# Chapter 5

# Real-Life Application at an Internationally Operating Freight Forwarding Company

*At the beginning of this chapter, a detailed analysis of the general requirements for long-haul transportation in Europe is conducted (Section 5.1). Afterwards, the specific planning situation at the cooperating freight forwarding company is investigated (Section 5.2). In Section 5.3 the main adjustments applied to the existing MNS procedure are outlined. In Section 5.4 the preprocessing of the available real-life test data set and the derivation of benchmark objective function values are illustrated. Finally, computational results, generated with the adapted MNS procedure for the real-life test data set are presented (Section 5.5).*

## 5.1 General Requirements for Long-Haul Transportation in Europe

This section introduces the main requirements that have to be considered for planning long-haul transportation tasks in Europe. For this purpose, four important categories of requirements are analyzed:

- Social Regulation[12] EC 561/2006,
- Social Regulation AETR,
- Directive[13] EC 2002/15 on working hours, and
- General Driving Bans.

The first three aspects are *driver related*, while the fourth aspect is of general type.

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[12] A *regulation* (German: *Verordnung*) immediately becomes effective, without explicit transfer to national law. (Ministry of Social Affairs, Baden-Württemberg, 2010)

[13] A *directive* (German: *Richtlinie*) does not become effective immediately. It has to be transferred to national law first. (Ministry of Social Affairs, Baden-Württemberg, 2010)

Steffen Schorpp, *Dynamic Fleet Management for International Truck Transportation,*
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### 5.1.1 Social Regulation EC 561/2006

In March 2006 the European Parliament and the Council of the European Union passed the new Social Regulation EC 561/2006 (in the following: EC 561) in order to harmonize driving and rest period restrictions in the European Union. EC 561 came into effect on 11.04.2007. All subsequent *article references* refer to the document: European Union (2006b).

EC 561 was motivated by the fact that it was possible with the former regulation "to schedule daily driving periods and breaks so that a driver could drive for too long without a full break, leading to reduced road safety and a deterioration in the driver's working conditions *(legislation preamble (16))*." This is supported by findings of the European Safety Council, whereupon driver over-fatigue is responsible for 20% of commercial road transport crashes (Kok et al., 2009).

The new regulation is applied to carriage by road, when the gross vehicle weight, including any trailer, exceeds 3.5 tonnes. It is applied to transports, undertaken either exclusively within the European Union or between the European Union, Switzerland and the countries party to the Agreement on the European Economic Area (Norway, Liechtenstein and Iceland).

However, for cross border transports between countries with EC social regulation and countries having ratified the AETR (European Agreement concerning the Work of Crews of Vehicles engaged in International Road Transport, e.g. Russia, Belarus, Albania, and Turkey), AETR must be applied for the whole journey – and not EC 561. Figure 5.1 shows a map with the European countries and their respective membership in EC 561 or in AETR.

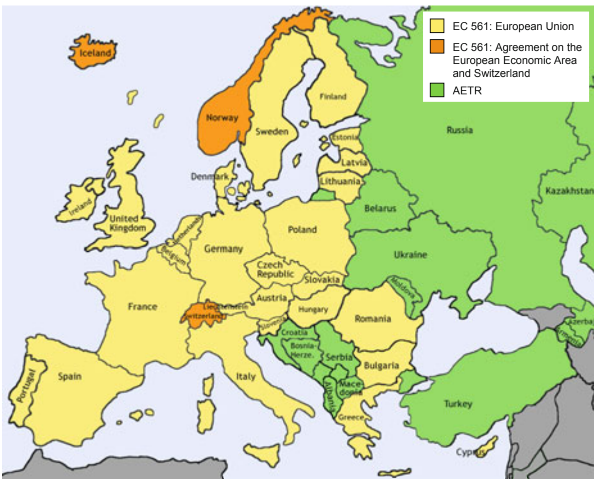


**Figure 5.1:** Application of EC 561 and AETR

The most important aspects of EC 561 will be introduced in the following, differentiated between single and team driver mode. For this purpose, short definitions, basic rules and exceptions are outlined for the categories *daily driving time*, *weekly and fortnightly driving time*, *breaks*, *daily rest period*, and *weekly rest period*.

**Single Driver Mode**

- **Daily driving time:** The daily driving time is defined as the total accumulated driving time (measured with a digital tachograph) between the end of one daily rest period and the beginning of the following daily rest period. The word "daily" is not necessarily congruent with a weekday. Therefore, the actual meaning would be better represented by the word "interval". Daily driving time is limited to 9 hours (basic rule) and may be extended to 10 hours twice a week (exception).
  *(article 8(2), article 4k)*

- **Weekly and fortnightly driving time:** The weekly driving time is counted for a real week (from 0:00 on Monday until 24:00 on Sunday). It must not exceed 56 hours (basic rule). Furthermore, the total driving time during two consecutive weeks must not exceed 90 hours (basic rule). There is no exception available.
  *(article 6(2,3))*

- **Breaks:** A break is defined as a non driving period. After a driving period of 4.5 hours, a driver shall take an uninterrupted break of at least 45 minutes (basic rule), unless he takes a rest period. The break may be split into a break of 15 minutes, followed by a break of 30 minutes (exception).
  *(article 7)*

- **Daily rest period:** The daily rest period is a time between two daily driving time intervals, during which a driver may freely dispose of his time. It regularly has a duration of at least 11 hours (*regular daily rest period*, basic rule). Three times a week, however, it may be reduced to at least 9 hours (*reduced daily rest period*, exception). For this reduction no compensation is required. The combination of an uninterrupted 3-hour rest period with a subsequent 9-hour rest period is also counted as a *regular daily rest period*.
  *(article 4,g)*

  In addition, a *24-hour-rule* has to be considered: Within each period of 24 hours after the end of the previous daily rest period, a driver shall *have taken* a new daily rest period. This means that for a *regular daily rest period* (*reduced daily rest period*) the daily rest period must be started after a 13-hour (15-hour) interval of activities (driving, loading, breaks, waiting, etc.) at the latest.
  *(article 8(2))*

  Figure 5.2 shows two ways of scheduling driving times and daily rest periods: scheduling with basic rules and scheduling with exceptions.

- **Weekly rest period:** The weekly rest period is a time in between two weekly sequences of driving intervals and daily rest periods, during which a driver may freely dispose of his time. The weekly rest period has a regular duration of at least 45 hours (*regular weekly rest period*, basic rule), but may be shortened to a minimum

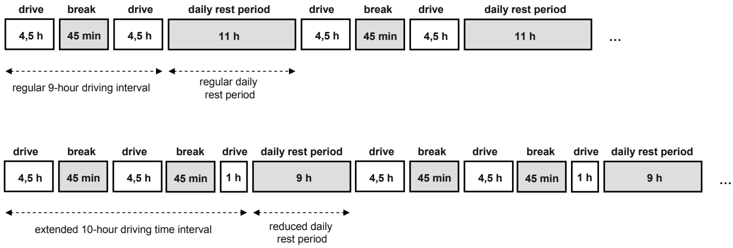


**Figure 5.2:** Basic rule scheduling vs. scheduling with exceptions

of 24 hours (*reduced weekly rest period*, exception).

Full compensation is needed for this reduction, which means that a 21-hour rest period has to be attached (en bloc) to another (either daily or weekly) rest period of at least 9 hours. The compensation has to be accomplished before the end of the third week after the reduced weekly rest period. See Figure 5.3 for illustration.

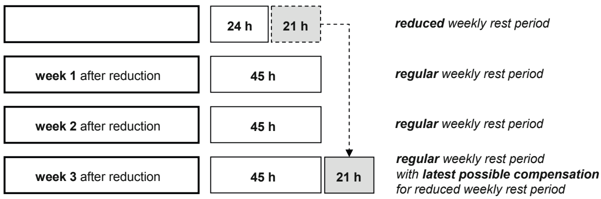


**Figure 5.3:** Latest compensation for a reduced weekly rest period

In addition: two reduced weekly rest periods must not succeed each other. Therefore, the maximum number of "open, not compensated" reduced weekly rest periods may be *two*, before compensation of the first reduced weekly rest period has to be accomplished at the latest. Generally, a weekly rest period shall not start later than six 24-hour periods from the end of the previous weekly rest period.
*(article 4h, article 8(6))*

When the crew consists of **two drivers**, modified restrictions have to be considered for the scheduling. The five previous categories are reviewed for this new adjusted situation, focusing on the differences to the single driver mode.

### Team Driver Mode

- **Daily driving time:** The maximum daily driving time is now 18 hours (9 hours for each driver, basic rule). Again, each driver is allowed to use two weekly 10-hour extensions (exception). This may result in an interval driving time of up to 20 hours if both drivers use one 10-hour extension in the same interval.

- **Weekly and fortnightly driving time:** The weekly driving time must not exceed 112 hours (56 hours for each driver, basic rule) and the total driving time during two consecutive weeks must not exceed 180 hours (90 hours for each driver, basic rule). Exceptions are not available for this category.

- **Breaks:** After each driving period of 4.5 hours, a change of driver operating the steering wheel is required. Times as a co-driver in a moving vehicle are counted as breaks, therefore an explicit vehicle stop of 45 minutes is no longer required.

- **Daily rest period:** Every daily rest period must have a duration of at least 9 hours. There is no more differentiation between *regular* and *reduced*, and hence, no more exceptional rule.

  The *24-hour-rule* is changed to a *30-hour-rule*: Within each period of 30 hours after the end of the previous daily rest period, both drivers shall *have taken* a new daily rest period. This means that the daily rest period has to be started after a 21-hour interval of activities (driving, loading, breaks, waiting, etc.) at the latest. *(article 8(5))*

- **Weekly rest period:** The rules are identical to the single driver mode.

Not all European transport activities are covered by EC 561, some are covered by AETR. According to the Ministry of Social Affairs, Baden-Württemberg (2010), an adaptation of AETR to EC 561 standards is planned. Nevertheless, AETR is still applied today and will therefore be considered in the following.

### 5.1.2 Social Regulation AETR

AETR regulations are similar to EC 561. The following section summarizes the most important aspects (cp. United Nations Economic Commission for Europe, 2006), in particular the differences to EC 561 (cp. Table 5.1). All aspects not explicitly mentioned are identical to EC 561.

In AETR, a **driving time** limit per week is not given, just a 90-hour limit for the total travel time of two subsequent weeks *(article 6(1))*. Regulation of **breaks** includes the *additional option of splitting* a 45-minute break into three breaks of at least 15 minutes *(article 7(2))*.

**Daily rest periods** have to be taken within each 24-hour interval with a duration of at least 11 hours and may be reduced to 9 hours three times a week. In contrast to EC 561, *compensation before the end of the following week is mandatory*. The daily rest period may be split into *three separate rest periods, with one part of at least 8 consecutive hours*. If the daily rest period is split, the total minimum length increases to 12 hours *(article 8(1))*. For team driver mode, AETR specifies *just 8 consecutive hours of daily rest period* within a 30-hour period, instead of 9 hours in EC 561 *(article 8(2))*.

**Weekly rest period** regulation is less restrictive in comparison to EC 561: AETR just says that within each week one rest period shall be extended to 45 hours. An explicit maximum time gap between two subsequent weekly rest periods is not specified, just the requirement that the next weekly rest period shall be scheduled after six *daily driving periods (article 6(1))*.

| EC 561 | AETR |
|---|---|
| Driving time limit per week: 56 hours, fortnightly 90 hours | No driving time limit per week, fortnightly 90 hours |
| Splitting option for 45-minute break: 15 min + 30 min | Splitting option for 45-minute break: $3 \cdot 15$ min |
| Reduced daily rest period: no compensation | Reduced daily rest period: mandatory compensation, until the end of the following week |
| Regular daily rest period: splitting option 3 hours + 9 hours | Regular daily rest period: splitting option into three parts $x + y + z = 12$ hours, with one part $\geq 8$ hours |
| Team driver daily rest period: 9 hours | Team driver daily rest period: 8 hours |
| Maximum time gap between weekly rest periods: six 24-hour intervals | Maximum time gap between weekly rest periods: six daily driving periods |
| Not two subsequent reduced weekly rest periods | Two subsequent reduced weekly rest periods allowed |
| Maximum number of "open, not compensated" reduced weekly rest periods: 2 | Maximum number of "open, not compensated" reduced weekly rest periods: 3 |

**Table 5.1:** Differences between EC 561 and the AETR

Suppose a truck in team driver mode: a *daily driving period* lasts 30 hours, which results in *six daily driving periods* lasting 180 hours. In addition, between driving periods possibly some additional waiting times may be scheduled, so a weekly rest period may be taken much later than six 24-hour intervals (144 hours) after the previous one.

A reduction of a weekly rest period to 24 hours is possible, requiring (identically to EC 561) a 21-hour compensation before the end of the third following week *(article 8(3))*. However, scheduling *two subsequent reduced weekly rest periods* is not strictly prohibited, which allows for a maximum number of three "open, not compensated" reduced weekly rest periods.

Social regulations EC 561 and AETR in particular deal with *driving time*. However, depending on the degree of other activities, it may be possible that *restrictions on total working time* also become stringent.

### 5.1.3 Directive EC 2002/15 on Working Hours

Driving time regulations are supplemented by the general EC Directive on working hours "for persons performing mobile road transport activities" (*EC 2002/15*, see European Union, 2002), which is transferred to German law in *§21a Working Time Act* (Federal Ministry for Labor and Social Affairs, Germany, 2009).

Here, working time does not only involve driving time, but also loading and unloading time, cleaning and technical maintenance, and all other work intended to ensure the safety of the vehicle and its cargo or to fulfil the legal or regulatory obligations (e.g., customs), etc. In addition, the regulation also includes times during which a driver cannot dispose freely of his time (e.g., during periods awaiting loading or unloading, where their foreseeable duration is not known in advance)". *(article 3,a)*

The main aspects of regulation EC 2002/15 are outlined in the following:

- **Weekly working time:** A week is defined identically to EC 561, ranging from Monday 0:00 to Sunday 24:00. Maximum weekly working time is limited to 60 hours. In addition, over a four-month horizon, the average weekly working time shall not exceed 48 hours.
  *(article 4,a)*
- **Breaks:** A break has to be scheduled after 6 hours of consecutive working time. The length of the break must be 30 minutes, if working hours total between six and nine hours. The length of the break must be 45 minutes, if working hours total more than nine hours. Breaks may be subdivided into periods of at least 15 minutes each.
  *(article 5)*
- **Night work:** The night is defined as the time between 0:00 and 7:00. If at least four working hours fall during this time interval, it is referred to as *night work*. If night work is performed, the daily working time shall not exceed ten hours in each 24-hour period.
  *(article 7,1)*

Since 23.03.2009, EC 2002/15 also contains "self employed (independent) drivers" who perform transports with their own vehicle. This modification, however, has not yet been adapted to German law (Vogel, 2010).

### 5.1.4 Traffic Bans

The last main group of regulations for scheduling vehicles is traffic bans *at weekends*, *public holidays* and *special annual periods*. This group is not covered by a common regulation in the European Union. Instead, each country has its own regulation, from "relatively strict" up to "nonexistent", making the situation quite complex.

