University of Pardubice
Faculty of Transport engineering

PREDICTIVE VEHICLE MAINTENANCE PLAN

DISSERTATION THESIS

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Study program

Technology and management in Traffic

Study specialization

P1041D040001 Technology and management in Traffic

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INTRODUCTION

With increasing demands on the operational reliability of public transport, there is a growing need to maintain the operation of individual vehicles and ensure not only the smooth running of the service, but also safety. Today, we are faced with much higher demands resulting from constantly changing regulations and laws. It is still the case that the main objective of maintenance is to consider the safety and reliability of vehicles and to reduce the ecological impact on the environment. Maintenance is an important and necessary factor for the timely diagnosis of the current state of the vehicle, including the determination of necessary replacements and repairs of individual components of the vehicles.

This work specifically focuses on the maintenance of the fleet of public transport operators. These transport undertakings are characterised by the fact that the operator usually operates many vehicles of different types, the different vehicle types are operated on clearly defined routes due to their capacity and performance, and the specific vehicles have a very varied history of performance, breakdowns and accidents, with part of the fleet usually still under warranty and part already beyond its minimum moral life.

The basis for the development of maintenance plans changes over time and updating them tends to be a challenging process because the physical maintenance plan itself interferes with economic planning and must fit within the economic framework available to the transport undertaking. Retirement of obsolete vehicles and purchase of new ones, as well as unforeseen events such as accidents, lack of spare parts and other resources to carry out the actual maintenance (lack of human resources, already occupied sidings, etc.) enter the maintenance planning process. Thus, managerial decision making in vehicle maintenance planning is a complex task which in practice requires the creation of alternative maintenance plans according to set parameters.

Therefore, this dissertation focuses on vehicle maintenance, specifically on predictive maintenance planning, which aims to develop an optimal vehicle maintenance planning model that ensures reliability, safety, low economic and environmental impact of the operation of individual vehicles and the transport company.

1 CURRENT STATUS OF THE STUDIED ISSUE

The term vehicle maintenance has many definitions, but in general it is a complex and complicated process. Regardless of the type of equipment, the operation of maintenance and the individual steps within the applicable regulations is challenging. The main challenge for the repair industry and individual professionals in the field is to find the most effective way to keep the equipment running safely (Skřivánek, 1976).

The main objective of the maintenance programme is to ensure the smooth running of the vehicles, to prevent deterioration in their reliability and to maintain the service life and durability of the vehicles within the prescribed limits (Skřivánek, 1976). Generally speaking, vehicle maintenance is the process by which administrative and technical activities are managed during the life cycle of a piece of equipment.

According (Lehder, 2000) to maintenance, the objective is not only to maintain but also to restore the equipment to a state in which it can perform the required function with an appeal to quality, safety, optimum cost and environmental requirements.

(Kobbacy, 2008) describes the key objective of maintenance as "*optimising the overall life cycle of the equipment*". This means that maximising equipment availability and reliability must be achieved in a cost-effective manner and in compliance with environmental and safety regulations.

(Furch, 2010) characterized possession as: "the*sum of all technical, administrative and managerial activities during the life cycle of an object, the purpose of which is to maintain the object in a state or to return it to a state in which it can perform the desired function*." One definition of maintenance is to characterise it as a set of activities to ensure the fitness and economically viable operation of selected equipment. It is also defined as a set of measures to assess the actual condition of an object and to ensure that the desired condition is maintained or restored. The individual maintenance activities (Lehder, 2000) include:

- Basic maintenance (lubrication, cleaning)
- Inspection and revision inspections
- Fault detection
- Repair

Maintenance is carried out according to predetermined rules, which are linked to detailed time planning.

Vehicle maintenance plan

Maintenance planning encompasses a range of methods to ensure the maintenance, repair or replacement of the equipment being monitored. The main objective of maintenance planning is to minimize the total cost of inspection, repair and downtime resulting from equipment failure (Mirghani, 2001).

High levels of automation initiated advances in machine maintenance. described that equipment maintenance activities were increasingly important in the context of quality and production costs. (Ben-Daya & Duffuaa, 1995) The link with quality and production costs directly influenced the increase in maintenance expenditure and maintenance personnel. Therefore, in some industries, we still see maintenance departments as the largest department, accounting for approximately 30% of the total work (Bjorklund, 2010).

Many strategies for planning maintenance activities emphasise a strategy that is usually associated with top and middle management responsibilities. This means that operational level staff often perform maintenance tasks that are too general and difficult to transfer to the maintenance plan.

However, the main disadvantage of these maintenance strategies for the operational level is that they require input information that is difficult to obtain. They support (Sharma, 2005) this view and point out that many of these input factors are not easy to evaluate because of the uncertainties associated with estimating the failure/repair characteristics of individual equipment components.

In recent years, we have therefore pursued changes in the form of the development of several models, methods, concepts and strategies in order to properly plan and evaluate maintenance activities and quantify their effectiveness (Lundgren, Skoogh, & Bokrantz, 2018). Some of the maintenance planning models include Value Driven Maintenance (VDM) (Haarman H, 2004), Total Productive Maintenance (TPM) (Nakajima, 1988), Reliability Centered Maintenance (RCM) (Rausand, 1998) and Total quality maintenance (Al-Najjar, 1996).

