Reviewing the Decision Criteria for Developing the Work Schedule of Train Attendant Teams

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Summary
Developing work schedules for train attendant teams and engine drivers is now a challenge for rail carriers. It is essential that the work time of employees during shifts is used in the best possible way. This paper discusses the decision criteria which limit the planning of train teams' work. This is hindered primarily by rolling stock circulations, technical time, changes of trains handled by one carrier, timetable and the reduced number of links outside rush hours, as well as delays in the railway network. Depending on the type of transport, the problem may be regional or domestic. The work has been based on analysis of Koleje Dolnośląskie's data.

Keywords: railway, timetable, schedule, conductor teams

1. General conditions

Trains are operated by train crews consisting of the engine crew and train attendant team or just the engine crew. The train attendant team in slow trains which transport passengers should consist of at least a train manager, unless his/her physical tasks are fulfilled by another employee or by technical equipment. Passenger trains can run without the train manager if a door shutting function is provided when travelers get off and on the train, and the door shutting is signaled to the train operator through technical devices [3].

The train manager is responsible for the train on a designated route section and is superior to all train operating employees, except for supervisors and inspectors. The conductor, in turn, is in charge of commercial and transportation duties (selling and checking tickets, activities related to the takeover and handover of the train, monitoring the law and order on the train). With regard to engine drivers, aside from adhering to statutory work time [9], the following are also important:

- knowledge of the route,
- type of vehicle the employee is authorized to be on,
- type of traction (diesel, electric),
- permission to go abroad,
- depending on permissible route speed and traffic control devices, selection of two- or one-person teams.

Due to formalities, it is necessary to arrange the work time in the settlement period and define this period (it may last from one to three months). It is necessary to pay attention to days off work in this settlement period (Sunday, holidays and bank holidays). The number of employees should exceed the number of shifts as there is a likelihood of potential accidents and replacements. For this reason, everyone has substitute shifts in their schedule, which allow replacements in the settlement period. This substitute shift should be about 22% [4].

While planning the timetable for engine drivers, it is necessary to start from analyzing the current train timetable and checking how many employees are: authorized to operate a specific type of vehicle, familiar with a specific route, allowed to go abroad. These are the most important requirements, according to which it is necessary to start drawing up the schedule from the lowest number of employees satisfying the requirements. Another important issue is to check if the employees' certificates are still valid. According to the regulations [4], the employee's shift must not fall on the third night in a row (11:00pm-05:00am), third Sunday in a row or start during the previous shift. The

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rest time must be 12 hours. When a few employees meet the requirements, the first employee should be the one whose period after the end of the previous shift is the longest. Substitute shifts are established on the basis of calculating the time an employee needs in the settlement period to correspond to the standard work time. Evenly distributed substitute shifts ensure the employee can cover for the sick, the transferred or those off work. If employees cannot find employment during the substitute shift, they should be assigned replacement jobs which correspond to their competences. It is also necessary to establish whether the number of days off work in the employee's work time schedule is at least equal to the number of Sundays and holidays in a specific month. Scheduled employee holiday leave must be considered as well [9].

The work time of the train attendant teams is regulated by the Labor Code. Art. 129 § 1. of chapter II on standards and general work time emphasizes the following: "the work time must not exceed 8 hours a day and, on average, 40 hours in a five-day week in the settlement period of max. 4 months, subject to art. 135-138, 143 and 144 [9]." Chapter IV on systems and work time schedules allows certain exceptions. Art. 135 § 1 states: "if the kind of work or its organization justify it, flexible working hours can be adopted and it is permissible to extend the daily work time, up to 12 hours in the settlement period of max. 1 month. The extended daily work time is compensated with a shorter work time on certain days or days off work." When assigning shifts to particular persons, it is necessary to remember that the employee must have 11 hours of continuous rest with regard to extended work time and a continuous 35-hour period off work a week. In terms of eight-hour work time, this time usually falls on weekends. A special case is when employees are transferred to another hub. The time of a business trip in which the employee does not fulfill work duties is not included in the work time. The business trip must not prevent night rest (at least 8 hours) and day rest (at least 11 hours) [8].