In Germany, for example, vehicles with more than 7.5 tonnes gross vehicle weight are not allowed to drive on Sundays between 0:00 and 22:00. Exceptions only exist for vehicles transporting fresh and perishable products, as well as pre- and post-carriage of multimodal transports. Additional traffic bans exist on public holidays from 0:00 until 22:00 and on Saturdays in the summertime (03.07.-28.08.) from 7:00 until 20:00 on selected highways (cp. Vogel, 2010).

The European countries can be roughly classified into three groups:

(i) with general traffic bans,

(ii) with partial traffic bans, and

(iii) without traffic bans.

Figure 5.4 shows the ten countries (Germany, France, Czech Republic, Switzerland, Liechtenstein, Austria, Slovakia, Croatia, Italy, and Slovenia) of group (i) and their main aspects of regulation. In order to keep track and due to the variety of individual rules and exceptions, only a very aggregated view is chosen.

| | | |
|---|---|---|
| Germany<br>**Sunday** and public holidays **0:00 – 22:00**, special summer holiday restrictions | Switzerland/Liechtenstein<br>**Sunday** and public holidays **0:00 – 24:00**, general night traffic ban 22:00 – 5:00 | Croatia<br>**Sunday** and public holidays **12:00 – 23:00**, previous day of public holiday 15:00 – 23:00 |
| France<br>**Sat 22:00 – Sun 22:00** and public holidays (previous day 22:00 – public holiday 22:00), special route restrictions Paris | Austria<br>**Sat 15:00 – Sun 22:00** and public holidays 0:00 – 22:00, special summer holiday restrictions | Italy<br>**Sunday** and public holidays **8:00 – 22:00** (Oct.-May), **7:00 – 24:00** (June-Sep.), special summer holiday restrictions |
| Czech Republic<br>**Sunday** and public holidays **13:00 – 22:00**, special summer holiday restrictions | Slovakia<br>**Sunday** and public holidays **0:00 – 22:00**, special summer holiday restrictions | Slovenia<br>**Sunday** and public holidays **8:00 – 21:00**, special summer holiday restrictions |

**Figure 5.4:** European countries with general traffic bans

Countries of group (ii) with less restrictive and less general partial traffic bans are: Poland, Luxembourg, Hungary, Portugal, Spain, Bulgaria, Romania, Greece, and Turkey. These countries only have traffic bans for public holidays, selected highways, special annual periods or for hazardous goods transportation.

In group (iii), there are (more or less) no such regulations at all. Countries belonging to this group are: Sweden, Norway, Finland, Denmark, The Netherlands, Belgium, United Kingdom, Ireland, Ukraine, Belarus, Russia, Estonia, Latvia, Lithuania, Malta, Cyprus, Albania, Macedonia, Bosnia-Herzegovina, Serbia and Montenegro.

### 5.1.5 Inspection of Compliance

The driver-related restrictions are controlled with the help of a digital driver card (see Figure 5.5). For every traveling activity of a vehicle, such a digital driver card has to be logged in to the vehicle's digital tachograph. The tachograph writes information about driving time, breaks, other working time, and rest periods, etc. onto the digital driver card. This information is stored on the card for 28 days, then it is overwritten by new information. Thus, a freight forwarding company must download data from the digital driver's cards at least every 28 days and store each driver's activity log for one year.

According to Directive EC 2006/22 (European Union, 2006a) "on minimum conditions for the implementation of EC 561", random checks have to be performed both at the freight forwarding company and directly on-the-road. In Germany, checks at the freight forwarding companies are performed by local *commercial regulatory authorities (German: Gewerbeaufsichtsämter)*, while checks on-the-road are carried out by the *police* and the *Federal Office for Goods Transport (German: Bundesamt fuer Güterverkehr - BAG)*. Starting from 01.01.2010, at least 3% of days worked by drivers' shall be controlled, with not less than 30% of the total number (of checked working days) being checked at the roadside and not less than 50% being checked at the premises of freight forwarding companies.


**Figure 5.5:** Digital driver card (Kraftfahrtbundesamt, 2010)

According to the Ministry of Social Affairs, Baden-Württemberg (2010), infringements against EC social regulations are penalized in the range of € 5000 up to a maximum of € 15000. However, this doesn't mean that every small violation is penalized: especially in situations where a driver cannot find a suitable stopping place or where a traffic jam causes delay, this is handled with courtesy. In the most cases of penalty, systematically recurring infringements are punished (Commercial Regulatory Authority, 2010).

In Germany, a non-compliance with the Sunday or public holiday traffic ban is penalized with € 75 for the driver and € 380 for the vehicle owner (Vogel, 2010).

### 5.1.6 Some Recent Literature

The incorporation of the introduced general requirements for International Truck Transportation into tour planning algorithms has only been considered, by some of the latest publications. All of those publications deal with static problem definitions and only partially include the actual real-life requirements.

One of the first publications considering EC 561 is Goel (2009). The author presents two algorithms for the VRP with hard time windows which comply with the *basic rules* of EC 561 (only single driver mode). *Exceptions* are completely neglected "in order to increase the robustness of the generated plan": it is argued that exceptions are of particular importance if delays, e.g., due to bad traffic conditions, result in longer driving times than expected.

While the first algorithm uses "naive" scheduling (break and rest periods are scheduled when the respective accumulated driving time is exhausted), the second procedure takes into account the fact that it can be beneficial to schedule rest periods before the respective accumulated driving time is exhausted. The primary objective of both approaches is to minimize the number of vehicles, the secondary objective is to minimize total traveled distance.

For testing purposes, Goel modifies the Solomon (1987) data set: the planning horizon is extended to six days, a handling time of one hour per customer is introduced, and the average vehicle speed is increased to five units per hour. Results show a better performance of the second procedure. However, a drawback of the used data set is its short planning horizon of only six days, excluding any tests of scheduling weekly rest periods.

Kok et al. (2009) also deal with the incorporation of EC 561 into a VRP with hard time windows. They propose an extended Dynamic Programming Heuristic (only single driver mode), with two implemented versions: one considers all basic rules of EC 561, but no exceptions (*basic method*), the other additionally considers the exceptions. In a first step, the authors benchmark the *basic method* with the results published by Goel (2009), using the same modified Solomon (1987) data set. Results show a significant reduction in the average number of vehicles (-18.26%) and in the average traveled distance (-5.41%) compared to Goel (2009).

In a second step, the authors compare the different versions of their algorithm with each other. Further improvements are reported when considering the exceptions of EC 561: the number of vehicles is reduced by 4.28% and the total distance traveled by 1.54% (in comparison to the basic method). It is also mentioned that computation time more than doubled when incorporating the exceptions, which is attributed to additional checks. Finally, a version of the algorithm is tested extending the *basic method* by EC 2002/15 on working hours. This leads (in comparison to the basic method) to slightly worse results: the average number of vehicles increases by 4% and the average distance traveled increases by 1%. This is an intuitive finding, since additional restrictions are added to the planning problem.

In the following section, the general restrictions for International Truck Transportation are supplemented by a look at the actual planning situation at a freight forwarding company. This exemplary real-life planning situation is used as indication of how a practical adaptation of the dynamic MNS procedure should look.

## 5.2 Exemplary Real-Life Planning Situation at a Freight Forwarding Company

The considered freight forwarding company distinguishes national and international transportation tasks and allocates the associated responsibilities to separate divisions. This makes it easier to regard only the international activities which consist of transportation tasks over the entire European territory.

Most of the company's international **requests** belong to the group of *occasional transportation tasks* (tramp transportation, independent of predefined networks), a smaller part of recurring requests can be attributed to the group of *line haul tasks.* The majority of requests are of type Full Truckload between a Pickup and a Delivery location (P → D).

In addition, it is also possible that one request may possess several load and unload locations (subsequently labeled as "request bundle"). Such request bundles may be predefined by a given customer order or created by a dispatcher, who merges two or more compatible requests manually. The only logical requirement for request bundles is the precedence constraint of scheduling a Pickup before the associated Delivery. Apart from that, all combinations are allowed: e.g. P1 → P2 → D1 → D2, P1 → D1 → P2 → D2 or P1 →

P2 → D1 → P3 → D3 → D2. In total, approx. 40% of all orders are part of a bundle. The sequence within a bundle is fixed and shall not be changed in the optimization process.

Further request attributes are: soft time windows for Pickup and Delivery location, geographical coordinates for Pickup and Delivery location, required vehicle type, information about the need for hazardous goods equipment in the vehicle, and duration of load and unload process.

The company employs approximately 1200 vehicles of different type (see Section 5.4 for details). The available **vehicles** are registered in different European countries. All vehicles are equipped with a digital tachograph. Main vehicle attributes are the vehicle's type and the information about whether equipment for transportation of hazardous goods is carried. Both aspects are crucial requirements for a feasible load-to-vehicle assignment. A vehicle is operated by one or two drivers, which may be subject to change. On average, approx. 70% of vehicles are operated in single driver mode and approx. 30% in team driver mode.

The **drivers** come from 19 European countries, with a focus on Eastern Europe. Driver scheduling directly influences the tour planning. This is explained as follows:

- An international driver, who usually spends several weeks en route, may want to get home occasionally for a holiday. So, at the end of his *operating time*, the dispatcher has to find a request with target location preferably near to the driver's home location. If this is not possible, drivers may also be exchanged at several European meeting points alternatively, from where they are brought home by minivans. However, unfavorable far away exchange points may cause higher costs for bringing the driver home and may also result in driver dissatisfaction.
- Furthermore, EC social regulation has to be observed. Especially in the one driver mode, fortnightly maximum driving time and the compensation for a reduced weekly rest period can be quite restrictive. Therefore, it is an incentive for the freight forwarding company to frequently exchange drivers (every two or three-week interval).

  Each time, the *new driver* starts without any outstanding compensation time for weekly rest periods and with an unconsumed travel time account. The *old driver* takes his outstanding rest period near the meeting point or at home (by any means: separated from the vehicle).

  By performing this kind of driver exchange, the vehicle's utilization can be significantly increased.

Subsequently, the **planning process** is described in detail.

The planning process is subdivided (see Figure 5.6). In a first *acquisition step*, an acceptance/rejection decision is made (level 1). This also includes the active solicitation of requests.[14] In a second step, the actual *tour planning* including order-to-vehicle-assignment

[14] In the literature, the acceptance/rejection decision is distinguished from the cost/pricing problem: in the first case, the reward to be obtained is known and in the second case it is unknown. At the considered freight forwarding company both types of problems occur. However, since this aspect is not the focus of this work, we will only speak of an acceptance/rejection decision in the following.

and detailed vehicle scheduling is performed (level 2).

Coordination between both planning steps is reached by pricing: level 2 (tour planning) provides internal prices for transport relations, which, for example, include the probability of getting an *add-on request* in a specific target region. Prices may be changed on a daily basis, depending on the current planning situation. In addition, specific needs for add-on requests may be communicated directly between both planning levels.

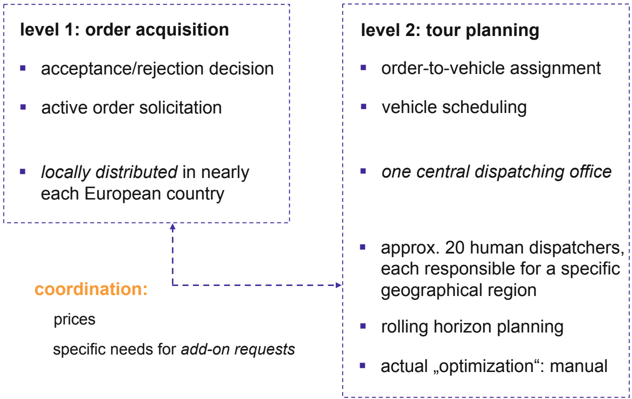


**Figure 5.6:** Planning process at the cooperating freight forwarding company

Acquisition is not performed at one central geographical place, but locally distributed in nearly every European country. This involves the advantage of being close to the local market with all its specific characteristics and languages. Tour planning, however, is executed at a central dispatching office: here, approximately 20 human dispatchers perform level 2 tasks, in which each dispatcher is reponsible for a specific geographical region coordinating inbound and outbound flows (that means the dispatcher has to find suitable *add-on requests* for incoming vehicles, e.g., with the objective of producing minimal unloaded traveled distance and minimal vehicle idle time).

Currently, “Decision Support” is contributed by only several “Information Systems”: a *database* (handling order data, vehicle data, etc.), a *route planner* (proposing route options with shortest travel distance/shortest travel time), and a *graphical representation of vehicle scheduling*. The actual “optimization” task of assigning orders to vehicles and subsequent vehicle scheduling, however, is performed completely manually in a rolling horizon approach.

While the first part of a day is basically used for monitoring the existing plan and conducting adjustments due to unforeseen events, like traffic jams, vehicle break downs, extended loading times or changes in order specifications, the second part of the day is used for incorporation of new requests into the plan. The specific scheduling for the following day has to be completed by approx. 18:00. EC social regulations are only considered indirectly, e.g. by maximum daily kilometer performances of 540 km - 600 km for a vehicle in single driver mode and of 900 km - 920 km for a vehicle in team driver mode.

The obtained insights at the considered freight forwarding company – planning data and planning process – serve as guidelines for the adjustments that have to be applied to the original MNS procedure of Section 4.1 in order to cover the real-life requirements for International Truck Transportation.

## 5.3 Adjustment of Multiple Neighborhood Search

This section describes the main *general* and *company specific requirements* that are actually incorporated into MNS in order to handle the real-life planning problem. The resulting adaptations primarily affect the MNS scheduling, whereupon the general planning process is not touched. To allow for a proper representation of the new scheduling activities, the internal data structure is revised. In addition, the program modules *Best Insertion* and *Scheduling* are adapted to the new planning requirements of the extended real-life SLPDPTW.

### 5.3.1 Selected General Requirements

In a first step, the **general requirements** that have actually been chosen for inclusion in the MNS procedure are presented. These are basically EC 561, EC 2002/15 on working hours and traffic bans (see Table 5.2).

| **considered requirements** |
|---|
| **EC 561: basic rules and exceptions** |
| Single Driver Mode |
| Team Driver Mode |
| |
| **EC 15/2002: working time restrictions** |
| partial: Team Driver Mode |
| |
| **traffic bans** |
| general Sunday traffic ban |
| 0:00 - 24:00 for <u>all</u> countries |

**Table 5.2:** Summary of general real-life restrictions included in MNS

Consideration of *EC 561* is a mandatory task, since the legislator explicitly specifies in *article 10(4)* (of *EC 561*) that "freightforwarders shall ensure that transport time schedules respect this regulation." In contrast to the actual planning at the cooperating freight forwarding company, where a tour's admissibility is only estimated, the adapted MNS procedure will produce an explicit scheduling in accordance with the given requirements.