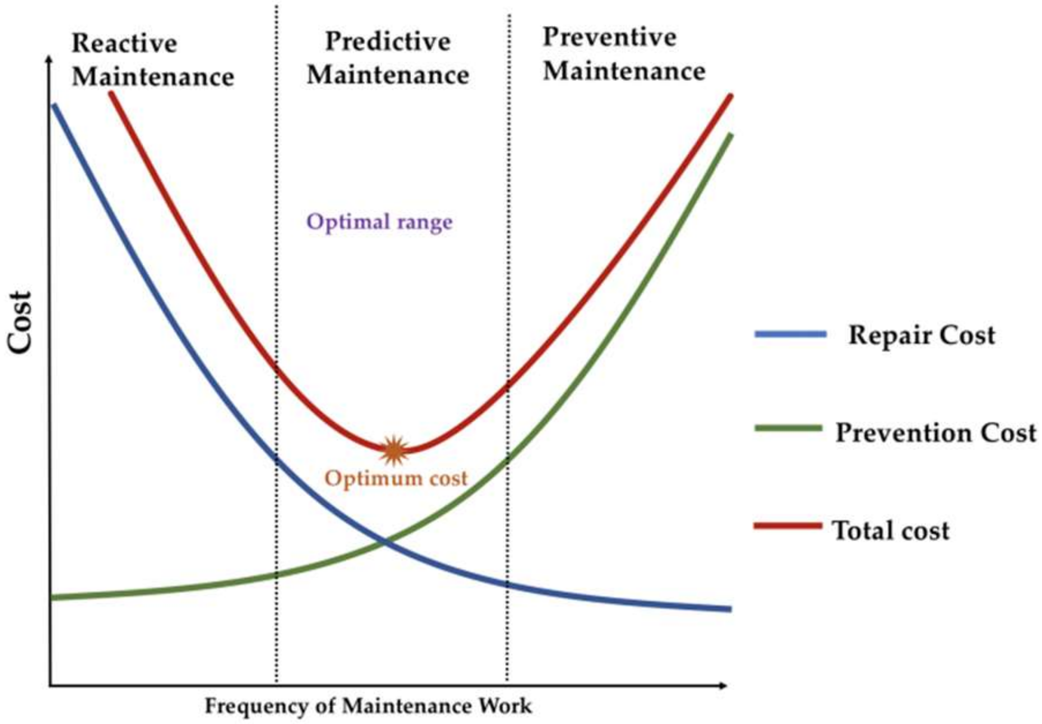


Figure 1 The trade-off between the costs of prevention and the costs of prevention

Predictive maintenance

Predictive maintenance is a type of maintenance that uses a variety of predictive tools to determine the timing of individual maintenance activities required for the equipment. It is based on continuous monitoring of the integrity of the equipment, allowing maintenance to be performed only when it is really necessary. In addition, it enables early detection of failures thanks to predictive tools based on historical data (e.g., machine learning techniques), integrity factors (e.g., visual aspects, wear and tear, coloration different from the original), and statistical interference methods (Carvalho, Soares, & Vita, 2019). He also described predictive maintenance as a new type of maintenance that works on the principle of obtaining representative features by monitoring the condition of the equipment and predicting the evolution of degradation based on this.

Predictive maintenance is concerned with predicting failures before they occur. According to (Jardine, Lin, & Banjevic, 2006), maintenance methods capable of monitoring the condition of equipment for diagnostic and prognostic purposes can be divided into three main categories:

- statistical approaches,
- artificial intelligence approaches,
- model-based approaches.

There are positives and negatives to the use of each procedure. In the case of model-based methods, it is necessary to have mechanical knowledge and master the theory of the devices to be monitored. Statistical approaches require a mathematical background, which is why we are increasingly seeing the use of artificial intelligence. In 2018 (Baptista, 2018) compared artificial intelligence with statistical methods, observing superior results in favor of artificial infrastructure.

2 DISSERTATION GOAL

The most used types of maintenance in public transport are planned maintenance, unplanned maintenance and post-accident maintenance. The main problem of the above maintenance in our territory is the limited information about the planned performance of individual vehicles and therefore the difficulty to estimate the extent of planned and unplanned maintenance of individual vehicles and to quantify future financial costs.

In this dissertation, we focus on vehicle maintenance planning processes of transport companies and its types implemented according to the practices in the Czechoslovak environment. The main objective of this thesis is to develop a predictive maintenance plan for transport company vehicles, which would ensure the refinement of maintenance planning and thus the cost of its implementation. All models and computational processes are to be managerially controllable at least in scope:

- Manual adjustments to projected costs (e.g. for contract changes, inflation, etc.).
- Manual correction of fleet utilisation (scrapping plan and purchase of new vehicles).
- Manual correction of mileage plan for individual plants and depots/vehicles.

A maintenance planning system that can be operated in this way should also be used to model hypothetical situations and to quickly assess the future maintenance costs of the transport undertaking's fleet. The fulfilment of the main objective of the thesis is linked to the fulfilment of the sub-objectives, namely:

- To create inputs for a functional inventory plan ensuring optimal reliability of vehicle maintenance from the perspective of the haulier.
- To create a functional tool for planning preventive maintenance depending on the mileage.
- Develop a prediction model based on a combination of stochastic and classical methods.

- Develop a cost prediction model based on cost history in relation to the fleet.

One of the requirements for the whole system is its user controllability. For this reason, the author of the thesis defines the following datasets:

- Km coefficient (km_coefficient)
- Final km plan (plan_km_vysledny)
- Price estimate (estimate_price)
- Vehicle-specific limit (limit_vehicle)

3 PROCESSING METHODS AND METHOD OF SOLUTION

Currently, there are available database data sources, others exist only in paper form and are not systemically captured. However, they are relevant to the maintenance planning process and need to exist in a manageable form.

For the design of the process, a schematic simplification of the existing data sources is presented as follows:

- Maintenance history (hitorie_maintenance)
- Basic vehicle data (vuz_hlavicka)
- Prices for maintenance and repairs (pp_price)
- Vehicle transport performance (km_denni_pribl)
- Maintenance prescription (limit_vuz_orig)

New data sources are being introduced over and above existing ones:

- Plan km (plan_km)
- Map of vehicle type codes (ciselnik_typ_vozu)
- Vehicle disposal plan (plan_liquidation)
- List of new vehicles (novy_vuz_hlavicka)
- Maintenance schedule for newly acquired/intended vehicles (novy_vuz_prohlidka)
- Maintenance prescription reserve (reserve_limit)
- Use of reserve (use_reserve)

Within the results, the author proposes control mechanisms to serve the user to validate the whole model, but also to validate manual inputs and edit intermediate results. For example, there may be a situation where the km plan plans km performance for a depot and vehicle type, but the system user plans their disposal and does not replace them with new vehicles. For such a situation, logically, the whole model will not be able to find the corresponding vehicles to which to assign the planned km for the given planned km and therefore such performance will not be reflected in the maintenance plan. Or, conversely, there may be an "overload" of vehicles that normally

- Maintenance plan
- Unallocated km (nedistribuovane)
- Comparison of distributed km and actual performance (distribuovane_vs_actual_km)

The whole procedure is shown in Figure 7. The procedure contains three processes (preprocessors) that are used to prepare the intermediate results and an algorithm for the compilation of the vehicle maintenance plan. All results of the preprocessors can be user controlled and edited.