The rail hub is a spot in which train attendant teams start and finish their work. Here, employees report that they are ready to work and collect the required devices (ticket printers, terminals) and documents (work sheets). When finishing their work, train managers and conductors account for previously collected documents and devices.

In view of the fact that work time depends on the timetable and there is a need to finish a working day in the home hub, it is not possible to define an explicit length of the shift. When scheduling, it is necessary to follow the Labor Code and establish duties which do not exceed 12 hours. The nominal work time is considered to be 6-10 hours (+/-2 hours), and in special cases it can be extended to reach 12 hours.

2. Boundary conditions in planning the work of train crews

The crews can go by trains of a specific carrier. As far as returning is concerned, it is possible to consider transportation by other companies' trains if the carrier does not provide any links or when the trains run too seldom.

The takeover and handover of the train in particular spots differ in terms of time, depending on the location of rail hubs and control points within the station.

The takeover of the train in the platform is concerned with checking the train cars (carriages). This involves an inspection of the completeness of signs at the end of the train, feces level in toilets, the presence of fire extinguishers and identification of potential signs of devastation. The takeover also includes the time required to move from the rail hub to platforms as well as preparation for work. In the hub, it is necessary to carry out administrative activities: provide the train dispatcher with a terminal number, report readiness for work, collect the work sheet and paper rolls to print tickets, and check the notice board for any new resolutions.

When the conductor reaches the platform, he or she has to take a written order from the traffic controller regarding warnings on the route to be communicated to the engine driver afterwards. The train takeover at the platform combined with a detailed braking test differs from the previously described procedure as it involves an obligatory braking test. It is required once a day, most frequently before the train departs. A simplified test is performed for each change of travel direction. To conduct the braking test, the train manager is not always required. For vehicles equipped with pneumatically combined brakes, the engine driver can conduct the test on his/her own and observe the lights on the panel in the cabin. As for vehicles equipped with regular brakes, the train manager is indispensable. While the engine driver brakes and releases, the train manager taps with a railway hammer and listens to the sound emitted by wheel sets. If the sound is hollow and low, it means the brakes are pressed and when the sound is resounding and high, they are released, that is, the brake blocks do not touch the disks. Rims are also inspected visually for any cracks. The simplified braking test differs from the detailed test with inspection of the operation of brakes in the last carriage of the traction unit. It does not require so much time and therefore is included in the "train takeover at the platform". The train handover is based on inspecting the train cars described in the train takeover procedure, finishing the work sheet and accessing the rail hub where it is obligatory to account for previously collected documents and devices.

The train team work planning can be combined with rolling stock circulations. In this way, it is possible to exclude train changing, which is not guaranteed and not always possible due to delays. If it is unfeasible to combine the entire duty with the circulation, a proper time for train changing must be established.

One circulation takes a few days and ends at its starting station. For this reason, there are several vehicles running in such a circulation and it is not clear whether they can return to the starting station on the same day. The train stays at various stations for the night. This leads to additional difficulties in creating team timing related directly to circulations.

Designing team timing is closely associated with train delays. They are critical when it is necessary to change trains. It is not advisable to delay the train by waiting for the team from another train which is behind schedule. Based on the data concerning train delays on a specific line, a delay distribution function was established (Fig. 1). To do so, the links handled by the carrier have been divided into loaded and unloaded lines.

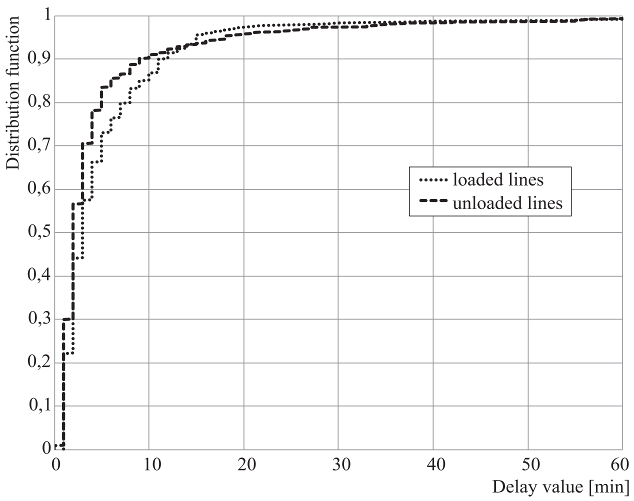

Fig. 1. Delay distribution function [own elaboration based on data from rail carrier]