All *basic rules* of EC 561 are incorporated[15]. In addition, nearly all *exceptions* to EC 561 are also integrated, except for the splitting option of the 45-minute break. This is

[15] We should point out that the *fortnightly driving time restriction for single driver mode* is relaxed for the computation of our final results. This is due to driver exchanges in the manual benchmark planning performed at our cooperating freight forwarding company, which lead to (permissible) fortnightly vehicle driving times in single driver mode of over 90 hours. Real-life MNS does not include explicit driver exchange and therefore performs planning with the same driver over the entire five-week planning horizon. The resulting disadvantage is partially compensated by the specified relaxation.

due to the fact that international (long distance) transportation tasks last two days on average, involving only a few loading and unloading activities. Thus, the advantage of scheduling split breaks seems to be negligible. While 93% of all transportation tasks (of the cooperating company) fall in the category of EC 561, approximately 7% involve *AETR regulation*. Since AETR regulations have been proved to be quite similar to EC 561 and are to be adapted to EC 561 soon, EC 561 is applied for all transportation tasks.

*Working time restrictions (EC 2002/15)* are considered partially: in agreement with the cooperating partner, an extra 30-minute break is scheduled in the team driver mode after 12 hours of driving. Table 5.3 visualizes all "driver-based" aspects for single driver and team driver scheduling that have been integrated into the planning procedure.

| Single Driver Mode | Team Driver Mode |
|---|---|
| **Daily driving time:**<br>- regular: 9 hours<br>- exception: twice a week 10 hours | **Interval driving time:**<br>- regular: 18 hours<br>- exception: 4 extra hours per week, max. 2 extra hours per interval |
| **Weekly driving time:**<br>- max. 56 hours a week<br>- fortnightly: 90 hours in total | **Weekly driving time:**<br>- max. 112 hours a week<br>- fortnightly: 180 hours in total |
| **Breaks:**<br>- regular: 45 min after 4.5 hours | **Breaks:**<br>- 30 min after a driving period of 12 hours, due to working hour regulation |
| **Daily rest period:**<br>- regular: 11 hours within 24-hour interval<br>- exceptions: reduction to 9 hours three times a week (without compensation), splitting option 3h+9h (as regular rest period) | **Daily rest period:**<br>- 9 hours within 30-hour interval |
| **Weekly rest period:**<br>- regular: 45 hours<br>- exception: 24 hours with 21-hour compensation | **Weekly rest period:**<br>- regular: 45 hours<br>- exception: 24 hours with 21-hour compensation |

**Table 5.3:** Included restrictions for scheduling single and team driver mode

Furthermore, *traffic bans* are also considered: since the variability of such rules is very high between European countries, a simplified approach is chosen, just assuming a complete Sunday traffic ban (0:00 - 24:00) for all countries.

### 5.3.2 Selected Requirements based on the Real-Life Planning Situation

In contrast to the original version of MNS, not every order is suitable any longer to be transported by every vehicle. To handle these **assignment restrictions**, the new variables "load_type" and "adr_class" are introduced for both orders and vehicles. An order may only be assigned to a vehicle if both variables are consistent or if there is a possible substitution option. The first variable "load_type" primarily provides information about the required and offered vehicle size (for orders and vehicles, respectively). The second variable "adr_class" indicates whether hazardous goods equipment is needed (order) and whether such equipment is available (vehicle).

Due to the consideration of a **Full Truckload problem**, original order information on weight and volume consumption and vehicle information on weight and volume capacity is skipped. However, the real-life situation is not perfectly consistent to a classic Single Load problem. Some orders arrive as **request bundles**, including transportation of more than one order at the same time. In the strictest sense, this is "Multi Load" transportation. However, due to the fixed sequence within such a request bundle, there are no remaining planning options. Further load consolidation or changes in sequence are not allowed.

Hence, such a request bundle is treated as a single order. For such bundled orders, the new attributes "bundle_no", "pos_p" and "pos_d" are introduced: "bundle_no" indicates whether an order is part of a bundle and also allows for identification of the other parts of the same bundle; "pos_p" and "pos_d" indicate the positions of the order's Pickup and Delivery tasks within the request bundle's sequence.

In addition, there is **no more central depot** from which a tour starts and finally ends. Hence, some information about each vehicle's initial geographical position is required ("geo_long_initial" and "geo_lat_initial"). A final destination is not defined, since planning with **open tours** is performed. Initial geographical information is supplemented by a specific time of availability ("av_from") that indicates from which point in time the vehicle is ready for execution of the first planning task.

Furthermore, two new vehicle attributes are introduced which indicate whether a vehicle is operated in **Single or in Team Driver mode:** "driver_one" and "driver_two". As we have seen in Section 5.1, a different number of available drivers results in completely different requirements for vehicle scheduling. The vehicle attributes "driver_one" and "driver_two" allow for a direct reference to real drivers. In the chosen adaptation, however, an exchange of the initial driver(s) is not explicitly considered.

Tables 5.4 and 5.5 summarize all **request and vehicle attributes** of the adapted MNS version. The first column shows the *internal abbreviation of an attribute*, the second column includes a short *description*, and the third column contains a note on the *internally used data type*.

Finally, it is also worth mentioning that in contrast to the original problem setting, a delayed arrival at a Pickup or Delivery location can no longer be scheduled completely freely. Instead, a **core arrival time** has to be considered. Such a core arrival time prevents delayed arrivals at undesirable times, e.g. at 03:00. The core arrival time specifies in which time interval (different to the order's original time window) a delayed arrival may occur.

The core interval at our cooperating company was chosen to be [7:00, 20:00]. Hence, if there is a delayed arrival at 21:00, the vehicle has to wait until 7:00 the next day to serve the location. The core interval, however, is extended if the location's original time window already contains a boundary outside of the core interval. Suppose the Delivery time window [5:00, 9:00]: in such a case, the delayed vehicle would be allowed to service the location already at 5:00 the next day.

| **request attributes** | | |
|---|---|---|
| *req_count* | unique request identifyer | ∈ Integer |
| *call_in* | the time, the request is revealed to the decision maker | ∈ Date-Format |
| *load_type* | specification, what vehicle is needed for transportation of the request | ∈ String |
| *adr_class* | indication (0,1), if hazardous material equipment is needed | ∈ Binary |
| *bundle_no* | number, indicating, if a request is part of a bundle | ∈ String |
| *pos_p* | indication of the Pickup's position within a bundle | ∈ Integer |
| *pos_d* | indication of the Delivery's position within a bundle | ∈ Integer |
| *EPT* | earliest Pickup time | ∈ Date-Format |
| *LPT* | latest Pickup time | ∈ Date-Format |
| *geo_long_Pickup* | geographical coordinate: longitude Pickup location (deg°mm'ss") | ∈ String |
| *geo_lat_Pickup* | geographical coordinate: latitude Pickup location (deg°mm'ss") | ∈ String |
| *loadtime* | time needed to perform loading procedure at Pickup location (in minutes) | ∈ Integer |
| *EDT* | earliest Delivery time | ∈ Date-Format |
| *LDT* | latest Delivery time | ∈ Date-Format |
| *geo_long_Delivery* | geographical coordinate: longitude Delivery location (deg°mm'ss") | ∈ String |
| *geo_lat_Delivery* | geographical coordinate: latitude Delivery location (deg°mm'ss") | ∈ String |
| *unloadtime* | time needed to perform unloading procedure at Delivery location (in minutes) | ∈ Integer |

**Table 5.4:** Attributes of a request in the real-life scenario

| **vehicle attributes** | | |
|---|---|---|
| *veh_count* | unique vehicle identifyer | ∈ Integer |
| *load_type* | specification, of a vehicle's load type (relevant for feasible assignment of a request) | ∈ String |
| *adr_class* | indication (0,1), if vehicle carries hazardous material equipment | ∈ Binary |
| *geo_long_initial* | geographical coordinate: longitude initial location (deg°mm'ss") | ∈ String |
| *geo_lat_initial* | geographical coordinate: latitude initial location (deg°mm'ss") | ∈ String |
| *av_from* | time, a vehicle is available for new transportation tasks | ∈ Date-Format |
| *driver_one* | number, of a first driver | ∈ Integer |
| *driver_two* | (optional) number, of a second driver | ∈ Integer |

**Table 5.5:** Attributes of a vehicle in the real-life scenario

### 5.3.3 Adjustment of Internal Data Structures

In the description of the original version of the MNS procedure, explaining details of the data structure which was used for internal representation of the vehicle scheduling was intentionally omitted. In the real-life case, however, the variety of planning options that have to be covered, combined with the general dynamic planning situation, justify a short consideration.

In this work a variably sized LinkedList is chosen for representation of each vehicle's scheduling. This list may include five scheduling elements: *Pickup*, *Delivery*, *Break*, *Wait*, and *Go*. Each element contains time information accurate to the minute. *Pickup* and *Delivery* elements additionally include information on the associated order number and the order's geographical position. Furthermore, two binary indicators ("time fixed" and "vehicle fixed") are stored with each *Pickup* and *Delivery* element, all the other elements only have a single binary indicator ("time fixed"). In a rolling horizon framework, those indicators signal what parts of the planning are open for further changes and what parts are permanently fixed.

Each element's specific meaning and the information stored with the elements is explained in the following.

- **Pickup:** This element is scheduled to indicate the arrival at a Pickup location. It contains information about what request is picked up ("req_count"), geographical coordinates of the Pickup location ("geo_long_Pickup", "geo_lat_Pickup"), actual arrival time (start of service), end of service (start of service + loading time), drive-on time, fixation indicator vehicle, and fixation indicator time.

  *P;15;100225;490746;600;660;660;1;1*, for example, means that the vehicle arrives at the Pickup location of request number 15 at geographical coordinate (10°02'25", 49°07'46") at system time 600. Service ends at system time 660 and the vehicle immediately drives towards another location at system time 660. Since fixation indicators are both equal to 1, this internal element must not be changed any more.

- **Delivery:** This element is scheduled to indicate the arrival at a Delivery location. It contains information about what request is delivered ("req_count"), geographical coordinates of the Delivery location ("geo_long_Delivery", "geo_lat_Delivery"), actual arrival time (start of service), end of service (start of service + unloading time), drive-on time, fixation indicator vehicle, and fixation indicator time.

  The example *D;15;113240;472209;900;960;1000;1;0* means that the vehicle arrives at the Delivery location of request number 15 at geographical coordinates (11°32'40", 47°22'09") at system time 900. Service ends at system time 960, the vehicle waits 40 minutes and subsequently drives towards another location at system time 1000. Since the first fixation indicator (vehicle fixed) is equal to 1 and the second fixation indicator (time fixed) is equal to 0, the Delivery element must not be exchanged to another vehicle, but it may be rescheduled within the current vehicle's tour.

- **Break:** This element is scheduled to indicate a non-driving period, primarily to satisfy regulation EC 561 on breaks, daily rest periods and weekly rest periods. A "Break" element is not penalized in the objective function. It contains a start time, an end time and a single fixation indicator.

*B;700;745;0*, for example, stands for a non-driving period, starting at system time 700 and ending at system time 745. Since the fixation indicator is equal to 0, this internal element may be rescheduled by improvement procedures.

- **Wait:** This element is scheduled to indicate a waiting period. Such a period may have several reasons: waiting time to avoid early arrival at a Pickup location, waiting time at a (fixed) Delivery location until the time window opens, or waiting time if the vehicle is idle. A "Wait" element is penalized in the objective function. Even if times of "Waiting" have another intention than "Break", they are certainly considered for compliance with EC social regulations.

  *W;800;900;0*, for example, stands for a non-driving period, starting at system time 800 and ending at system time 900. Since fixation indicator is equal to 0, this internal element may be changed by improvement procedures.

- **Go:** This element is scheduled to indicate a time of traveling. It is used in particular between "Break" elements. It contains a start time, an end time and a single fixation indicator.

  *G;700;970;0*, for example, stands for a driving period of 4.5 hours, starting at system time 700, and ending at system time 970. Since fixation indicator is equal to 0, this internal element may be changed by improvement procedures.

Certainly, there are some redundancies in this data structure. The chosen intuitive structure, however, helps to keep a clear perspective on intermediate planning results on command line level and therefore decisively simplifies the debugging process.

### 5.3.4 Adjustments to the MNS modules Best Insertion and Scheduling

Besides the underlying data structure, there are also major modifications to some program modules of the original MNS version of Section 4.1. The new real-life requirements result in updated versions of the modules *Best Insertion* and *Scheduling*. The applied changes are reported in the following.

The adapted workflow of module **Best Insertion** is visualized in Figure 5.7. Compared to the original Multi Load case, there are some simplifications: the number of possible insertion positions in the new Single Load case is significantly smaller, since Pickup and Delivery may be scheduled only in direct succession. Hereby, one loop is saved. In addition, recurring capacity checks within each tour have been substituted by an initial check of order-to-vehicle compatibility.

The general workflow proceeds as follows: The program module Best Insertion is called by the MNS main program, handing over a specific order number and the current fixation time. Best Insertion runs through all vehicles in an outer loop. If a vehicle passes the compatibility check, the number of open positions in this vehicle's scheduling is determined. Afterwards, a loop is started that successively inserts the new order into each possible position. For this purpose, the *Scheduling submodule* is called. If the associated

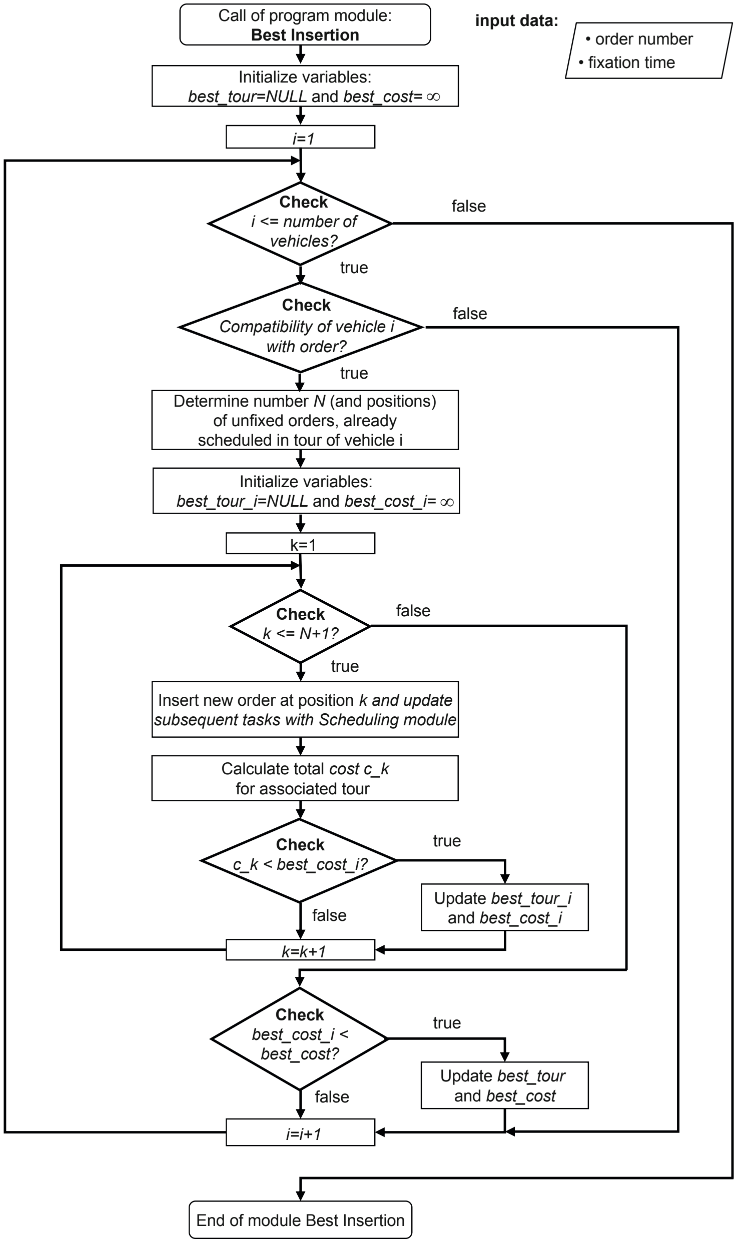


**Figure 5.7:** Program flow chart: Best Insertion

costs for a new scheduling undercut the currently best scheduling's cost, the vehicle's best scheduling is replaced by the new result. This investigation is repeated for all compatible vehicles. Finally, the insertion position over all vehicles and all associated open insertion positions is chosen, which generates the overall minimum insertion costs.