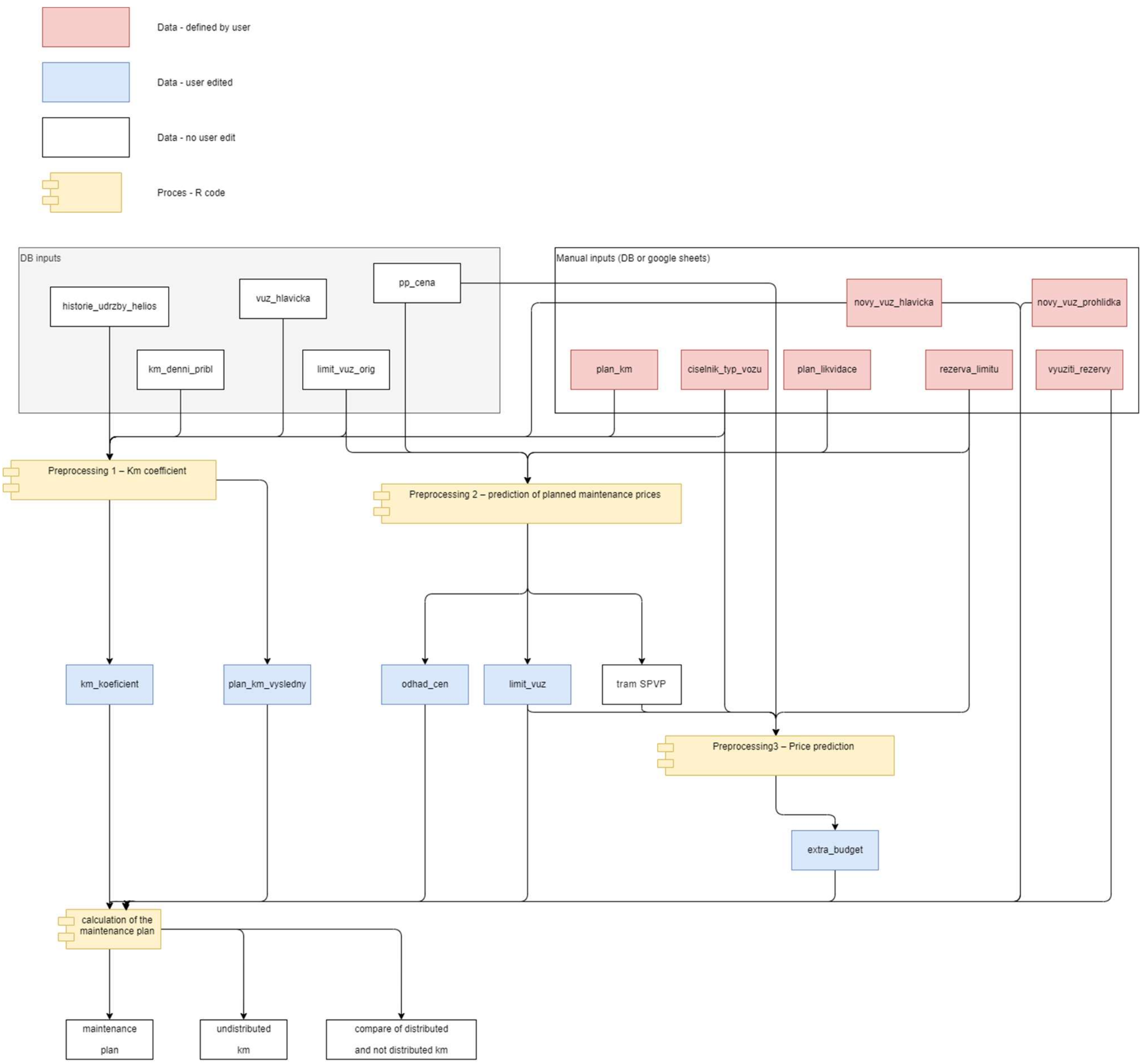


Figure 2 Maintenance plan development and costing process

3.1 Preprocessing 1 – vehicle km coefficient

This preprocessing consists of two successive processes. The first is the calculation of the km coefficient of the vehicle and the second is the subsequent distribution of the planned km for each vehicle.

If the proposed system is to be able to plan maintenance interventions, the implementation of which is overwhelmingly tied to a certain mileage interval (for each vehicle type there is a prescribed vehicle mileage in the range from-to), it is necessary to predict for each vehicle its mileage in order to determine when the vehicle reaches a defined threshold for the implementation of a certain level of prescribed maintenance.

Algorithm 1 vehicle km coefficient calcualtion

```
Inptuts: km_denni_pribl; vuz_hlavicka
Outputs: km koeficient
foreach vuz_hlavicka/typ_vozu // for each type of vehicle
    compute sum_typ_vozu = sum km_denni_pribl // calculate the total performance of the vehicle type
    foreach vuz_hlavicka/ID // for each vehicle in a given type
        compute sum_vuz = sum km_denni_pribl // calculate his total performance
        compute km_koeficient=sum_vuz/sum_typ_vozu // calculate its weight in a given type
    end
end
```

Algorithm 2 Km plan calculation

```
Inptuts: km_koeficient; plan_km; plan_likvidace
Outputs: km_plan_vysledny
set day = today+1 // set the day for tomorrow
while day<=max plan_km/day // for each day until the end of the plan
    foreach vuz_hlavicka/typ_vozu // for each type of vehicle
        compute sumkm_typ_vozu = plan_km/typ_vozu*váha dne // the power attributable to a given type of day, this is calculated analogously to Algorithm 1
        compute sum_vaha_typu = km_koeficient/typ_vozu where day<plan_likvidace/den_vyrazeni // the total weight of all vehicles of that type that are no longer in the process of being scrapped
        foreach vuz_hlavicka/ID // for each vehicle
            if day<plan_likvidace/den_vyrazeni // pokud vozidlo nebylo vyřazeno
                compute plan_km/day = km_koeficient/sum_vaha_typu*sumkm_typ_vozu // km vehicle performance for the day
            else set plan_km = 0 // if it is in liquidation, it has no performance
        end
    end
end
```

3.2 Preprocessing 2 - Prediction of scheduled maintenance prices by type

Further preprocessing addresses the issue of estimating the cost of planned maintenance interventions depending on the type of preventive maintenance intervention and the type of vehicle. Different methods such as Poisson process and time series models can be used to predict the cost of panned maintenance. Since the input data usually contains anomalies and cannot be completely cleaned, the author recommends the use of time series with an integrated moving average to "smooth out" any anomalies that the Poisson process would not be able to capture.

