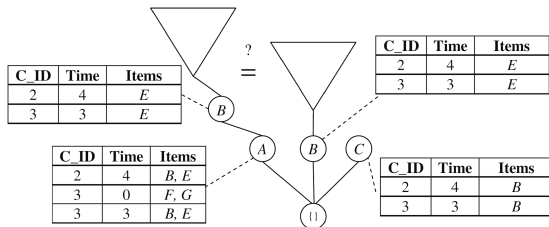


Figure 6: Illustration of the Algorithm to Find Closed Sequential Pattern.

The problem of mining frequent sub-routes or economic truck platoons cannot be solved easily by any of those algorithms. Due to the small support of two and the given sequences of hundreds of sections, those algorithms collapse. In the case of platoons the support has to be two, because two is the smallest number of participants to form a platoon. However, these algorithms are good approaches in finding possible solutions for solving this problem.

5.2 The Truck Platoon Sequential Pattern Algorithm

The so called TPSpan-Algorithm (Mining Truck Platoon Sequential pattern) had been already presented in detail in 2008 (Meisen et al., 2008). In this section, we will give a brief introduction into the TPSpan-Algorithm which searches for possible platoons in a route database, especially optimized to find economic truck platoons. The algorithm is split in four phases and illustrated in Figure 7.

In the first phase, the exclusion criteria are used to eliminate trucks or routes which do not meet those criteria. Within the second phase, the grouping criteria are applied to secure the forming of platoons within similar conditions. In the third phase, the data-mining

technique checks each group for possible economic truck platoons regarding the assessment criteria. Finally, in the fourth and last phase, the economic truck platoons are grouped by truck-id. The grouped information is then transmitted to each truck (e.g. meeting points, profit).

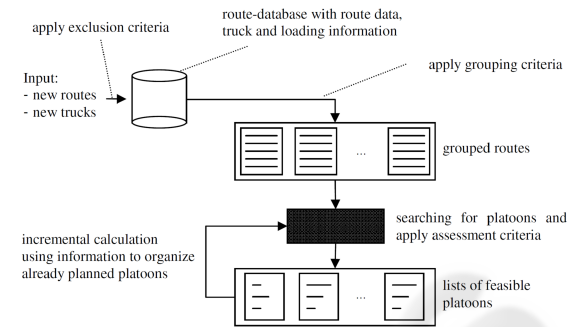


Figure 7: Illustration of the Algorithm to Find Truck Platoon Sequential Pattern.

The used data-mining technique in the third phase is based on the projected pattern-growth idea presented by Pei et al. (2001) and has been enhanced for solving the problem of mining frequent sub-routes. It generates a lexicographic tree as shown in Figure 6. Instead of starting with each frequent section, the tree starts with those frequent sections which have a meeting opportunity ($Meet(s_1) = 1$). This means that the first section has to be e.g. a rest area. Due to this, the width of the tree is reduced and the condition for a platoon (starting with a meeting opportunity) is ensured. Another important improvement is the so called node-compress-method which is used to reduce the validation of the assessment criteria. Instead of validating the criteria for every platoon, the common distance of a platoon will be increased as long as the number of participants does not change. It is ensured that the algorithm will still search for the most economic platoons: A platoon $l_1 = (s_1, \dots, s_n)$ with $Size(l_1) = k$ is always more economical than a platoon $l_2 = (s_1, \dots, s_n)$ with $Size(l_2) = k$, whereas $Length(l_1) > Length(l_2)$.

Figure 8 shows the framework of the data mining technique. The algorithm is working from the root of the tree to the leaves. In each node, the algorithm calculates possible platoons (line 4) and determines new children (line 6). If the projected database of the node does not support any more platoons (line 1) the recursion terminates. The framework also shows the already mentioned node-compress-method (line 3) which returns a true value if the compression terminated with a split. If this is the case, further children are possible, other wise the routes of the projected database end and no more children can be determined (line 5).

7 CONCLUSIONS

In this paper, we have introduced a data mining technique to plan and organize platoons. Furthermore, we have introduced and presented experimental results for an application area "truck platoons: trains on road". For this case, we have examined that it is possible to find truck platoons and that the amount of platoons increase exponentially with the amount of routes (participating trucks). Due to this rise, pruning parameters are necessary. Further experiments have shown that it is possible to find truck platoons reliable, efficient and flexible, even if pruning parameters are used. We have given suggestions for these parameters to achieve the mentioned factors. Further work has to be done in the field of realization. We have presented the dilemma of different results of reducing fuel consumption. Additional effort has to be put into the goal closing the gap between results of fuel reduction based on theory, simulation and tests and thus provide a further substantial contribution to the efficiency of truck platoons.