The workflow of the **Scheduling** module is summarized in Figure 5.8. The module is called by Best Insertion in order to produce a feasible scheduling that includes a new order at a specific position in a specific vehicle's tour. For this purpose, the following input data are handed from Best Insertion to the Scheduling module: request number, fixation time, current vehicle tour, and insertion position. In a preprocessing step, the Scheduling module analyzes, whether the vehicle is equipped with one or two drivers. Accordingly, the scheduling rules are selected (cp. Table 5.3). In addition, some auxiliary variables based on the driver's travel time history are calculated: available travel time until the next break is required, available travel time in the current travel time interval, available travel time in the current week, remaining options for scheduling with exceptions, outstanding compensations, etc.

Then, the earliest possible departure time for the new request's Pickup is calculated. Afterwards, scheduling to the first Pickup is performed using *basic regulation rules*. This is followed by a check whether the resulting arrival time conforms to the associated Pickup time window. If this is true, the Pickup's successor is scheduled. Otherwise, it is differentiated between *too early arrival* and *too late arrival*. In the case of too early arrival, an initial waiting time is scheduled at the Pickup's predecessor, so that a prompt arrival at EPT is ensured. In the case of too late arrival, re-scheduling is performed using exceptional regulation, thus trying to reduce delay.

In the following steps, the Pickup's fixed successors are scheduled: In the basic P $\rightarrow$ D case, this is just the trip to the associated Delivery location. In request bundles, there may be a whole number of fixed successors (Pickups and Deliveries). Scheduling is again executed according to *basic rules*. Then it is checked whether there is a "late arrival". If this is not true, scheduling is accepted and the algorithm turns towards the following successors (if existent). However, if there is a late arrival, re-scheduling is started, using *all possible exceptions* to the basic regulation rules.

In contrast to the Pickup case, prevention of too early arrival is not attempted by switching the waiting time to the predecessor. There would be no advantage: once processing of an order has been started, the execution of the first Pickup and all remaining parts of the respective order are fixed and cannot be exchanged by other tasks. Hence, it is irrelevant where to schedule the waiting time.

Finally, the Scheduling module returns the achieved results to Best Insertion.

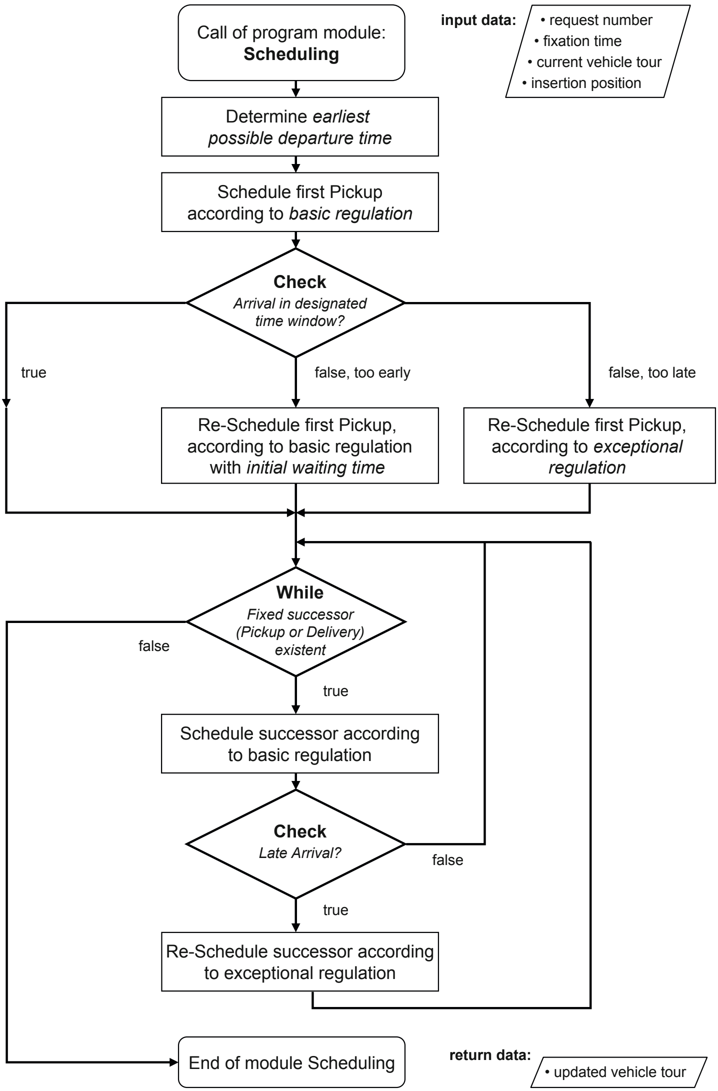


**Figure 5.8:** Program flow chart: Vehicle Scheduling

## 5.4 Real-Life Test Data Set: Preprocessing and Analysis

This section describes the preprocessing of a real-life test data set. First, the initially available raw data set is relieved from inappropriate data. Then, the remaining data are adjusted to a consistent notation. This is followed by some plausibility checks. Finally, benchmark values for the objective function criteria are derived.

The real-life raw data set contains order data of approximately five weeks (Monday, 17.08. 2009 until Saturday, 19.09.2009). It includes a total of 23,305 orders and 1,600 vehicles. In addition to the vehicle information, which is included in a separate table, the following order-related information is given:

- basic customer requests (type 1),
- request bundles (type 2),
- order(or bundle)-to-vehicle assignment (type 3), and
- the associated empty trips (type 4).

Type 1 and type 2 information can be interpreted as input data to the planning problem. Type 3 and type 4 information include the actual planning that was performed at the freight forwarding company.

**Selection of appropriate data**

Due to the fact that not only international transportation tasks and not only occasional transportation tasks without predefined networks are included, the data set has to be revised. For this purpose, each vehicle's actual tour (= planning result) is replicated with the type 3 and type 4 tables. Based on the specific tours, all vehicles only doing national transportation tasks are skipped. The same is applied to vehicles only performing regular line transportation. In addition, vehicles performing requests with origin or destination outside Europe (e.g. Afghanistan, Iran), as well as vehicles with nearly no activity are deleted. Vehicles changing from one driver operation to team driver operation and vice versa also have to be omitted. After this revision, there is a number of 953 remaining vehicles (related to the initial number of vehicles: approx. 60%).

In a next step, the requests that were actually transported with those vehicles remaining are selected. This results in a number of 14,025 requests (related to the initial number of orders: approx. 60%, as well): 900 static, and 13,125 dynamic (degree of dynamism = 93.6%). All the other requests – not transported with one of the remaining vehicles – are eliminated. This results in a total workload of 2,805 requests/week, and an average workload of 2.94 requests/week per available vehicle.

The remaining order and vehicle data, however, are not yet in a form that can be immediately handed to the adapted real-life MNS. Further preprocessing is required concerning notation inconsistencies and plausibility checks.

### Adjustment of notation inconsistencies

Because of the use of inconsistent notation for *load_type* in the request and the vehicle database, the according entries have to be harmonized to give clear order-to-vehicle assignment rules to the algorithm. This step results in five *load_type* categories for vehicles (272∗M, 451∗P, 171∗K, 8∗V, and 51∗HZ) and six *load_type* categories for orders (1450∗M, 9499∗P, 1840∗K, 294∗KP, 112∗V, and 830∗HZ). An illustration is given in Figure 5.9.

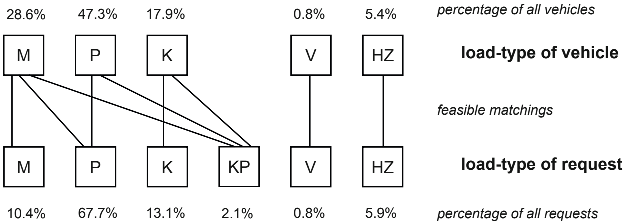


**Figure 5.9:** Feasible load-to-vehicle assignments

A matching is only possible, if the *load_type* of an order and the *load_type* of a vehicle are identical. This is symbolized by the direct connections between orders and vehicles with the same *load_type*. In the special case of request *load_type* “KP”, the vehicle types “K”, “P” and “M” are allowed for assignment. As a further exception, request *load_type* “P” may also be transported by vehicles with *load_type* “M”.

To give a little more insight into the meaning of these *load_type* shortcuts, the English and also the German truck descriptions shall be listed: “M” (Megatrailer - mega truck), “P” (LKW mit Plane - curtain side truck), “K” (Koffer/Kühler - box truck/refridgerated truck), “HZ” (Hängerzug - road train), and “V” (Vario truck). In addition, some exemplary pictures of the associated trucks and some technical details are shown in Figure 5.10.

Finally, it is also worth mentioning that 461 orders (3.2%) are classified as *hazardous goods*, therefore requiring a vehicle with special equipment for transportation of such goods. Two hundred and thirty-four vehicles (24.5%) carry such *hazardous goods* equipment.

### Plausibility checks

After selection of the remaining basic customer requests (type 1), the following plausibility checks and consequential modifications are executed:

(i) IF (EPT < Call-In) THEN {Call-In = EPT - 1 day}

(ii) IF (EPT=LPT=00:00) THEN {EPT=03:00 and LPT=14:00}

(iii) IF (EPT + 1 hour > LPT) THEN {LPT = EPT + 1 hour}

(iv) IF (EPT > EDT) THEN {EDT=EPT}


**Figure 5.10:** Different available vehicle types (Willi Betz Logistik, 2010)

(v) IF (EDT=LDT=00:00) THEN {EDT=07:00 and LDT=18:00}

(vi) IF (EDT + 1 hour > LDT) THEN {LDT = EDT + 1 hour}

The first check (i), ensures that an order's Call-In occurs before the associated Pickup time window opens. Checks (ii) and (v) catch a missing time window input. In such a case, the standard time windows [03:00, 14:00] and [07:00, 18:00] are chosen for Pickup and Delivery, respectively. Checks (iii) and (vi) make sure that all time windows possess a sufficiently long opening time. Check (iv) ensures a correct relative position of Pickup and Delivery time windows.

Furthermore, all times in an interval ranging from [23:00, 03:00] are set to 03:00 of the following day to comply with real-life restrictions. In cases with EDT - LPT > ten days, the time gap is set to exactly 10 days to avoid the need for storage.

### Determination of initial vehicle position and availability

Finally, the vehicle data set is completed with the information of *when* and *where* each vehicle is initially available for new transportation tasks. The vehicle attribute "av_from" is chosen as the beginning time of the first vehicle task that was actually performed in the five-week horizon real-life planning (derived from type 3 and type 4 information). Initial geographical coordinates "geo_long_initial" and "geo_lat_initial" are chosen respectively.

In this way, the vehicles available for MNS planning start at the same time and at the same geographical position as the vehicles do in the actual real-life planning. Since MNS also gets the same orders as in the real-life planning, it could theoretically end up producing the same scheduling that human dispatchers have produced in real-life. On the other hand, it also gets the chance to produce a completely different, maybe better, planning.

**Derivation of benchmark objective function values**

After finishing the preprocessing of the real-life data, some performance indicators of actually performed planning at the freight forwarding company can be derived.

First, *total delay* is determined for all Pickup and Delivery requests. This is performed by calculating the gap between actual arrival time at a Pickup (Delivery) location and LPT (LDT). All delays are added, resulting in a total delay of 2,260.52 days at Pickup locations and of 4,391.44 days at Delivery locations. Hence, a total delay of 6,651.96 days was generated.

Subsequently, the *empty traveled distance* has to be calculated. For the real-life orders and the actual planning, however, there are only geographical coordinates of Pickup and Delivery locations available, but no information on actually driven street distances. Hence, some assumptions are required. We choose to calculate the actual traveled distances with a Euclidean metric. The same metric, of course, is used for the calculation of distances in the MNS procedure in order to ensure comparability.

Basic distance between two geographical coordinates $A$ $(x_A, y_A)$ and $B$ $(x_B, y_B)$ (with $x_A$, $x_B$ representing geographical longitude of location $A$ and $B$, respectively; and $y_A$, $y_B$ representing geographical latitude of location $A$ and $B$, respectively) is calculated as follows:

$$dist(A,B) = 111.2 \cdot \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2 \cdot \cos(x_A) \cdot \cos(x_B)} \cdot 1.3$$

The formula contains an approximation of the air-line distance accounting for the curvature of the earth (cp. Fleischmann, 2010). The resulting distance is multiplied by a street factor of 1.3 in order to include deviations from the idealized air-line distance.

The distance formula is applied to all loaded and all unloaded trips which can be derived from type 3 and type 4 information. In this way, a total traveled distance of 16,535,592 kilometers is calculated. This number consists of 1,858,752 empty kilometers and 14,676,840 loaded kilometers. The associated *empty-to-all ratio* was:

$$\frac{\textit{empty driven kilometers}}{\textit{total number of driven kilometers (empty and loaded)}} = 11.2\%$$

The benchmark values which are used for comparison in Section 5.5 are summarized in Table 5.6. All values are given in “hours”. The translation of traveled distance into traveled time is performed with the assumption of a vehicle average speed of 72 km/h (in agreement with our cooperating freight forwarding company). This vehicle speed assumption is also applied to all travel time calculations in the modified MNS procedure.

As explained above, values of *delay* are directly derived from the freight forwarding company's data set. This is also true for *empty and loaded travel time* and *total operating time*. Further assumptions, however, have to be made for the category *loading time*, which includes the times of all loading and unloading processes. Each loading and each unloading process is assumed to last one hour. In the specific case of several loading and/or unloading processes at the same geographical position, however, only the last loading process is assumed to have a duration of one hour. All previous loading processes are scheduled with only a single minute of loading time.

| | |
|---|---|
| **delay** | 159,647 hours |
| **travel time** | 229,661 hours |
| loaded | 203,845 hours |
| unloaded | 25,816 hours |
| **loading time** | 24,000 hours |
| **break/wait** | 496,471 hours |
| **total operating time** | 750,132 hours |

**Table 5.6:** Benchmark results for the five-week real-life test data set

In a last step, the *break/wait value* has to be calculated. This is performed indirectly, by subtracting traveling time and loading time from total operating time.

At this point, the preprocessing and the analysis of the real-life data set is complete. The derived benchmark values for the objective function criteria are used in the following section to evaluate the performance of the adapted MNS procedure.