Algorithm 3 Calculating the cost of planned maintenance

```
Inptuts: historie_udrzby; pp_cena
Outputs: odhad_cen
foreach vuz_hlavicka/typ_vozu // for each type of vehicle
|  foreach historie_udrzby/typ_udrzby // for each type of maintenance
|  |  compute ARIMA (Kinney, 1978) // calculation of the time series of prices
|  end
end
```

3.3 Preprocessing 3 - Predicting other maintenance prices

In addition to planned maintenance during operation, there are additional maintenance costs arising from maintenance interventions that are difficult to predict. In this case, the following situations are particularly relevant:

- During a preventive maintenance intervention, vehicle defects are detected and need to be rectified.
- Maintenance after a breakdown.
- Maintenance after an accident.

Algorithm 4 Calculating the cost of unscheduled maintenance

```
Inputs: historice_udrzby; pp_cena; odhad_cen
Ouputs: extra_budget/neplanovana_udrzba
foreach vuz_hlavicka/typ_vozu // for each type of vehicle
|  set sum_PL=0
|  set sum_NP=0
|  foreach historie_udrzby/typ_udrzby // for each type of maintenance
|  |  if historie_udrzby/typ_udrzby ∈ PL // for planned maintenance
|  |  |  foreach histoire_udrzby/ID // for each maintenance
|  |  |  |  compute sum_PL=sum_PL+pp_cena/ID // retrieving the amount of planned
|  |  |  |  maintenance
|  |  |  end
|  |  else // for unscheduled maintenance
|  |  |  foreach histoire_udrzby/ID // for every maintenance
|  |  |  |  compute sum_NP=sum_NP+pp_cena/ID // retrieving the amount of planned
|  |  |  |  maintenance
```

```
    end
  end
end
Compute extra_budget/neplanovana_udrzba = sum_NP/sum_PL*odhad_cen // pro-rata
calculation of the cost of unscheduled maintenance
end
```

Calculation of the maintenance plan

The maintenance problem has network features just like PNS (process-network synthesis) problems, which are solved using the P-Graph methodology.

Figure 3 shows the most general generic PNS graph that is used for basic manufacturing systems. These systems can be continuous, batch or mixed. In continuous operation, the output of the unit is realized continuously from the start of operation. In batch operation, inputs are fed into the unit at one instant, then processed, and all outputs are also processed at one instant. The cycle is then repeated. A continuous unit can perform only one operation, but a batch unit can perform different tasks. The advantage of batch systems is that they are very flexible and therefore it is relatively easy to change the final products or production methods. In contrast, continuous systems are less expensive to operate in the long run. The PNS problem deals primarily with continuous systems. The elementary step then implements the transformation of input raw materials into products or output material.

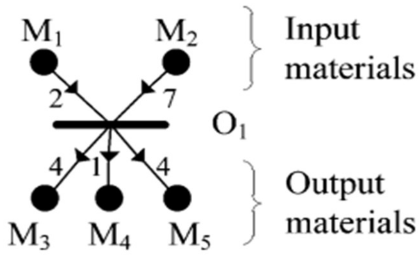


Figure 3 Graph representing maintenance units

Figure 3 right shows an already more complex network with three operating units $_{01-03}$ and input materials M_1-M_3, one intermediate product M_4, one product M_6 and one by-product M_5.

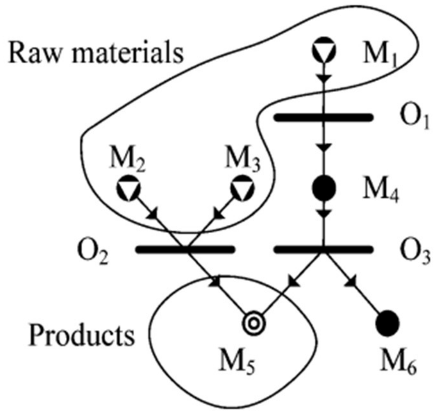
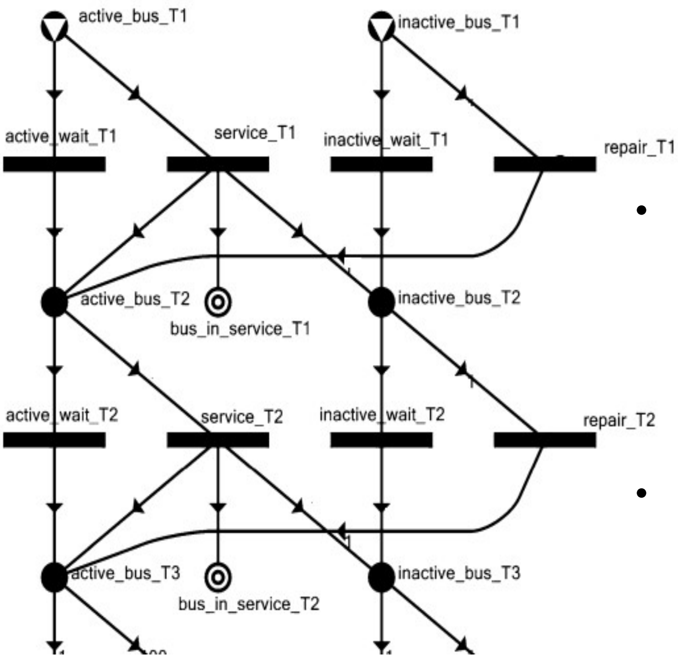


Figure 4 PNS network comprising three operating units and honour materials

To use P-charts to optimize the vehicle maintenance problem, the links between maintenance tasks and operational units need to be identified. These links are shown in Figure 5. The elements of the graph in the PNS categorization are on the right.