The loaded lines represent at least one train per hour, double-track sections, modern rail traffic control devices and electric traction. As for unloaded lines, the trains go less frequently than one train per hour, go through single-track sections, are equipped with older rail traffic control devices and can be non-electric.

Fig. 1 demonstrates that loaded lines result in longer delays when compared to unloaded lines. The purpose is to establish one limit delay for both lines so that crews can switch lines and get on the opposite line, and the delay guarantee must be 95%. In this way, it is possible to eliminate delays deviating from others, occurring rarely (accidents, unscheduled repairs, traffic control system failures). In effect, the distribution function 0.95 for loaded lines has been adopted. This is tantamount to the approximate delay of 25 minutes. This period has been adopted as the minimum time for the crew to switch the train.

3. Planning timetables based on boundary conditions

The location of rail hubs can be divided into two types:

- hubs located at railway junctions, being natural sources of increased rail traffic,
- hubs at the end/beginning of the route.

It is important that the network of these junctions is distributed evenly throughout the region, taking into account the railway line system and natural flow of peripheral centers to larger centers. While choosing the location of hubs, the following must be considered:

- number of trains which depart from a specific station in the morning, according to the train timetable,
- distance from the nearby hub and potential transport,
- infrastructure possibilities of location of the hub at the station,
- social factors related to earnings in the specific area.

More attention should be paid to trains which wait for the first journey in the morning at end stations for the night. Sometimes an engine driver and conductor have a night duty. Depending on the frequency of running, the length of lines and permissible route speed, the number of vehicles may vary. It is not always worth locating the rail hub at such stations. It depends on the number of trains which depart there. The surplus of trains at starting stations is presented in Fig. 2. The vertical axis stands for the time during the day, while the horizontal axis represents the total number of trains. At the beginning of the day, no trains leave the station. When the first rolling stock is to leave the station and no train has managed to arrive, the first train departs before arrival at the station. Two curves illustrate the total number of trains cleared and taken over. The field between them is the surplus of cleared trains in relation to taken over trains. In practice, this means there is a need to transport the crew for the first train runs. This diagram does not apply to junction stations where the number of trains changes disproportionately during the day. This results from the fact that various trains cross.

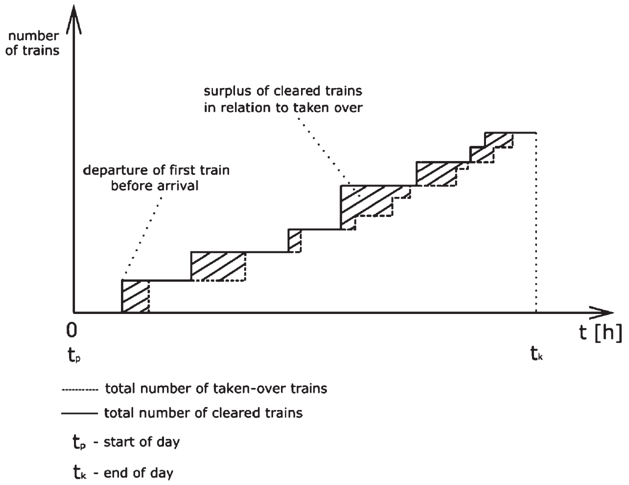

Fig. 2. Visual diagram of the surplus of trains at the end station [own elaboration]

When drawing up the crew work schedule, it is necessary to take into consideration various decision criteria. The author's work experience enables the definition of mathematical formulas related to: employee travel costs (1), night shift costs (2), hub organizing costs (3), total duty duration (4), time reserve (5), and required number of train crews (6). These notions have been defined further in the work.