## 5.5 Computational Results

This section starts with the parameterization of the adapted MNS procedure with regard to *penalty cost*, *anticipation horizon* and application of *improvement neighborhoods*. In addition, some insights into the impact of simulation speed on solution quality are derived (Section 5.5.1). Afterwards, an exemplary MNS generated tour for the five-week real-life test data set is presented. This includes a detailed analysis of the generated scheduling and an investigation of its compliance with the chosen general real-life requirements (Section 5.5.2).

In a next step, some of the computational results are reported, pointing out the solution's dependency on the weighting of the objective function criteria *delay* and *empty travel time* (Section 5.5.3). Finally, the pros and cons of the implementation of a dynamic Fleet Management System for International Truck Transportation are discussed (Section 5.5.4).

### 5.5.1 Parameterization

Parameterization and all subsequent simulation runs are executed on a quad core PC (Intel Core 2 Quad CPU, 2.83 GHz, 8 GB RAM), with each simulation running on one of the four available cores. All detailed parameterization results can be found in Appendix B. In the beginning, there is the open question of how to choose the **penalty costs for delay, empty travel time and waiting**. From our cooperating freight forwarding company, there is only the general specification of weighting the reduction of empty travel time highest and the reduction of delay second highest. The parameterization is started with a high simulation speed of s = 120, which is successively decreased to a real time simulation (s = 1).

To get a first impression of the impact of the different penalty cost values and of mutual dependency, several penalty cost combinations are investigated with a **high simulation speed of s = 120**. For the five-week real-life data set, this results in a simulation time of approximately seven hours for each cost combination. In total, 49 different penalty cost variations are tested: due to the relatively lower importance of *waiting*, the associated penalty costs are fixed at a value of 1 for all combinations. Penalty costs for *delay* and *empty travel time* are both chosen from the penalty cost set {1, 5, 8, 10, 20, 30, 40}. In the following, the chosen penalty cost pairs are denoted as "a,b", with *a* representing the penalty cost for *empty travel time*, and *b* representing the penalty cost for *delay*. As further parameter settings, the initial improvement time is set to 180 minutes (neighborhoods I:II:III = 1:1:1), for general improvement the neighborhoods I and II are chosen in relation 66:33, the tabu time of neighborhood I is set to 30 minutes, and the anticipation horizon is chosen to be 10 minutes.

The results are summarized in Table 5.7. For each penalty cost combination, the four solution criteria *empty travel time*, *delay*, *break/wait*, and *total operating time* are given in the form of the percentage deviation from the benchmark values derived in Section 5.4. Here, a negative value indicates an improvement of solution quality, while a worsening of solution quality is indicated by a positive value. For the penalty cost combination (30,5), for example, an empty travel time of 26,025 hours (+0.8%), a delay of 217,675 hours (+36.3%), a break/wait time of 489,456 hours (-1.4%), and a total operating time of 743,325 hours (-0.9%) are achieved. In total, the performance of the high simulation speed results is very modest. All results are clearly inferior to the benchmark.

However, some general observations can be made. A higher weighting of the cost for *empty traveling* induces a monotonous improvement in the associated empty travel time. This monotonous behavior can also be found in most of the cases of delay, when the associated penalty costs (for *delay*) are increased. The results indicate that there is antithetic behavior between minimization of empty travel time and minimization of delay. Improvements in one category are accompanied by a worsening in the other category. Therefore, a parameterization has to be found that achieves preferably good planning results for both requirements.

Fortunately, values of *break/wait* and *total operating time* seem to be less sensitive to the penalty cost variations for empty travel time and delay. It can be observed that the best break/wait result is achieved for a cost parameterization (1,1). This is an intuitive finding, since the penalty cost value of break/wait that has been initially fixed to 1, is relatively the highest for this cost combination. In addition, the results of *break/wait* and *total operating time* are also slightly better when "better" results for empty travel time are achieved.

The parameterization of delay and empty travel time penalty costs is continued with an analysis of a slower **simulation speed of s = 5**. Since a slower simulation speed induces longer simulation runs (for s = 5: approximately one week), we choose only a subset of

| penalty cost "traveling empty" | | penalty cost "delay" 1 | | 5 | | 8 | | 10 | | 20 | | 30 | | 40 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | | 56.9 | 26.3 | 69.5 | -12.2 | 74.5 | -9.8 | 74.3 | -5.3 | 78.3 | -2.2 | 78.9 | -3.7 | 78.5 | -7.7 |
| | | -7.4 | -2.9 | -3.5 | 0.0 | -2.8 | 0.7 | -2.5 | 0.9 | -1.9 | 1.5 | -1.8 | 1.5 | -2.1 | 1.3 |
| **5** | | 11.0 | 47.6 | 34.8 | -12.7 | 39.2 | -13.0 | 39.7 | -14.2 | 46.3 | -5.3 | 48.0 | -9.4 | 50.4 | -3.7 |
| | | -6.9 | -4.2 | -2.5 | -0.5 | -1.9 | 0.1 | -1.6 | 0.3 | -1.3 | 0.7 | -1.0 | 1.0 | -1.4 | 0.8 |
| **8** | | 0.3 | 68.0 | 25.2 | -12.0 | 30.4 | -12.2 | 34.0 | -12.2 | 40.6 | -10.1 | 41.9 | -10.8 | 43.3 | -9.3 |
| | | -6.7 | -4.4 | -2.1 | -0.5 | -1.2 | 0.2 | -1.1 | 0.4 | -1.1 | 0.7 | -0.8 | 0.9 | -0.6 | 1.1 |
| **10** | | -4.7 | 84.0 | 21.1 | -9.5 | 26.5 | -11.9 | 30.7 | -15.3 | 36.3 | -13.1 | 39.3 | -8.5 | 41.9 | -7.7 |
| | | -6.3 | -4.3 | -1.9 | -0.5 | -1.6 | -0.1 | -1.6 | 0.0 | -0.9 | 0.6 | -0.9 | 0.8 | -0.6 | 1.0 |
| **20** | | -17.1 | 164.3 | 9.6 | 10.2 | 16.4 | 3.7 | 19.3 | -3.9 | 29.6 | -8.3 | 34.7 | -4.4 | 36.6 | -6.4 |
| | | -4.8 | -3.8 | -1.4 | -0.6 | -1.6 | -0.5 | -0.8 | 0.1 | -0.7 | 0.5 | -0.3 | 1.0 | -0.2 | 1.1 |
| **30** | | -22.2 | 235.9 | **0.8** | **36.3** | 9.4 | 13.3 | 13.6 | 9.9 | 23.5 | -3.4 | 29.7 | -1.4 | 34.0 | -2.5 |
| | | -3.9 | -3.3 | **-1.4** | **-0.9** | -0.8 | -0.2 | -0.7 | 0.0 | -0.5 | 0.5 | -0.3 | 0.8 | -0.9 | 0.6 |
| **40** | | -26.2 | 316.2 | -4.5 | 55.0 | 3.5 | 32.0 | 8.4 | 19.3 | 20.2 | 3.7 | 25.9 | -1.5 | 30.7 | -1.7 |
| | | -4.1 | -3.6 | -1.2 | -1.0 | -0.8 | -0.4 | -0.7 | -0.2 | -0.4 | 0.4 | -0.6 | 0.5 | -0.4 | 0.8 |

**percentage deviation from benchmark**

| | |
|---|---|
| empty travel time | delay |
| break/wait | operating time |

penalty cost "waiting" = 1

**Table 5.7:** Parameterization of penalty costs (sim speed s: = 120, improvement neighborhoods: I-II 66%-33%, anticipation horizon: 10 min)

nine promising parameter combinations from the initial analysis for further investigation: 20,8; 30,10; 30,8; 20,5; 40,8; 30,5; 40,5; 8,1; 10,1. All other settings are kept the same as in the first case.

The results are visualized in Figure 5.11 (black triangles). On the x-axis and the y-axis, the actually achieved objective function values for delay and empty travel time are outlined. For the penalty cost combination (30,10), for example, an empty travel time of 27,424 hours, a delay of 128,188 hours, a break/wait time of 489,660 hours, and a total operating time of 744,927 hours is generated. The reproduction of detailed results for break/wait and total operating time is skipped in this illustration to allow for a clear representation of empty travel time and delay.

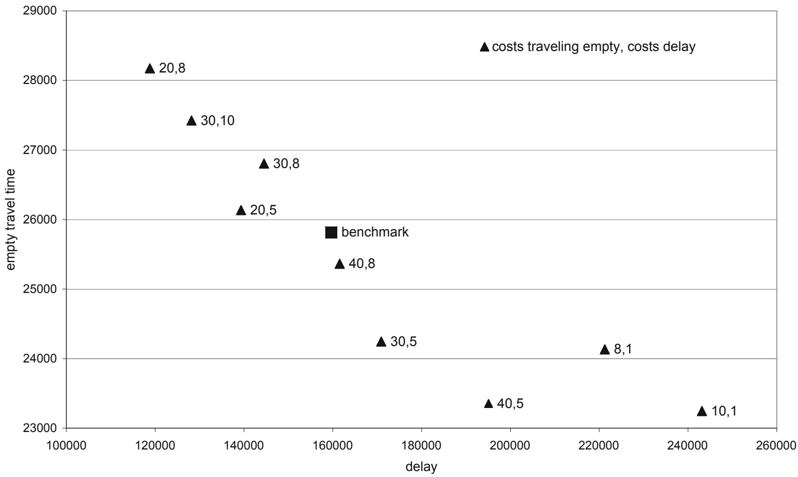


**Figure 5.11:** Parameterization of penalty costs (sim speed: s = 5, improvement neighborhoods: I:II 66:33, anticipation horizon: 10 min)

Furthermore, the relative location of the benchmark result is included (black square), which allows for a division of the figure into four quadrants relative to the benchmark result. In the upper-left quadrant, delay can be reduced in comparison to the benchmark, but there is an increase in empty travel time. In the lower-right quadrant, empty travel time can be reduced in comparison to the benchmark, but there is a increase in delay. In the upper-right quadrant, there are no relative improvements at all. In the lower-left quadrant, both categories, delay and empty travel time, can be improved. All achieved results fall into the upper-left quadrant (penalty cost combinations: 20,8; 30,10; 30,8; 20,5) and into the lower-right quadrant (penalty cost combinations: 40,8; 30,5; 40,5; 8,1; 10,1). Hence, only one objective function criterion can be improved in each case, but not both at the same time.

Since the reduction in simulation speed from s = 120 to s = 5 has caused significant improvements in solution quality, we (again) select a subset of promising cost parameter settings from the current s = 5 results (30,10; 20,5; 40,8; 30,5; 40,5) for a final analysis with the **simulation speed of s = 1 (real time simulation)**. Consequently, the simulation time for a single real time simulation run is now approximately five weeks.

The s = 1 results are visualized in Figure 5.12. The gray triangles show the results that are generated with a simulation speed of s = 1. In this case, two penalty cost combinations – 40,8 and 30,5 – reach the preferred lower-left quadrant. With the penalty cost values (40,8), an empty travel time of 24,817 hours and a delay of 150,976 hours is achieved. In comparison to the benchmark, this is a significant reduction of 3.9% (empty travel time) and of 5.4% (delay). With the penalty cost values (30,5) empty travel time is reduced even further (-6.4%), but with the drawback of an only slightly reduced delay (-0.1%). Nevertheless, the penalty cost combination (30,5) is chosen for the remaining parameterizations.

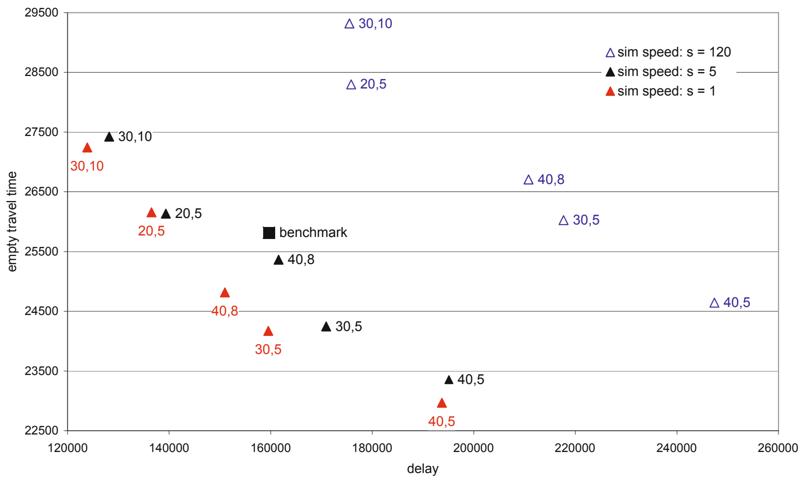


**Figure 5.12:** Parameterization of penalty costs (sim speed: s = 1, improvement neighborhoods: I:II 66:33, anticipation horizon: 10 min), impact of solution speed

Figure 5.12 also allows for an analysis of the *impact of simulation speed on the solution quality*. For the five penalty cost combinations that are simulated in real time, the results that are achieved with simulation speeds s = 5 (black triangles) and s = 120 (blank triangles) are also given. In this way, the improvement that is achieved by slower simulation times can be tracked:

In the exemplary case of the penalty cost values (40,8), with a simulation speed of s = 120, an empty travel time of 26,707 hours and a delay of 210,785 hours is produced. This is reduced to 25,364 hours of empty travel time (-5.1%) and to 161,562 hours of delay (-23.4%) with simulation speed s = 5. Further improvements are achieved with the real time simulation. Empty travel time is reduced once more by 2.2%, and delay is reduced by 6.6%.

These results definitely indicate an *advantage of the real time simulation*. The extra time that is given to applying the improvement neighborhoods of MNS seems to be beneficial. A drawback, however, is the long calculation time that only allows for a limited number of parameterizations to be tested.

In a second step, the **anticipation horizon** is parameterized, investigating the following values: 5 min, 10 min, 30 min, 60 min, 90 min, and 120 min. As further settings, the penalty costs values (30,5) and the improvement neighborhoods I:II in relation 66:33 are chosen. All other settings are the same as in the previous tests. The simulations are executed twice: with a simulation speed of s = 5 and with a simulation speed of s = 1. Figures 5.13 and 5.14 show the achieved results for the respective simulation speeds. The results are grouped according to the objective function criteria empty travel time, delay, break/wait, and total operating time. For each variation, the results that are achieved with a specific anticipation horizon are given as percentage deviations from the benchmark.

For a simulation speed of s = 5, best performance in empty travel time is achieved for an anticipation horizon of 10 minutes. Interestingly, the 30-minute horizon achieves the worst result of all investigated anticipation horizons. In category delay, the anticipation horizon of 30 minutes, however, shows the best performance and is slightly better than the 10-minute horizon. For longer anticipation horizons (e.g., 90 min or 120 min), solution quality in delay drops significantly. Break/Wait and total operating time show quite insensitive behavior to variations of the anticipation horizon. In total, the 10-minute anticipation horizon shows the best performance for a simulation speed of s = 5.