- Input:
  - active_bus_TN - The available, operable buses in period TN.
  - inactive_bus_TN - The unavailable, faulty buses in period TN.
  - bus_in_service_TN - The actually working buses in period TN
- Operational units:
  - active_wait_TN - The waiting of the active buses in period TN.
  - service_TN - The regular operation of buses in period TN.
  - inactive_waiting_TN - The waiting of the inactive buses in period TNs.
  - repair_TN - The maintenance of buses in period TN.
- Secondary-products:
  - bus_in_maintenance - maintenance state that can be reached proactively without waiting for non-operational state. Applies to scheduled maintenance

Figure 5 The relation between the terms used in PNS and the Maintenance problem

The constructed line graph represents operational days with structured activities represented as operational units. Vehicles move between activities and states over time. The graph has no edges in its initial state or only the value 1 can be considered on all edges.

The P-graph itself is algorithmic already in the generation of the structural model and is able to provide a solution already in its construction, which may not obey all conditions, but provides at least some solution. Due to the neglected constraints in this paper, the already generated graph represents the solution of the problem itself.

The following rules apply for creating the chart:

- Each vehicle is only in activity (operation) or maintenance on one day
- Vehicles enter maintenance only when they become inoperable. A vehicle becomes inoperable in the following situations:
  - The vehicle has exceeded the maximum allowable value of the prescribed inspection limit, optionally including tolerance.
  - The vehicle has incurred a maintenance requirement following an accident or other incident.

The graph is always generated from the day following the day from which the actual performance is known. On the input, it is known which vehicles for that day will be in maintenance (decisions from the previous day) and which will be in service. Thus, the following Algorithm 5 is always run after the close of the operating day and always after running Algorithm 2.

Algorithm 5 Procedure for creating a P-graph for vehicle maintenance

***Inputs**: historie_udrzby; km_denni_pribl; plan_km_vysledny; limit_vuz; rezerva_limitu; vyuziti_rezervy; vuz_hlavicka*

***Outputs:** maintenance plan*

```
foreach vuz_hlavicka/ID // for each vehicle
    set day = today+1 // set the day for tomorrow
    set plan_km_real/(day-1) = km_denni_pribl/day // set real vehicle performance for today from history
    while day<=max plan_km/day // by the end of the plan
        if provoz/day // is the vehicle in use on that day?
            compute plan_km_real/day = plan_km_real/(day-1)+plan_km/day // add the planned performance for the day
            set P=1 // set the inspection to the highest level
            while P<=max P // until the lowest level inspection
                if vyuziti_rezervy = 1 // is the reserve being used?
                    if plan_km_real-historie_udrzby/km > limit_vuz*(1+rezerva_limitu) // the limit of the reserve inspection has been reached?
                        Compute Algorithm 6// sub-algorithm of tour settings
                    else // continues until the next day
                elseif plan_km_real-historie_udrzby/km > limit_vuz // the inspection limit has been reached without a reserve?
                    Compute Algorithm 6 // sub-algorithm of tour settings
                else // continues until the next day
            end
        else set provoz/(day+1) = 1 // set the vehicle in service the next day
```

```
    end
end
```

Algorithm 6 Procedure for maintenance setting

```
Inputs: P parameter
Outputs: making records of inspections carried out
set provoz/(day+1)=0 // set up a tour for tomorrow
set PP=P // from the current inspection level
while PP<=max P // to the lowest inspection level
    compute historie_udrzby/km=plan_km_real // for each type of lower
    inspection, make a record of the inspection
end
```

The proposed Algorithm 5 does not consider the likelihood of unscheduled maintenance occurring. Its cost is computed independently in Algorithm 4. If the occurrence of unscheduled maintenance were stochastically considered, the entire maintenance plan itself would be very unstable because the maintenance plan itself is purely deterministic. In fact, it is represented in the P-graph by a by-product that represents the maintenance itself. This product is completely deterministic on the timeline. The occurrence of any event in any schedule based on any stochastic approach is a procedure that is never applied in deterministic schedules and belongs rather to simulation models.

The graph generation described in Algorithm 5 is realistically a degeneration of the stochastic P-graph, since it lacks the decision problem arising from capacity constraints. The advantage is the speed and the completely deterministic behavior of the entire proposed system. In practice, the results of the proposed process should be recalculated every day after the close of the operating day.

Neglected conditions

There are a set of conditions that should generally be considered in the vehicle maintenance planning procedure, but for practical reasons they are not relevant for the Czechoslovak environment.

Although these are conditions that are not themselves considered in the proposed procedure and algorithms, for each algorithm and step of the procedure it is pointed out that it would be appropriate to take the condition into account in the given algorithm or procedure. Neglected conditions:

- Resource capacities for planned and unplanned maintenance
- Connections and lines served
- Heterogeneous fleet
- Resource capacities for carrying out planned and unplanned maintenance represent human resources and areas for carrying out planned and unplanned maintenance.

In the Czechoslovakian environment, the resource constraints mentioned above do not represent a real problem for all types of inspection and maintenance except for large inspections for rolling stock, which in this thesis corresponds to the designation P1. As large inspections of rolling stock involve almost complete dismantling of vehicles at the layby, where some inspections realistically last a week and others involve the use of resources for up to three months, P1 inspections require a completely human management system.

It is a logical assumption that the need for especially unscheduled maintenance, which arises as a result of breakdowns or the expectation of breakdowns, primarily through direct wear and tear on the vehicle and its parts, is dependent on the area it serves. In practice, different wear and tear on different parts of the vehicles arises for vehicles that are deployed on services where they have to negotiate higher elevations or are otherwise more heavily loaded, e.g. with a higher number of passengers. Similarly, for accidents, it is logical to assume that there are places in the territory served with higher and lower accident risks. Thus, any proposed procedure and model should logically also take into account the specific links served and the wear and tear and risks that therefore arise on them.

In practice, km plans, arise on individual vehicle types. At the same time, transport undertakings try to have as homogeneous a fleet as possible, precisely because of maintenance and overall stock maintenance costs.