REFERENCES

- Agrawal, R. and Srikant, R. (1995). Mining Sequential Patterns. In *Proc. of the 11th Intl Conf. on Data Engineering, Taipei (Taiwan)*.
- Antunes, C. and Oliveira, A. L. (2004). Sequential Pattern Mining Algorithms: Trade-offs between Speed and Memory. In *Proc. of the 2nd Intl Workshop on Mining Graphs, Trees and Sequences (ECML/PKDD)*.
- Bonnet, C. and Fritz, H. (2002). Fuel Consumption Reduction Experienced By Two PRO-MOTE-CHAUFFEUR Trucks. In *Electronic Towbar Operation*.
- Califano, A. and Rigoutsos, I. (1993). Flash: A fast look-up algorithm for string homology. In *Proc. of the 1st Intl Conf. on Intelligent Systems for Molecular Biology, Bethesda (USA)*.
- Commission of the European Communities, E. U. (2003). *Europe at a crossroad - The need for sustainable transport*. Brussels, Belgium.
- Commission of the European Communities, E. U. (2006). *Keep Europe moving Sustainable mobility for our continent*. Brussels, Belgium.
- Economic and Social Commission for Asia and the Pacific, U. N. (2008). *Statistical Yearbook for Asia and the Pacific*. United Nations Publication, Bangkok, Thailand.
- Friedrichs, A. (2008). *A Driver Information System for Truck Platoons*. VDI, Duesseldorf, Germany.
- Friedrichs, A., Meisen, P., and Henning, K. (19.-22.05.2008). *A Generic Software Architecture for a Driver Information System to Organize and Operate Truck Platoons*. International Conference on Heavy Vehicles (HHVT2008), Paris, France.
- Henning, K. and Preuschoff, E. (2003). *Einsatzszenarien fuer Fahrerassistenzsysteme im Strassengueterverkehr und deren Bewertung*. VDI, Duesseldorf, Germany.
- Henning, K., Wallentowitz, H., and Abel, D. (2007). Das Lkw-Konvoisystem aus den Perspektiven Informations-, Fahrzeug- und Automatisierungstechnik. In *Mechatronik 2007 - Innovative Produktentwicklung*.
- Kunze, R., Tummel, C., and Henning, K. (19.-20.12.2009). *Determination of the Order of Electronically Coupled Trucks on German Motorways*. 2nd Conference on Power Electronics and Intelligent Transportation System (PEITS 2009), Shenzhen, China.
- Mannila, H., Toivonen, H., and Verkamo, A. I. (1997). Discovery of frequent Episodes in Event Sequences. In *Data Mining and Knowledge Discovery*.
- Meisen, P. (2006). *Data-Mining Technique for Truck Platoons*. RWTH Aachen University, ZLW/IMA, Aachen, Germany.
- Meisen, P., Henning, K., and Seidl, T. (2008). A Data-Mining Technique for the Planning and Organization of Truck Platoons. In *Proceedings of the International Conference on Heavy Vehicles*.
- Pei, J., Han, J., Mortazavi-Asl, B., Pinto, H., Chen, Q., Dayal, U., and Hsu, M.-C. (2004). PrefixSpan: Mining Sequential Patterns Efficiently by PrefixProjected Pattern Growth. In *Proc. of the Intl. Conf. Data Engineering (ICDE'01)*.
- Savelsberg, E. (2005). *Lastenheft fuer elektronisch gekoppelte Lkw-Konvois*. VDI, Duesseldorf, Germany.
- Schmitz, J. (2004). *Energy-economic cost-benefit-analysis of electronically coupled truck convoys*. RWTH Aachen University, ZLW/IMA, Aachen, Germany.
- Yan, X., Han, J., and Afshar, R. (2003). CloSpan: Mining Closed Sequential Patterns in Large Datasets. In *SDM'03*.
- Zaki, M. J. (2001). SPADE: An Efficient Algorithm for Mining Frequent Sequences. In *Proc. of Machine Learning Journal, Special issue on Unsupervised Learning (Doug Fisher, ed.)*.