For a simulation speed of s = 1, the situation changes. In terms of empty travel time reduction, the 10-minute horizon is outperformed by all longer anticipation horizons. For this category, best results are achieved with a horizon of 60 minutes, followed by a horizon of 30 minutes. In category delay, the best result is achieved with a horizon of 30 minutes. Like in the s = 5 simulation, break/wait and total operating time show quite insensitive behavior to variations of the anticipation horizon. In total, the 30-minute anticipation horizon now demonstrates the best performance (for s = 1).

It is interesting that parameterizations with different simulation speeds cause different results. This observation indicates that a proper parameterization for a real time simulation should be also executed in real time, at least if there is enough time. For the calculation of the final results, which is of course performed in real time, the anticipation horizon is therefore chosen to be 30 minutes.

The last parameterization concerns the **allocation of improvement time** to available neighborhood operations. For detection of the best combination, the following variations are analyzed: 100:0, 75:25, 66:33, 50:50, 33:66, 25:75, and 0:100. These numbers can be interpreted as percentage values and serve as a basis of how much computation time is allocated to neighborhoods I and II. As further settings, the penalty cost values (30,5) and an anticipation horizon of 10 minutes are chosen. All other settings are kept the same as in the previous tests. As in the previous case, the simulation of the investigated variations are executed twice: with a simulation speed of s = 5 and with a simulation speed of s = 1.

Figures 5.15 and 5.16 show the achieved results for both simulations, respectively. The results are grouped again according to the objective function criteria empty travel time,

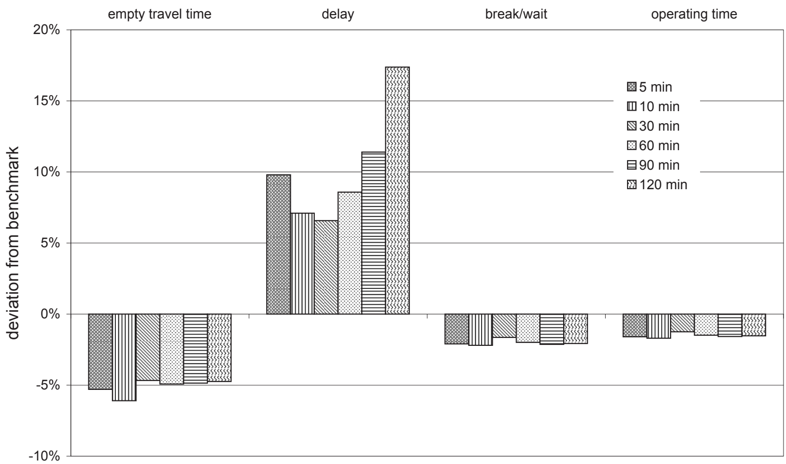


**Figure 5.13:** Parameterization of anticipation horizon, 5 min up to 120 min (penalty costs: 30,5, sim speed: s = 5, improvement neighborhoods: I:II 66:33)

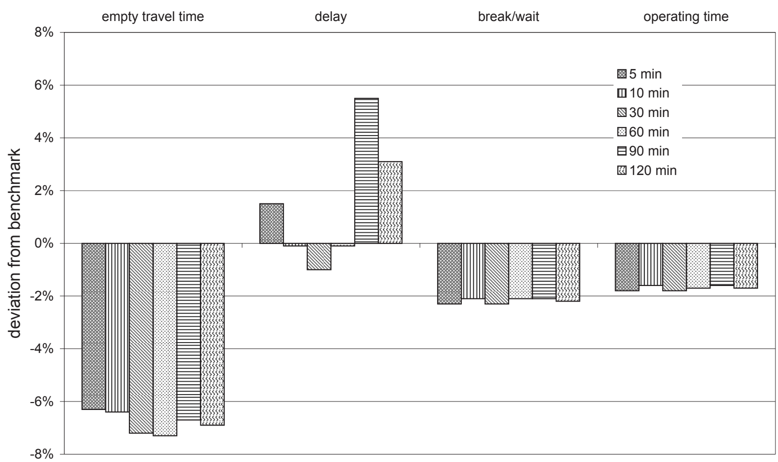


**Figure 5.14:** Parameterization of anticipation horizon, 5 min up to 120 min (penalty costs: 30,5, sim speed: s = 1, improvement neighborhoods: I:II 66:33)

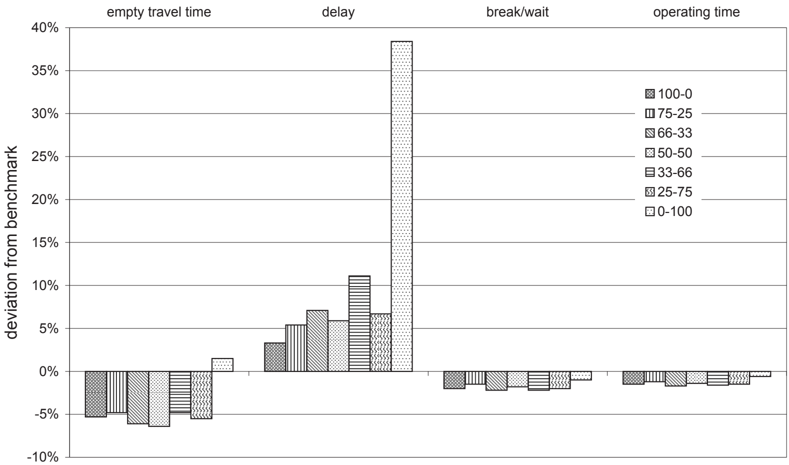


**Figure 5.15:** Parameterization “allocation of improvement time”, neighborhood I : neighborhood II (penalty costs: 30,5, sim speed: s = 5, anticipation horizon: 10 min)

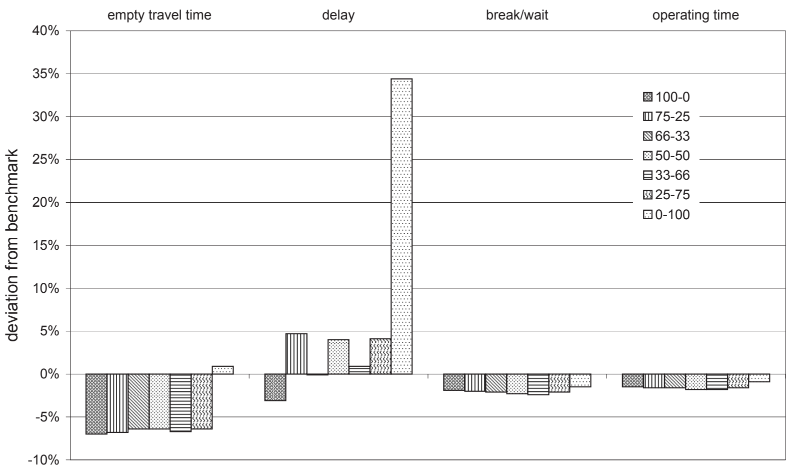


**Figure 5.16:** Parameterization “allocation of improvement time”, neighborhood I : neighborhood II (penalty costs: 30,5, sim speed: s = 1, anticipation horizon: 10 min)

delay, break/wait, and total operating time. For each variation, the results that are achieved with a specific allocation of improvement time are given as percentage deviations from the benchmark.

For a simulation speed of s = 5, the best performance in empty travel time is achieved by the allocation 50:50, which is followed by the allocation 66:33 with the second best result. In terms of delay, the best result is generated by the allocation 100:0. The opposite allocation 0:100 results in the worst level of delay. 50:50, here as well, is slightly better than 66:33. Again, break/wait and total operating time show a quite insensitive reaction to the applied variations. In conclusion, best overall performance is achieved with the allocation 50:50 (for s = 5).

For a simulation speed of s = 1, however, differing results are generated. The best performance in terms of empty travel time, and also delay, is achieved with the allocation 100:0. While the other allocations produce empty travel times at least in the same range as 100:0, the picture changes in delay: here, a 3.1% reduction is generated by 100:0, with the second best allocation 66:33 being stuck only at a 0.1% reduction.

The surprising success of allocation 100:0 can be explained as follows. The real time simulation allocates a five times higher amount of calculation time to improvement procedure II (intraroute exchanges). In some cases, all exchange operations of improvement procedure II are investigated before the allocated time is actually consumed. If such a situation occurs, the excessive time is not used for any other calculation in order to keep the percental allocation of improvement time at the specified levels. In contrast, improvement procedure I has so many exchange operations available that it never "runs out of work". With the allocation 100:0, therefore, the available improvement time can be used completely, which declares its better performance.

At this point, the main parameterizations of penalty costs, anticipation horizon and improvement procedure are finished. Table 5.8 summarizes all internal parameters and penalty cost settings that are finally selected for the application of the real-life MNS on the real-life data set.

| **Real-Life MNS** | |
|---|---|
| **internal parameters** | |
| initial improvement | |
| duration: | 180 min |
| neighborhoods I:II:III | 1:1:1 |
| general improvement: | |
| neighborhoods I:II | 100:0 |
| tabu time: | 30 min |
| anticipation: | 30 min |
| **penalty costs** | |
| c_traveling_empty (per min): | 30, 40, 40 |
| c_delay (per min): | 5, 5, 8 |
| c_wait (per min): | 1, 1, 1 |

**Table 5.8:** Parameter settings for real-life test data set

The results that are achieved with this "best" parameterization will be presented in Section 5.5.3. However, before we come to the final results, the following section analyzes a typical vehicle tour that is produced with MNS.

### 5.5.2 Exemplary Real-Life Scheduling

In this subsection an exemplary real-life vehicle tour that is produced by MNS for the five-week real-life data set is selected for detailed investigation. For this purpose, simply the very first available vehicle (in single driver mode) with internal number “00001” is chosen. The tour planning is generated with the parameter settings: penalty costs (40,8), an anticipation horizon of 10 minutes and with the application of improvement neighborhoods I:II in proportion 66:33. All other settings are kept the same as in the previous tests. The simulation is executed in real time (simulation speed s = 1).

Figure 5.17 visualizes the **course of the resulting five-week vehicle tour on a European map**. The vehicle starts its trip in Reutlingen (Germany) and finishes its tour in Dieppe (France). The sequence of locations that are included in the tour is indicated in capital letters from A (Reutlingen, Germany) to S (Dieppe, France). Furthermore, information on Pickup and Delivery locations of every *loaded trip* is given. In the exemplary tour, there are also some request bundles having more than one Pickup and/or Delivery location. Due to the relative geographical proximity of these locations, they are treated as a single location (only one capital letter).

The *first loaded trip* directs the vehicle from Reutlingen (Germany) at point A, to Miskolc (Hungary) at point B. Afterwards, the vehicle has to perform an empty trip from Miskolc (Hungary) at point B to Mosonszolnok (Hungary) at point C. Here, the vehicle gets its *second loaded trip* from Mosonszolnok (Hungary) at point C, to Vienna (Austria) at point D. In Vienna (Austria) at point D, the *third loaded trip* is directly available: Vienna (Austria) at point D, to Mannheim (Germany) at point E. From Mannheim (Germany) at point E, the vehicle has to perform a short empty traveling distance to Heidelberg (Germany) at point F. From Heidelberg (Germany) at point F the *fourth loaded trip* is started, which has its destination in Busalla (Italy) at point G. And so on... The resulting vehicle tour has an empty-to-all ratio of 9.38% and an average travel time per week of 42.6 hours.

Figures 5.18, 5.19, 5.20, and 5.21 show the associated **detailed scheduling** (Excel output file of MNS). The **meaning of the available columns** is explained as follows. In the first column, an *activity log* is included that describes the vehicles respective activity (e.g., “trip to Pickup of order 1307”, “break of journey”). In the second column, the *time interval for the respective activity* is given (e.g., “Mo 24.8.2009 8:30 – Mo 24.8.2009 13:00”). Columns three and four include the *geographical coordinates (longitude and latitude)* of Pickup and Delivery locations (in the format “degree,mmss”). This is followed by column four, which is not originally included in the MNS output file. Column four is created, in order to allow for a cross-reference to the European map in Figure 5.17: The capital letters which are used to visualize the vehicle’s main Pickup and Delivery locations in Figure 5.17 are included here in the detailed vehicle scheduling for a better traceability of the vehicle’s tour.

Column six contains the Pickup or Delivery *time window* when a respective location is reached (e.g., “Tu 18.8.2009 16:00 – Tu 18.8.2009 22:00”). Afterwards, the actually sched-

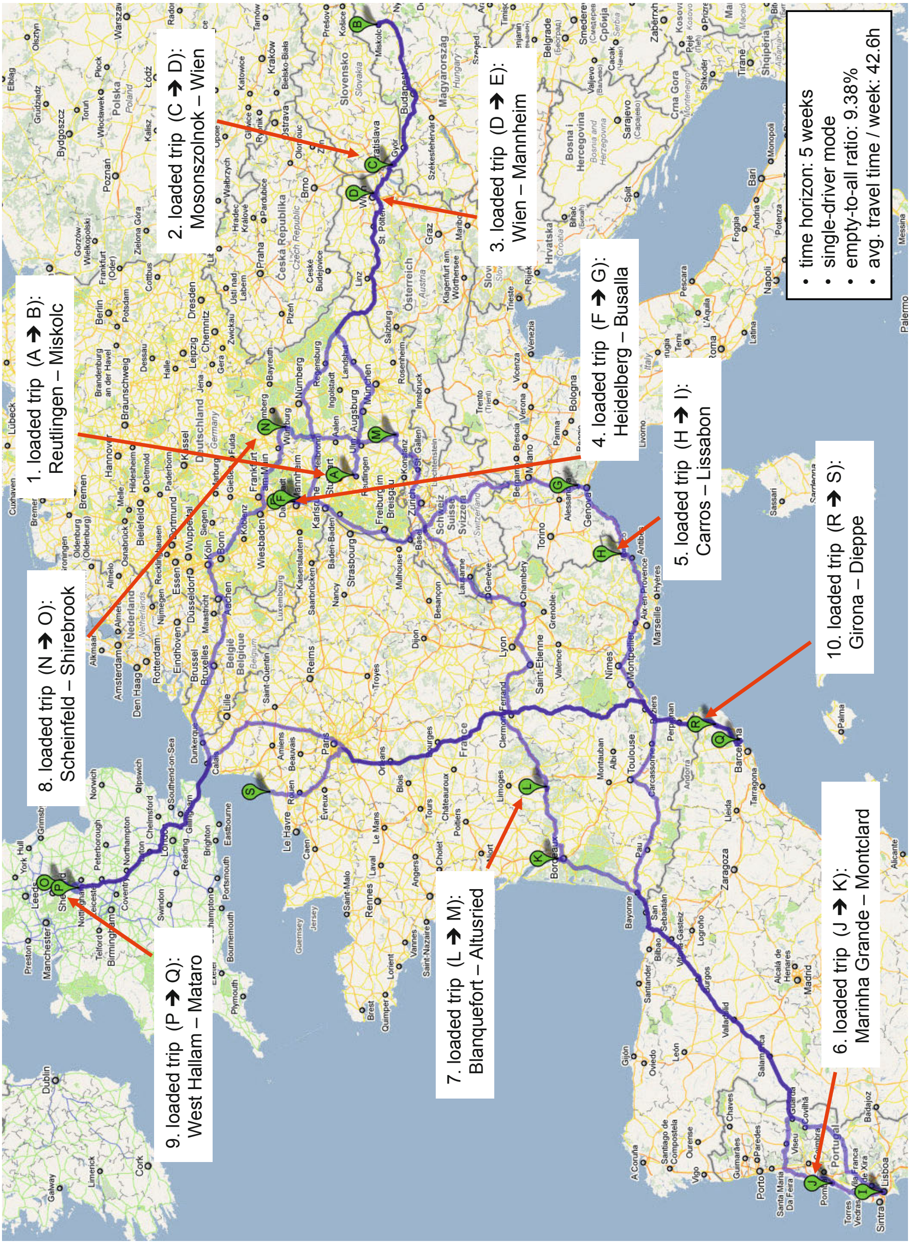


**Figure 5.17:** Exemplary results: five-week vehicle tour - geographical illustration

uled *arrival* time is given in column seven (e.g., "Tu 18.8.2009 16:00"). Columns eight to eleven include summary values for *break* time, *wait* time, *travel* time, and *load* time for the current activity (in the format "hh:mm"). These values support the inspection of whether all real-life restrictions have actually been complied with. If an arrival at Pickup or Delivery occurs after LPT or LDT, the associated *delay* is given in the last column (in the format "hh:mm").