Transport companies acquire different types of vehicles precisely for the purpose of servicing areas, or lines and connections that have non-standard conditions. For example, in Liberec there is a group of buses of the transport company which are deployed on the lines to Bedřichov. These buses overcome the highest altitude and gradients and run at maximum load in winter, which means that they are subject to the highest demands in terms of performance and maintenance. This group of vehicles is logically not deployed on other routes. Similarly, in Prague, for example, an isolated group of vehicles is used, for example, for the line connecting the zoo and the Bohnice housing estate, which overcomes significant ascents/descents for most of its length. A similar situation prevails in other cities in the Czechoslovak area.

For the above reasons, the combination of input data means that the problem solves itself in combination with the operational approach. An analogous reasoning applies to the heterogeneity of the fleet.

Neglected conditions solution

If the simplifications in the form of neglected conditions in the form of technician capacities, maintenance crews, and maintenance area capacities were to be discontinued, the graph would have weighted edges (the weighting of the edges would represent time) and there would be additional input material to represent technicians, maintenance crews, and maintenance area capacities. The procedure for creating such a graph is described in (Adonyi, Heckl, & Olti, 2013).

The P-graph model is able to exploit the structural properties of the problem and, as a consequence, reduce the search space. The general branch and bound (B&B) algorithm usually decides on a single decision variable in a single step, but the accelerated branch and bound (ABB) algorithm, which can be used in P-graphs, is able to decide on multiple integer values at once.

The specific procedure of how to solve PNS decision problems using ABB is described in (Friedler, Varga, & Fan, 195).

4 CASE STUDY

The whole procedure proposed in this thesis, including the algorithms, was fully implemented in the R language by the author of this thesis with the contribution of Kateřina Šulcová Ph.D. on data provided by Dopravní podnik Ostrava a.s.

The whole procedure and algorithms were validated and verified in cooperation with the management employees responsible for the creation of vehicle maintenance plans and its outputs and benefits were presented at the joint meeting of the Transport Operational Groups of the Association of Transport Operators of the Czech and Slovak Republic.

Real solution

For validation and verification, it was not possible to have direct access to the operational databases and the whole system had to be built in such a way that it did not burden any operational system in any way. Even if the procedure is implemented at another transport undertaking, the system must first be built in a sandbox environment so that its operation does not compromise the transport undertaking's operational systems in any way and can be effectively validated and verified.

In the present case and at the time, the transport undertaking chose to use Microsoft's Power BI tool to read the database data, which already existed for other purposes. The entire process is shown in Figure 6.

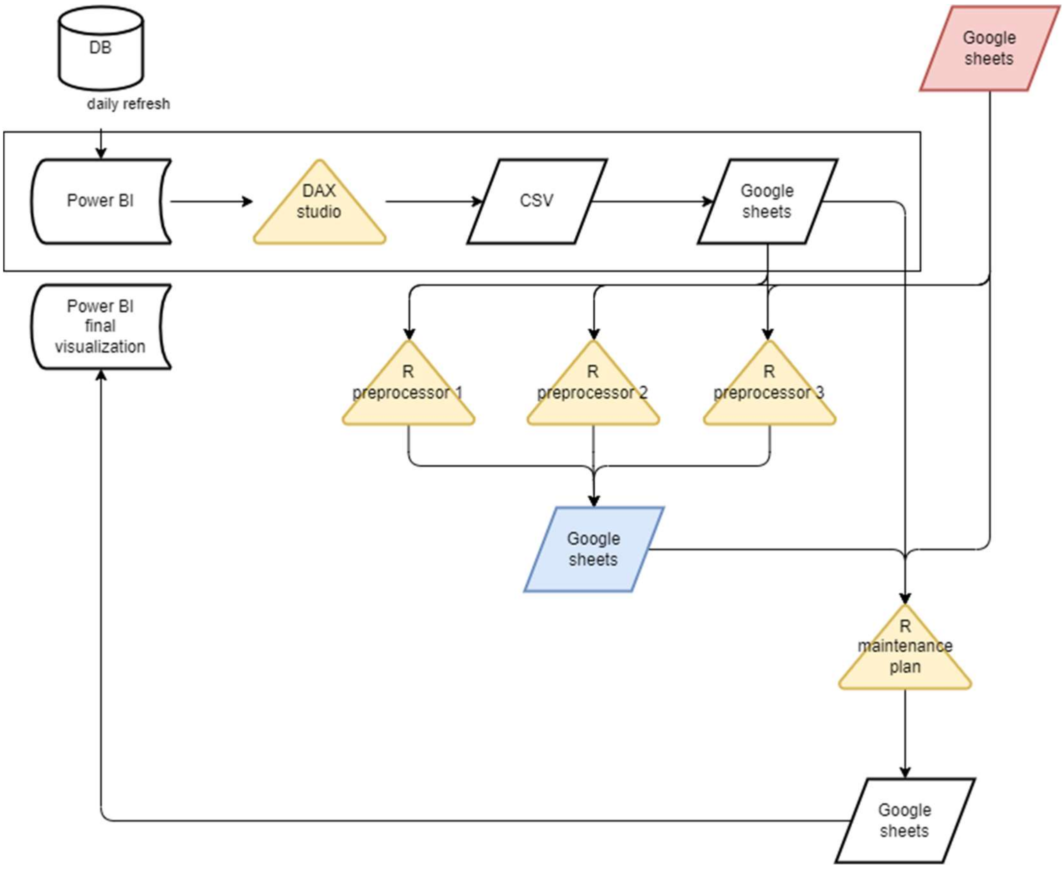
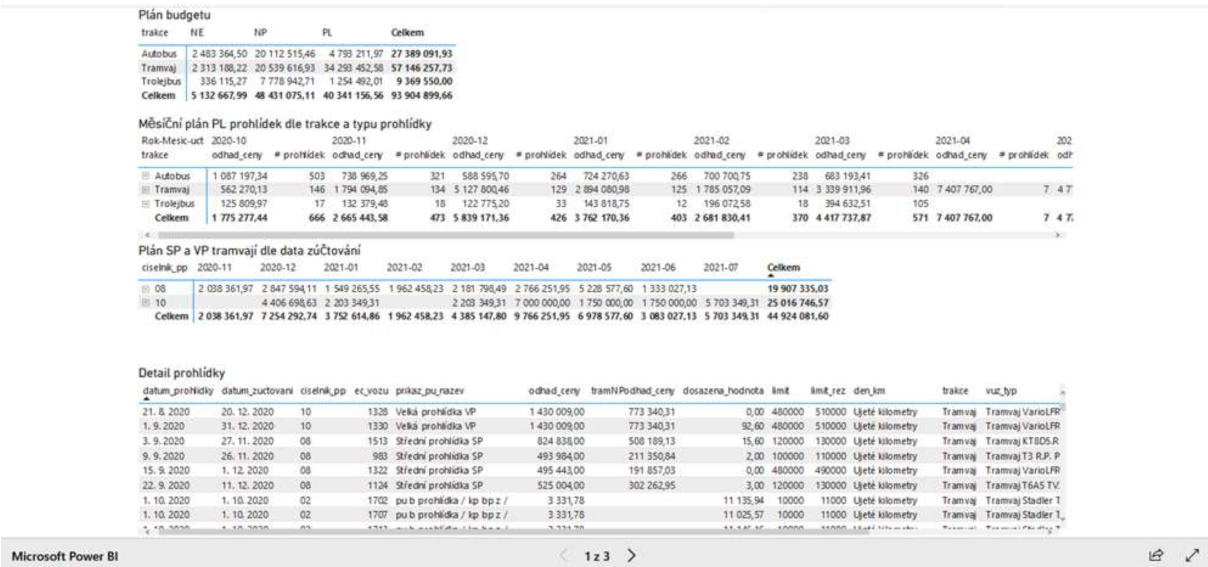