When planning the crew for the morning shift of the first departure from a station at which there is no crew grouping spot, it is necessary to make a decision related to the cost-efficiency of transporting employees by car to the nearest hub, or a night shift on the train. Depending on the length of the travel distance, we can distinguish higher or lower costs. The longer the distance, the higher the cost, whereas the costs of sleeping in the train rise along with the time of providing the employee with remuneration. The longer the journey, the longer the night service, so it is more profitable to sleep in the train than travel in the morning to the starting point of the train. The transport time and travel distance in undisturbed conditions due to traffic holdup, repairs, etc. change proportionally. When the distance to be covered is longer, more time is needed.

The costs related to transporting employees (K_D) for the morning run into the place where there is no hub can be defined as the total of elements expressed in the equation (1). Fig. 3 presents the example of results for these dependencies (1) considering prolongation of the transportation route and return and related longer time of transport and return.

$$K_D = Q_k(t_d + t_o + t_p) + n \cdot Q_p \cdot t_d + R(s_d + s_p) + m \cdot Q_p \cdot t_p \quad (1)$$

where:

Q_k – hourly rate paid to the driver [PLN/h],
t_d – transport time [h],
t_o – waiting time [h],
t_p – return time [h],
n – number of employees transported,
Q_p – hourly rate of the crew member [PLN/h],
R – rate per kilometer of using the vehicle [PLN/km],
s_d – transport distance [km],
s_p – return distance [km],
m – number of employees transported back.

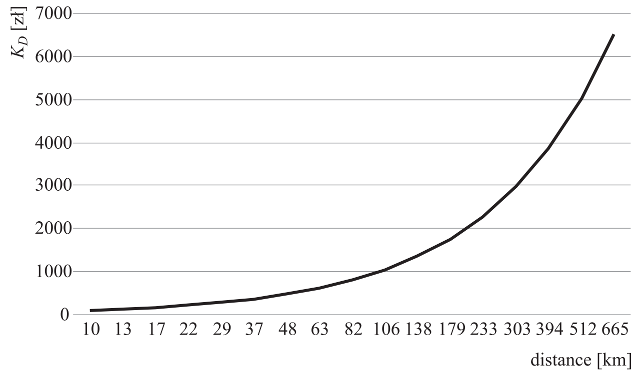

Fig. 3. Dependence of employee transport costs on distance for the equation (1) [own elaboration]

Night shift cost (K_N) can be expressed through the following equation:

$$K_N = Q_p \cdot t_n \quad (2)$$

where:

Q_p – hourly rate of the crew member [PLN/h],
t_p – night accommodation time [h].

When planning a new crew grouping spot, it is necessary to adjust it to ensure proper employee conditions. Depending on the number of employees who start and finish work there, it is possible to transport them to this place by company car and take them back after the work is finished, or create a permanent hub there. Fig. 4 shows two curves indicating the rising costs of employee transportation along with the rising number of employees as well as costs related to organization of the hub, whose curve inclines at a smaller angle. There is a limit of cost-efficiency for creating the hub when transporting ceases to pay off and organization of the hub is cost-efficient. The cost-efficiency curve indicates the selection of the optimal solution in terms of costs dependent upon the number of employees in the specific hub.

The hub organization entails fixed costs related to the rental of rooms, and this is why this curve does not start from 0. The transportation can be settled by kilometers.