In the following, a **detailed description of how to read the scheduling entries** is given.

In the beginning *(line 1)*, the vehicle's initial position ("9,1329, 48,3031") is given. Afterwards *(line 2)*, it is indicated that this specific vehicle is not available from the very beginning of the simulation, but first at "Tu 18.8.2009 16:00". In the scheduling of *line 3*, the vehicle is sent to the Pickup of order 1307. Since the associated Pickup location is in very close proximity to the vehicles initial position, no travel time is scheduled. The loading activity is started immediately, and takes one minute *(line 4)*. This is due to the fact that this Pickup is bundled with a second order at the same geographical position. *Line 5* contains the scheduling of the second order "trip to Pickup of order 1338". This Pickup location is also reached immediately. Since it is the last loading activity at the same geographical location, it results in the scheduling of the regular one-hour loading time *(line 6)*.

At "Tu 18.8.2009 17:01", the loading activities are finished and the vehicle starts its first real trip towards Delivery of order 1307 *(line 7)*. The first travel time interval lasts 4:30h from "Tu 18.8.2009 17:01 – Tu 18.8.2009 21:31". Then, a 45-minute break is scheduled from "Tu 18.8.2009 21:31 – Tu 18.8.2009 22:16" *(line 8)*. This is followed by the next 4:30h travel time interval from "Tu 18.8.2009 22:16 – We 19.8.2009 02:46" *(line 9)*. After a further 45-minute break *(line 10)*, an exceptional extra driving hour is scheduled from "We 18.8.2009 03:31 – We 19.8.2009 04:31" *(line 11)*. At this point, the maximum daily interval driving time of 10 hours is reached. Hence, a daily rest period is scheduled: in the present case, a reduced daily rest period of 9 hours *(line 12)*.

At "We 19.8.2009 13:31", the journey is continued with the next 4:30h travel time interval from "We 19.8.2009 13:31 – We 19.8.2009 18:01" *(line 13)*. This is followed, by a 45-minute break *(line 14)*, a further 4:30h travel time interval *(line 15)*, one more 45-minute break *(line 16)*, and a final driving hour from "Th 20.8.2009 00:01 – Th 20.8.2009 01:01" *(line 17)*. Due to this second extension to 10 hours of daily travel time, this week's potential 10-hour travel time extensions are completely utilized. Afterwards, the next reduced daily rest period is scheduled from "Th 20.8.2009 01:01 – Th 20.8.2009 10:01" *(line 18)*. This consumes the second of in total three reduced daily rest periods available per week.

At "Th 20.8.2009 10:01", the vehicle continues its trip for 3:55h and finally reaches the Delivery location of order 1307 at "Th 20.8.2009 13:56" *(line 19)*. This arrival time involves a delay of 15:56h. *Line 20* contains the associated one-hour unloading activity. In a next step, the vehicle travels 0:49h from "Th 20.8.2009 14:56 – Th 20.8.2009 15:45" to the request bundle's second Delivery of order 1338 *(line 21)*. This arrival time is also delayed, in this case by 17:45h. After the unloading activity is finished *(line 22)*, a weekly

| | activity log | interval of activity | geo.long. | geo.lat. | | time window | arrival | break | wait | travel | load | delay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | initial position | | 9,1329 | 48,3031 | | | | | | | | |
| 2 | vehicle not yet available! | Mo 17.8.2009 00:00 -- Tu 18.8.2009 16:00 | | | | | | | | | | |
| 3 | trip to Pickup of order 1307 | Tu 18.8.2009 16:00 -- Tu 18.8.2009 16:00 | 9,1324 | 48,3041 | A | Tu 18.8.2009 16:00 -- Tu 18.8.2009 22:00 | Tu 18.8.2009 16:00 | | | | | |
| 4 | loading of order 1307 | Tu 18.8.2009 16:00 -- Tu 18.8.2009 16:01 | | | | | | | | | :01 | |
| 5 | trip to Pickup of order 1338 | Tu 18.8.2009 16:01 -- Tu 18.8.2009 16:01 | 9,1324 | 48,3041 | | Tu 18.8.2009 16:00 -- Tu 18.8.2009 22:00 | Tu 18.8.2009 16:01 | | | | | |
| 6 | loading of order 1338 | Tu 18.8.2009 16:01 -- Tu 18.8.2009 17:01 | | | | | | | | | 1:00 | |
| 7 | trip to Delivery of order 1307 | Tu 18.8.2009 17:01 -- Tu 18.8.2009 21:31 | | | | | | | | 4:30 | | |
| 8 | break of journey | Tu 18.8.2009 21:31 -- Tu 18.8.2009 22:16 | | | | | | :45 | | | | |
| 9 | continuation of journey | Tu 18.8.2009 22:16 -- We 19.8.2009 02:46 | | | | | | | | 4:30 | | |
| 10 | break of journey | We 19.8.2009 02:46 -- We 19.8.2009 03:31 | | | | | | :45 | | | | |
| 11 | continuation of journey | We 19.8.2009 03:31 -- We 19.8.2009 04:31 | | | | | | | | 1:00 | | |
| 12 | break of journey | We 19.8.2009 04:31 -- We 19.8.2009 13:31 | | | | | | 9:00 | | | | |
| 13 | continuation of journey | We 19.8.2009 13:31 -- We 19.8.2009 18:01 | | | | | | | | 4:30 | | |
| 14 | break of journey | We 19.8.2009 18:01 -- We 19.8.2009 18:46 | | | | | | :45 | | | | |
| 15 | continuation of journey | We 19.8.2009 18:46 -- We 19.8.2009 23:16 | | | | | | | | 4:30 | | |
| 16 | break of journey | We 19.8.2009 23:16 -- Th 20.8.2009 00:01 | | | | | | :45 | | | | |
| 17 | continuation of journey | Th 20.8.2009 00:01 -- Th 20.8.2009 01:01 | | | | | | | | 1:00 | | |
| 18 | break of journey | Th 20.8.2009 01:01 -- Th 20.8.2009 10:01 | | | | | | 9:00 | | | | |
| 19 | trip to Delivery of order 1307 | Th 20.8.2009 10:01 -- Th 20.8.2009 13:56 | 21,0749 | 47,5135 | | We 19.8.2009 06:00 -- We 19.8.2009 22:00 | Th 20.8.2009 13:56 | | | 3:55 | | 15:56 |
| 20 | unloading of order 1307 | Th 20.8.2009 13:56 -- Th 20.8.2009 14:56 | | | | | | | | | 1:00 | |
| 21 | trip to Delivery of order 1338 | Th 20.8.2009 14:56 -- Th 20.8.2009 15:45 | 20,4725 | 48,0656 | B | We 19.8.2009 06:00 -- We 19.8.2009 22:00 | Th 20.8.2009 15:45 | | | :49 | | 17:45 |
| 22 | unloading of order 1338 | Th 20.8.2009 15:45 -- Th 20.8.2009 16:45 | | | | | | | | | 1:00 | |
| 23 | break of journey | Th 20.8.2009 16:45 -- Mo 24.8.2009 08:30 | | | | | | 87:45 | | | | |
| 24 | trip to Pickup of order 3693 | Mo 24.8.2009 08:30 -- Mo 24.8.2009 13:00 | | | | | | | | 4:30 | | |
| 25 | break of journey | Mo 24.8.2009 13:00 -- Mo 24.8.2009 13:45 | | | | | | :45 | | | | |
| 26 | trip to Pickup of order 3693 | Mo 24.8.2009 13:45 -- Mo 24.8.2009 16:30 | 17,1038 | 47,5104 | C | Mo 24.8.2009 15:00 -- Mo 24.8.2009 17:00 | Mo 24.8.2009 16:30 | | | 2:45 | | |
| 27 | loading of order 3693 | Mo 24.8.2009 16:30 -- Mo 24.8.2009 17:30 | | | | | | | | | 1:00 | |
| 28 | trip to Delivery of order 3693 | Mo 24.8.2009 17:30 -- Mo 24.8.2009 19:04 | 16,2731 | 48,1056 | D | Mo 24.8.2009 18:00 -- Mo 24.8.2009 19:00 | Mo 24.8.2009 19:04 | | | 1:34 | | :04 |
| 29 | unloading of order 3693 | Mo 24.8.2009 19:04 -- Mo 24.8.2009 20:04 | | | | | | | | | 1:00 | |
| 30 | trip to Pickup of order 3762 | Mo 24.8.2009 20:04 -- Mo 24.8.2009 20:04 | | | | | | | | | | |
| 31 | waiting time | Mo 24.8.2009 20:04 -- Tu 25.8.2009 07:00 | | | | | | | 10:56 | | | |
| 32 | trip to Pickup of order 3762 | Tu 25.8.2009 07:00 -- Tu 25.8.2009 07:00 | 16,2731 | 48,1056 | | Mo 24.8.2009 18:00 -- Mo 24.8.2009 19:00 | Tu 25.8.2009 07:00 | | | | | 12:00 |
| 33 | loading of order 3762 | Tu 25.8.2009 07:00 -- Tu 25.8.2009 07:01 | | | | | | | | | :01 | |
| 34 | trip to Pickup of order 3765 | Tu 25.8.2009 07:01 -- Tu 25.8.2009 07:01 | 16,2731 | 48,1056 | | Mo 24.8.2009 18:00 -- Mo 24.8.2009 19:00 | Tu 25.8.2009 07:01 | | | | | 12:01 |
| 35 | loading of order 3765 | Tu 25.8.2009 07:01 -- Tu 25.8.2009 07:02 | | | | | | | | | :01 | |
| 36 | trip to Pickup of order 3766 | Tu 25.8.2009 07:02 -- Tu 25.8.2009 07:02 | 16,2731 | 48,1056 | | Mo 24.8.2009 18:00 -- Mo 24.8.2009 19:00 | Tu 25.8.2009 07:02 | | | | | 12:02 |
| 37 | loading of order 3766 | Tu 25.8.2009 07:02 -- Tu 25.8.2009 08:02 | | | | | | | | | 1:00 | |
| 38 | trip to Delivery of order 3762 | Tu 25.8.2009 08:02 -- Tu 25.8.2009 12:32 | | | | | | | | 4:30 | | |
| 39 | break of journey | Tu 25.8.2009 12:32 -- Tu 25.8.2009 13:17 | | | | | | :45 | | | | |
| 40 | continuation of journey | Tu 25.8.2009 13:17 -- Tu 25.8.2009 17:47 | | | | | | | | 4:30 | | |