Figure 6 Process of indirect reading and data processing

The resulting maintenance schedules were then loaded back into Power BI, where a user-friendly presentation was created for them with the option of filtering by traction, vehicle types, etc. The resulting presentation is shown in Figure 7.



Plán budgetu

trakce	NE	NP	PL	Celkem
Autobus	2 483 364,50	20 112 515,46	4 793 211,97	**27 389 091,93**
Tramvaj	2 313 188,22	20 539 616,93	34 293 452,58	**57 146 257,73**
Trolejbus	336 115,27	7 778 942,71	1 254 492,01	**9 369 550,00**
Celkem	**5 132 667,99**	**48 431 075,11**	**40 341 156,56**	**93 904 899,66**

Měsíční plán PL prohlídek dle trakce a typu prohlídky

Rok-Mesic-uct	2020-10		2020-11		2020-12		2021-01		2021-02		2021-03		2021-04		202
trakce	odhad_ceny	# prohlídek	odhad_ceny	# prohlídek	odhad_ceny	# prohlídek	odhad_ceny	# prohlídek	odhad_ceny	# prohlídek	odhad_ceny	# prohlídek	odhad_ceny	# prohlídek	odh
Autobus	1 087 197,34	503	738 969,25	321	588 595,70	264	724 270,63	266	700 700,75	238	683 193,41	326			
Tramvaj	562 270,13	146	1 794 094,85	134	5 127 800,46	129	2 894 080,98	125	1 785 057,09	114	3 339 911,96	140	7 407 767,00	7	4 7
Trolejbus	125 809,97	17	132 379,48	18	122 775,20	33	143 818,75	12	196 072,58	18	394 632,51	105			
Celkem	**1 775 277,44**	**666**	**2 665 443,58**	**473**	**5 839 171,36**	**426**	**3 762 170,36**	**403**	**2 681 830,41**	**370**	**4 417 737,87**	**571**	**7 407 767,00**	**7**	**4 7**

Plán SP a VP tramvají dle data zúčtování

ciselnik_pp	2020-11	2020-12	2021-01	2021-02	2021-03	2021-04	2021-05	2021-06	2021-07	Celkem
08	2 038 361,97	2 847 594,11	1 549 265,55	1 962 458,23	2 181 798,49	2 766 251,95	5 228 577,60	1 333 027,13		**19 907 335,03**
10		4 406 698,63	2 203 349,31		2 203 349,31	7 000 000,00	1 750 000,00	1 750 000,00	5 703 349,31	**25 016 746,57**
Celkem	**2 038 361,97**	**7 254 292,74**	**3 752 614,86**	**1 962 458,23**	**4 385 147,80**	**9 766 251,95**	**6 978 577,60**	**3 083 027,13**	**5 703 349,31**	**44 924 081,60**

Detail prohlídky

datum_prohlidky	datum_zuctovani	ciselnik_pp	ec_vozu	prikaz_pu_nazev	odhad_ceny	tramNPodhad_ceny	dosazena_hodnota	limit	limit_rez	den_km	trakce	vuz_typ
21. 8. 2020	20. 12. 2020	10	1328	Velká prohlídka VP	1 430 009,00	773 340,31	0,00	480000	510000	Ujeté kilometry	Tramvaj	Tramvaj VarioLFR
1. 9. 2020	31. 12. 2020	10	1330	Velká prohlídka VP	1 430 009,00	773 340,31	92,60	480000	510000	Ujeté kilometry	Tramvaj	Tramvaj VarioLFR
3. 9. 2020	27. 11. 2020	08	1513	Střední prohlídka SP	824 838,00	508 189,13	15,60	120000	130000	Ujeté kilometry	Tramvaj	Tramvaj KT8D5.R
9. 9. 2020	26. 11. 2020	08	983	Střední prohlídka SP	493 984,00	211 350,84	2,00	100000	110000	Ujeté kilometry	Tramvaj	Tramvaj T3 R.P. P
15. 9. 2020	1. 12. 2020	08	1322	Střední prohlídka SP	495 443,00	191 857,03	0,00	480000	490000	Ujeté kilometry	Tramvaj	Tramvaj VarioLFR
22. 9. 2020	11. 12. 2020	08	1124	Střední prohlídka SP	525 004,00	302 262,95	3,00	120000	130000	Ujeté kilometry	Tramvaj	Tramvaj T6A5 TV.
1. 10. 2020	1. 10. 2020	02	1702	pu b prohlídka / kp bp z /	3 331,78		11 135,94	10000	11000	Ujeté kilometry	Tramvaj	Tramvaj Stadler T
1. 10. 2020	1. 10. 2020	02	1707	pu b prohlídka / kp bp z /	3 331,78		11 025,57	10000	11000	Ujeté kilometry	Tramvaj	Tramvaj Stadler T

Figure 7 Presentation of the maintenance plan in Power BI

5 ACHIEVED RESULTS

During the development of the essential parts of this dissertation in the Czechoslovak area, knowledge-based methods for the development of regular and irregular maintenance plans and post-accident maintenance were still used in public transport companies. The associated budgets for the above types of maintenance were also produced using knowledge-based methods. Vehicle maintenance costs represent a significant proportion of the costs of transport undertakings.