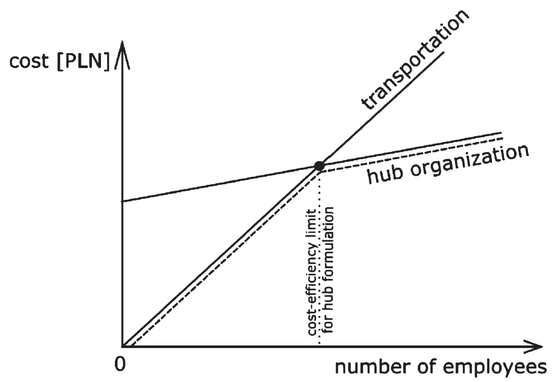

Fig. 4. Approximate costs related to transporting employees and organizing the hub [own elaboration]

The costs related to organizing a hub for crews (K_G) and its maintenance can be defined through the formula (3). Fig. 5 shows the results of the calculation of dependencies (3) with reference to the space of the premises rented in the first month.

$$K_G = K_L + K_E + K_W + K_U + K_P \tag{3}$$

where:
- K_L – premises rental cost [PLN],
- K_E – service charges [PLN],
- K_W – premises equipment costs [PLN],
- K_U – premises cleaning costs [PLN],
- K_P – remuneration for employees who settle accounts with conductors [PLN].

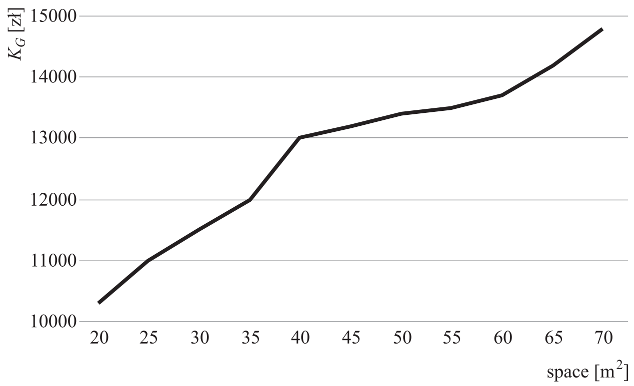

Fig. 5. Example dependence of hub organization costs on premises space for the formula (3) [own elaboration]

Total duty duration can be specified on the basis of the following:

$$T_C = \sum_{i=1}^{2} t_{oi} + \sum_{i=1}^{n} t_{ji} + \sum_{i=1}^{n} t_{pi} \tag{4}$$

where:
- t_o – handling time (1-initial, 2-final) [h],
- t_j – duration of the route [h],
- t_p – break time [h].

If the breaks are longer than one hour, it is possible to change the mode of transport. To determine if this solution is reasonable, the time reserve notion (T_R) was adopted. This is related to communication. The following dependency must be considered:

$$T_R = \sum_{i=1}^{2} t_{pi} + t_t + \sum_{i=1}^{2} t_{bi} \tag{5}$$

where:
- t_p – travel time on the section (1-transport and 2-return) [min],
- t_t – technical time (braking test, train handover/takeover) [min],
- t_b – safety time related to connection (1-time for first train change, 2-time for second train change) [min].

The required number of train crews (engine crew and train attendant crew) according to [1] can be calculated through the formula (6). Fig. 6 depicts an example of calculation results of the number of train crews for various lengths of sections handled by one crew.

$$n = \frac{1}{24}\left(\frac{2L}{v_h} + t\right) N \cdot k \tag{6}$$

where:
- L – length of section handled by one crew [km],
- v_h – commercial speed [km/h],
- t – time for train takeover and handover [h],
- N – number of trains per day,
- k – coefficient showing number of times the real crew work time is in the day.

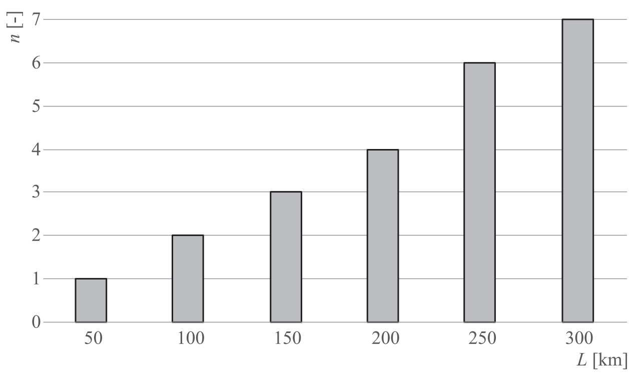

Fig. 6. Dependence of the required number of train crews on the length of the section handled by one crew for the formula (6) [own elaboration]

The commercial speed included in the formula (6) depends on the speed of the vehicle, traffic conditions and stop time.