Thus, the aim of this work was to propose a procedure and algorithms to speed up and refine the processes leading to the design of vehicle maintenance plans and associated budgets. The procedure and algorithms were intended to allow control of intermediate results and user input into the processes of cost prediction, fleet utilisation and individual vehicle performance prediction. Similarly, the sub-objective of creating inputs for a functional inventory plan that ensures optimal vehicle maintenance reliability from a carrier's perspective was met.

In this paper, a general procedure for the development of vehicle maintenance plans and the determination of maintenance costs is proposed in such a way as to speed up and refine these processes and verified in practice on a selected transport company, where the proposed procedure and algorithms were validated and verified in their concrete form. For future implementation and development, the author provided practical experience and guidance for implementation in the operational environment of transport enterprises in the case study.

The proposed procedure and algorithms partially retained knowledge-based methods but made significant use of a combination of data processing-based methods and traditional algorithms. Similarly, practical or data cleaning methods must also be used in practice.

Thus, it can be concluded that the main motivation for this dissertation was fulfilled, i.e. the development of a procedure and algorithms that would serve to support managerial decision making in vehicle maintenance planning and facilitate the costing of planned and unplanned maintenance. Thus, the result of this dissertation may find its application in practice in transport companies operating public transport throughout the Czechoslovakia.

6 BENEFITS OF A DISSERTATION

Regarding the applicability of the proposed procedure and algorithms in practice for the Czechoslovak environment, steps are proposed to include variables that were omitted in this dissertation. Their list and place of inclusion are clearly listed in the full version of the thesis.

The proposed procedure uses algorithms that are all implemented in available libraries in R and Python, and the proposed system can be replicated on any transport company by anyone with only basic knowledge of programming and mathematics.

Based on a thorough literature review, it can be concluded that the proposed approach and algorithms are novel and original in their combination. The reviewed literature does not describe any procedure and algorithms for the constraining conditions and requirements for controllability by system users that are required in this dissertation.

The proposed procedure and algorithms are designed to not affect the existing data preparation processes and data recording method. In the event of major changes in the data base or the method of data recording and collection or refinement of the data base, the results of the proposed procedure and algorithms will also be more accurate.

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Honors & awards

[I] Session's Best Paper AwardSession's Best Paper Award

Issued by The 22nd World Multi-Conference on Systemics, Cybernetics and Informatics · Jul 2018; Session: Computer Science and Engineering paper: Detection of Minimal Set of Trips Causing the Necessity to Use Extra Vehicle for Vehicle Scheduling Problem

Internships and courses

[I] E.I.D.S. Summer Workshop 2018, 14–17 May 2018, Umea, Sweden

[II] UITP Training on Planning and Scheduling of Bus Operations, 16-18 April 2018, Hamburg, Germany

[II] The 22nd World Multi-Conference on Systemics, Cybernetics and Informatics: WMSCI 2018 July 8 - 11, 2018 ~ Orlando, Florida, USA

SOUHRN/ABSTRACT

V disertační práci autor provedl vyhodnocení vývoje údržby, její kategorizace a obecných přístupů k jejímu plánování. Následně autor v práci provedl analýzu současného stavu vědeckého poznání a shrnul metodiky, které se v plánování údržby vozidel uplatňují, a to včetně stochastických modelů a modelů časových řad. Dále se v rámci práce zaměřil na současný stav v praxi se zaměřením na československé prostředí, pro které by měly výsledky této práce výt využitelné. Na základě současné praxe pak autor definoval rozsah metod vhodných k užití k dosažení cílů, které si v rámci této práce vytyčil. Pro další postup autor definoval rozsah předpokladů a opomíjených podmínek, které odůvodnil. V samotném návrhu postupu a algoritmů autor zvolil vhodné formalismy, zejména pak samotný P-graf, k němuž uvedl způsob jeho generování, resp. degeneraci základní úlohy P-grafu. Pro jednotlivé prvky systému byly definovány jejich vazby, následnost při užití a byly definovány nové prvky systému, které jsou v praxi reprezentovány datovými sadami. Autor navrhl i postup zakomponování omezujících podmínek, které v této práci cíleně opomenul a odkázal na již existující práce, s jejichž pomocí lze rozšířenou úlohu vyřešit. Celý navržený postup a algoritmy byly otestován na datech vybraného dopravního podniku, kde byly validovány a verifikovány. Autor práce poskytl i popis architektury výsledného řešení a soupis praktických problémů včetně jejich řešení, aby bylo možné výsledky této práce snadné replikovat a výsledky uplatnit v praxi.

In the dissertation the author evaluated the development of maintenance, its categorization and general approaches to its planning. Subsequently, the author analysed the current state of scientific knowledge and summarised the methodologies applied in vehicle maintenance planning, including stochastic and time series models. Furthermore, the thesis focuses on the current state of the practice with a focus on the Czechoslovak environment, for which the results of this thesis should be useful. Based on the current practice, the author then defined a range of methods suitable for use to achieve the goals he has set out within this thesis. For further progress, the author defined a range of assumptions and neglected conditions, which he justified. In the actual design of the procedure and algorithms, the author has chosen appropriate formalisms, in particular the P-graph itself, for which he has given the method of its generation, or the degeneracy of the basic P-graph problem. For the elements of the system, their links and sequence of use were defined and new elements of the system were defined, which in practice are represented by datasets. The author also proposed a procedure for incorporating constraint conditions, which he purposely omitted in this paper, and referred to existing works with the help of which the extended problem can be solved. The entire proposed procedure and algorithms were tested on data from a selected transport company, where they were validated and verified. The author has also provided a description of the architecture of the resulting solution and a list of practical problems including their solutions, so that the results of this work can be easily replicated and the results applied in practice.