4. Planning models

The following division of work time scheduling methods has been adopted: linear model (sectional) and circulation model. The former is concerned with preparing crew work so that they are assigned to particular route sections, while the latter assigns crews to circulations. Both models have advantages and drawbacks, as listed in Table 1, based on the author's own work experience.

The best solution has been deemed the sectional-circulation model which eliminates the vices of both methods separately. In the first place, the schedule is adapted to the circulation to eliminate uncertain train changes; and in the case of longer breaks, a free link is looked for.

5. Summary and conclusions

The issue of scheduling the train crews' work time is not explicitly defined in the literature. Foreign articles [5–7] present graphic interpretations of the train attendant crew's work schedule. Two publications [2, 4] show general stages of planning the schedules. Due to the fact that creating the crew's work timing is strictly related to the current train timetable and conditions of the specific carrier, each case should considered separately.

When planning the assignment of crews to particular routes, it is necessary to review boundary conditions. This entails hours and the frequency of running on specific routes which the shifts must be adapted to. With regard to lines reaching the borders of the country, it is necessary to concentrate on where the crew changes. At the beginning of the duty, the train is taken over and, at the end, handed over. This is concerned with administrative actions in the rail hub and actions related to the train itself. Depending on the stage of circulation that the train is at, the time for takeover and handover of the train may vary. When the train departs, it is necessary to conduct the braking test and the crew must reach the train stopping place. When the train arrives, the crew must hand over the train to the stopping group (if any) and have time to reach the hub. If the train is taken over or handed over directly at the station, the takeover/handover time is shorter. This differs depending on the location of rail hubs and control points within the station.

A favorable solution is to combine the rolling stock circulations (circulation model) with the crew work timing. In this way, it is possible to exclude train changes which, due to delays, may prove to be unfeasible. It is not always possible to combine the circulation with the crew so that their duty ends in the home hub. For this reason, analysis of delays of trains of the specific rail carrier was carried out and the delay distribution function with a value of 0.95 was determined. This corresponds to a delay of 25 minutes and is deemed the minimum time for train change. We can also distinguish the linear (sectional) model which, when combined with the circulation model, forms a timing system with a limited number of train changes.

The rail hubs have been divided into two types: hubs located at railway network junctions and hubs at the beginning and end of the route. As for determining the network of rail hubs, the emphasis is placed on the

Table 1

Advantages and drawbacks of the sectional and circulation models

Linear (sectional) model	
Advantages	**Drawbacks**
• conductors know the routes well (are able to instantly inform travelers about a need to change trains without checking this in the timetable), • the work schedule includes shorter breaks as crews are not assigned to a specific vehicle (better work efficiency), • handling routes close to the hub (when returning to the hub, several conductors do not meet in one train).	• train delays may prevent or hinder the change of trains, • fixed crew per route may get acquainted with the travelers easily and this may result in various deceptions.
Circulation model	
Advantages	**Drawbacks**
• low sensitivity to delays, • no need to create a separate timetable for crews as it complies with the circulations, • no meetings of several crews in one train.	• longer breaks (reduced work efficiency), • more likely to meet engine drivers and conductors who they know well, which may result in failure to follow the procedures (e.g. braking test), • difficulties related to employee's return to the home hub.

[Own elaboration]

number of trains which depart from and arrive at specific stations, as well as analysis of transporting crews by car into the specific spots. With respect to the first trains that depart from the specific station for morning runs, it is essential that we focus on the number of trains departing in the morning from the station before the first train with a crew comes. Depending on this, a suitable number of crews in this spot is required.

Depending on the length of the night duty, it is possible to choose to transport the employee in the morning for the first departure from the station. To make the final decision, the work suggests formulas related to employee transport costs and night shift costs. The organization of a hub in a specific spot is determined by the number of employees who start and finish work there. The creation of a hub is a considerable initial cost when compared to transporting employees by company car.

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