**Figure 5.18:** Exemplary results: five-week vehicle tour - scheduling I

| | activity log | interval of activity | geo.long. | geo.lat. | | time window | arrival | break | wait | travel | load | delay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 41 | break of journey | Tu 25.8.2009 17:47 -- Tu 25.8.2009 18:32 | | | | | | :45 | | | | |
| 42 | continuation of journey | Tu 25.8.2009 18:32 -- Tu 25.8.2009 19:32 | | | | | | | | 1:00 | | |
| 43 | break of journey | Tu 25.8.2009 19:32 -- We 26.8.2009 04:32 | | | | | | 9:00 | | | | |
| 44 | continuation of journey | We 26.8.2009 04:32 -- We 26.8.2009 09:02 | | | | | | | | 4:30 | | |
| 45 | break of journey | We 26.8.2009 09:02 -- We 26.8.2009 09:47 | | | | | | :45 | | | | |
| 46 | trip to Delivery of order 3762 | We 26.8.2009 09:47 -- We 26.8.2009 11:45 | 8,1630 | 48,5220 | | Tu 25.8.2009 08:00 -- Tu 25.8.2009 16:00 | We 26.8.2009 11:45 | | | 1:58 | | 19:45 |
| 47 | unloading of order 3762 | We 26.8.2009 11:45 -- We 26.8.2009 11:46 | | | | | | | | | :01 | |
| 48 | trip to Delivery of order 3765 | We 26.8.2009 11:46 -- We 26.8.2009 11:50 | 8,1459 | 48,5430 | | Tu 25.8.2009 08:00 -- Tu 25.8.2009 16:00 | We 26.8.2009 11:50 | | | :04 | | 19:50 |
| 49 | unloading of order 3765 | We 26.8.2009 11:50 -- We 26.8.2009 12:50 | | | | | | | | | 1:00 | |
| 50 | trip to Delivery of order 3766 | We 26.8.2009 12:50 -- We 26.8.2009 14:10 | 8,3310 | 49,3039 | E | Tu 25.8.2009 08:00 -- Tu 25.8.2009 16:00 | We 26.8.2009 14:10 | | | 1:20 | | 22:10 |
| 51 | unloading of order 3766 | We 26.8.2009 14:10 -- We 26.8.2009 15:10 | | | | | | | | | 1:00 | |
| 52 | trip to Pickup of order 4241 | We 26.8.2009 15:10 -- We 26.8.2009 15:25 | 8,3816 | 49,2438 | F | We 26.8.2009 08:00 -- We 26.8.2009 09:00 | We 26.8.2009 15:25 | | | :15 | | 6:25 |
| 53 | loading of order 4241 | We 26.8.2009 15:25 -- We 26.8.2009 16:25 | | | | | | | | | 1:00 | |
| 54 | trip to Delivery of order 4241 | We 26.8.2009 16:25 -- We 26.8.2009 17:18 | | | | | | | | :53 | | |
| 55 | break of journey | We 26.8.2009 17:18 -- Th 27.8.2009 04:18 | | | | | | 11:00 | | | | |
| 56 | continuation of journey | Th 27.8.2009 04:18 -- Th 27.8.2009 08:48 | | | | | | | | 4:30 | | |
| 57 | break of journey | Th 27.8.2009 08:48 -- Th 27.8.2009 09:33 | | | | | | :45 | | | | |
| 58 | continuation of journey | Th 27.8.2009 09:33 -- Th 27.8.2009 13:45 | | | | | | | | 4:12 | | |
| 59 | waiting time | Th 27.8.2009 13:45 -- Fr 28.8.2009 08:00 | | | | | | | 18:15 | | | |
| 60 | trip to Delivery of order 4241 | Fr 28.8.2009 08:00 -- Fr 28.8.2009 08:00 | 8,5720 | 44,3425 | G | Fr 28.8.2009 08:00 -- Fr 28.8.2009 09:00 | Fr 28.8.2009 08:00 | | | | | |
| 61 | unloading of order 4241 | Fr 28.8.2009 08:00 -- Fr 28.8.2009 09:00 | | | | | | | | | 1:00 | |
| 62 | trip to Pickup of order 5710 | Fr 28.8.2009 09:00 -- Fr 28.8.2009 12:51 | 7,1154 | 43,4632 | H | Fr 28.8.2009 08:00 -- Fr 28.8.2009 12:00 | Fr 28.8.2009 12:51 | | | 3:51 | | :51 |
| 63 | loading of order 5710 | Fr 28.8.2009 12:51 -- Fr 28.8.2009 13:51 | | | | | | | | | 1:00 | |
| 64 | trip to Delivery of order 5710 | Fr 28.8.2009 13:51 -- Fr 28.8.2009 18:21 | | | | | | | | 4:30 | | |
| 65 | break of journey | Fr 28.8.2009 18:21 -- Fr 28.8.2009 19:06 | | | | | | :45 | | | | |
| 66 | continuation of journey | Fr 28.8.2009 19:06 -- Fr 28.8.2009 20:45 | | | | | | | | 1:39 | | |
| 67 | break of journey | Fr 28.8.2009 20:45 -- Sa 29.8.2009 05:45 | | | | | | 9:00 | | | | |
| 68 | continuation of journey | Sa 29.8.2009 05:45 -- Sa 29.8.2009 10:15 | | | | | | | | 4:30 | | |
| 69 | break of journey | Sa 29.8.2009 10:15 -- Sa 29.8.2009 11:00 | | | | | | :45 | | | | |
| 70 | continuation of journey | Sa 29.8.2009 11:00 -- Sa 29.8.2009 15:30 | | | | | | | | 4:30 | | |
| 71 | break of journey | Sa 29.8.2009 15:30 -- Mo 31.8.2009 00:00 | | | | | | 32:30 | | | | |
| 72 | continuation of journey | Mo 31.8.2009 00:00 -- Mo 31.8.2009 04:30 | | | | | | | | 4:30 | | |
| 73 | break of journey | Mo 31.8.2009 04:30 -- Mo 31.8.2009 05:15 | | | | | | :45 | | | | |
| 74 | continuation of journey | Mo 31.8.2009 05:15 -- Mo 31.8.2009 09:45 | | | | | | | | 4:30 | | |
| 75 | break of journey | Mo 31.8.2009 09:45 -- Mo 31.8.2009 10:30 | | | | | | :45 | | | | |
| 76 | continuation of journey | Mo 31.8.2009 10:30 -- Mo 31.8.2009 11:30 | | | | | | | | 1:00 | | |
| 77 | break of journey | Mo 31.8.2009 11:30 -- Mo 31.8.2009 20:30 | | | | | | 9:00 | | | | |
| 78 | continuation of journey | Mo 31.8.2009 20:30 -- Tu 01.9.2009 01:00 | | | | | | | | 4:30 | | |
| 79 | break of journey | Tu 01.9.2009 01:00 -- Tu 01.9.2009 01:45 | | | | | | :45 | | | | |
| 80 | continuation of journey | Tu 01.9.2009 01:45 -- Tu 01.9.2009 06:15 | | | | | | | | 4:30 | | |
| 81 | break of journey | Tu 01.9.2009 06:15 -- Tu 01.9.2009 07:00 | | | | | | :45 | | | | |
| 82 | trip to Delivery of order 5710 | Tu 01.9.2009 07:00 -- Tu 01.9.2009 07:09 | -9,0907 | 38,4359 | I | Tu 01.9.2009 07:00 -- We 02.9.2009 07:00 | Tu 01.9.2009 07:09 | | | :09 | | |

**Figure 5.19:** Exemplary results: five-week vehicle tour - scheduling II

| | activity log | interval of activity | geo.long. | geo.lat. | | time window | arrival | break | wait | travel | load | delay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 83 | unloading of order 5710 | Tu 01.9.2009 07:09 -- Tu 01.9.2009 08:09 | | | | | | | | | 1:00 | |
| 84 | trip to Pickup of order 6511 | Tu 01.9.2009 08:09 -- Tu 01.9.2009 09:00 | | | | | | | | :51 | | |
| 85 | break of journey | Tu 01.9.2009 09:00 -- Tu 01.9.2009 18:00 | | | | | | 9:00 | | | | |
| 86 | trip to Pickup of order 6511 | Tu 01.9.2009 18:00 -- Tu 01.9.2009 19:12 | -8,5558 | 39,4456 | J | Tu 01.9.2009 09:00 -- Tu 01.9.2009 17:30 | Tu 01.9.2009 19:12 | | | 1:12 | | 1:42 |
| 87 | loading of order 6511 | Tu 01.9.2009 19:12 -- Tu 01.9.2009 20:12 | | | | | | | | | 1:00 | |
| 88 | trip to Delivery of order 6511 | Tu 01.9.2009 20:12 -- We 02.9.2009 00:42 | | | | | | | | 4:30 | | |
| 89 | break of journey | We 02.9.2009 00:42 -- We 02.9.2009 01:27 | | | | | | :45 | | | | |
| 90 | continuation of journey | We 02.9.2009 01:27 -- We 02.9.2009 04:45 | | | | | | | | 3:18 | | |
| 91 | break of journey | We 02.9.2009 04:45 -- We 02.9.2009 15:45 | | | | | | 11:00 | | | | |
| 92 | continuation of journey | We 02.9.2009 15:45 -- We 02.9.2009 20:15 | | | | | | | | 4:30 | | |
| 93 | break of journey | We 02.9.2009 20:15 -- We 02.9.2009 21:00 | | | | | | :45 | | | | |
| 94 | continuation of journey | We 02.9.2009 21:00 -- Th 03.9.2009 01:30 | | | | | | | | 4:30 | | |
| 95 | break of journey | Th 03.9.2009 01:30 -- Th 03.9.2009 12:30 | | | | | | 11:00 | | | | |
| 96 | continuation of journey | Th 03.9.2009 12:30 -- Th 03.9.2009 17:00 | | | | | | | | 4:30 | | |
| 97 | break of journey | Th 03.9.2009 17:00 -- Th 03.9.2009 17:45 | | | | | | :45 | | | | |
| 98 | continuation of journey | Th 03.9.2009 17:45 -- Th 03.9.2009 18:12 | | | | | | | | :27 | | |
| 99 | waiting time | Th 03.9.2009 18:12 -- Mo 07.9.2009 08:00 | | | | | | | 85:48 | | | |
| 100 | trip to Delivery of order 6511 | Mo 07.9.2009 08:00 -- Mo 07.9.2009 08:00 | -0,3655 | 44,5538 | K | Mo 07.9.2009 08:00 -- Mo 07.9.2009 14:30 | Mo 07.9.2009 08:00 | | | | | |
| 101 | unloading of order 6511 | Mo 07.9.2009 08:00 -- Mo 07.9.2009 09:00 | | | | | | | | | 1:00 | |
| 102 | trip to Pickup of order 9021 | Mo 07.9.2009 09:00 -- Mo 07.9.2009 10:16 | | | | | | | | 1:16 | | |
| 103 | waiting time | Mo 07.9.2009 10:16 -- Mo 07.9.2009 14:00 | | | | | | | 3:44 | | | |
| 104 | trip to Pickup of order 9021 | Mo 07.9.2009 14:00 -- Mo 07.9.2009 14:00 | 1,1321 | 45,0753 | L | Mo 07.9.2009 14:00 -- Mo 07.9.2009 15:00 | Mo 07.9.2009 14:00 | | | | | |
| 105 | loading of order 9021 | Mo 07.9.2009 14:00 -- Mo 07.9.2009 15:00 | | | | | | | | | 1:00 | |
| 106 | trip to Delivery of order 9021 | Mo 07.9.2009 15:00 -- Mo 07.9.2009 19:30 | | | | | | | | 4:30 | | |
| 107 | break of journey | Mo 07.9.2009 19:30 -- Mo 07.9.2009 20:15 | | | | | | :45 | | | | |
| 108 | continuation of journey | Mo 07.9.2009 20:15 -- Mo 07.9.2009 23:00 | | | | | | | | 2:45 | | |
| 109 | break of journey | Mo 07.9.2009 23:00 -- Tu 08.9.2009 08:00 | | | | | | 9:00 | | | | |
| 110 | continuation of journey | Tu 08.9.2009 08:00 -- Tu 08.9.2009 12:30 | | | | | | | | 4:30 | | |
| 111 | break of journey | Tu 08.9.2009 12:30 -- Tu 08.9.2009 13:15 | | | | | | :45 | | | | |
| 112 | continuation of journey | Tu 08.9.2009 13:15 -- Tu 08.9.2009 17:45 | | | | | | | | 4:30 | | |
| 113 | break of journey | Tu 08.9.2009 17:45 -- We 09.9.2009 04:45 | | | | | | 11:00 | | | | |
| 114 | trip to Delivery of order 9021 | We 09.9.2009 04:45 -- We 09.9.2009 07:24 | 10,1550 | 47,4747 | M | We 09.9.2009 07:00 -- We 09.9.2009 12:00 | We 09.9.2009 07:24 | | | 2:39 | | |
| 115 | unloading of order 9021 | We 09.9.2009 07:24 -- We 09.9.2009 08:24 | | | | | | | | | 1:00 | |
| 116 | trip to Pickup of order 10286 | We 09.9.2009 08:24 -- We 09.9.2009 12:05 | 10,2722 | 49,3955 | N | We 09.9.2009 08:00 -- We 09.9.2009 13:00 | We 09.9.2009 12:05 | | | 3:41 | | |
| 117 | loading of order 10286 | We 09.9.2009 12:05 -- We 09.9.2009 13:05 | | | | | | | | | 1:00 | |
| 118 | trip to Delivery of order 10286 | We 09.9.2009 13:05 -- We 09.9.2009 16:45 | | | | | | | | 3:40 | | |
| 119 | break of journey | We 09.9.2009 16:45 -- Th 10.9.2009 01:45 | | | | | | 9:00 | | | | |
| 120 | continuation of journey | Th 10.9.2009 01:45 -- Th 10.9.2009 06:15 | | | | | | | | 4:30 | | |
| 121 | break of journey | Th 10.9.2009 06:15 -- Th 10.9.2009 07:00 | | | | | | :45 | | | | |
| 122 | continuation of journey | Th 10.9.2009 07:00 -- Th 10.9.2009 11:30 | | | | | | | | 4:30 | | |
| 123 | break of journey | Th 10.9.2009 11:30 -- Th 10.9.2009 12:15 | | | | | | :45 | | | | |

**Figure 5.20:** Exemplary results: five-week vehicle tour - scheduling III

| | activity log | interval of activity | geo.long. | geo.lat. | | time window | arrival | break | wait | travel | load | delay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 124 | continuation of journey | Th 10.9.2009 12:15 -- Th 10.9.2009 13:15 | | | | | | | | 1:00 | | |
| 125 | break of journey | Th 10.9.2009 13:15 -- Th 10.9.2009 22:15 | | | | | | 9:00 | | | | |
| 126 | continuation of journey | Th 10.9.2009 22:15 -- Fr 11.9.2009 02:45 | | | | | | | | 4:30 | | |
| 127 | break of journey | Fr 11.9.2009 02:45 -- Fr 11.9.2009 03:30 | | | | | | :45 | | | | |
| 128 | continuation of journey | Fr 11.9.2009 03:30 -- Fr 11.9.2009 08:00 | | | | | | | | 4:30 | | |
| 129 | break of journey | Fr 11.9.2009 08:00 -- Fr 11.9.2009 17:00 | | | | | | 9:00 | | | | |
| 130 | trip to Delivery of order 10286 | Fr 11.9.2009 17:00 -- Fr 11.9.2009 18:47 | -1,1328 | 53,1136 | O | Fr 11.9.2009 08:00 -- Fr 11.9.2009 09:00 | Fr 11.9.2009 18:47 | | | 1:47 | | 9:47 |
| 131 | unloading of order 10286 | Fr 11.9.2009 18:47 -- Fr 11.9.2009 19:47 | | | | | | | | | 1:00 | |
| 132 | break of journey | Fr 11.9.2009 19:47 -- Mo 14.9.2009 15:30 | | | | | | 67:43 | | | | |
| 133 | trip to Pickup of order 11721 | Mo 14.9.2009 15:30 -- Mo 14.9.2009 16:00 | -1,2136 | 52,5811 | P | Mo 14.9.2009 08:00 -- Mo 14.9.2009 16:00 | Mo 14.9.2009 16:00 | | | :30 | | |
| 134 | loading of order 11721 | Mo 14.9.2009 16:00 -- Mo 14.9.2009 17:00 | | | | | | | | | 1:00 | |
| 135 | trip to Delivery of order 11721 | Mo 14.9.2009 17:00 -- Mo 14.9.2009 21:30 | | | | | | | | 4:30 | | |
| 136 | break of journey | Mo 14.9.2009 21:30 -- Mo 14.9.2009 22:15 | | | | | | :45 | | | | |
| 137 | continuation of journey | Mo 14.9.2009 22:15 -- Tu 15.9.2009 02:15 | | | | | | | | 4:00 | | |
| 138 | break of journey | Tu 15.9.2009 02:15 -- Tu 15.9.2009 13:15 | | | | | | 11:00 | | | | |
| 139 | continuation of journey | Tu 15.9.2009 13:15 -- Tu 15.9.2009 17:45 | | | | | | | | 4:30 | | |
| 140 | break of journey | Tu 15.9.2009 17:45 -- Tu 15.9.2009 18:30 | | | | | | :45 | | | | |
| 141 | continuation of journey | Tu 15.9.2009 18:30 -- Tu 15.9.2009 23:00 | | | | | | | | 4:30 | | |
| 142 | break of journey | Tu 15.9.2009 23:00 -- We 16.9.2009 10:00 | | | | | | 11:00 | | | | |
| 143 | continuation of journey | We 16.9.2009 10:00 -- We 16.9.2009 14:30 | | | | | | | | 4:30 | | |
| 144 | break of journey | We 16.9.2009 14:30 -- We 16.9.2009 15:15 | | | | | | :45 | | | | |
| 145 | continuation of journey | We 16.9.2009 15:15 -- We 16.9.2009 17:25 | | | | | | | | 2:10 | | |
| 146 | waiting time | We 16.9.2009 17:25 -- Th 17.9.2009 08:00 | | | | | | | 14:35 | | | |
| 147 | trip to Delivery of order 11721 | Th 17.9.2009 08:00 -- Th 17.9.2009 08:00 | 2,2606 | 41,3205 | Q | Th 17.9.2009 08:00 -- Th 17.9.2009 12:00 | Th 17.9.2009 08:00 | | | | | |
| 148 | unloading of order 11721 | Th 17.9.2009 08:00 -- Th 17.9.2009 09:00 | | | | | | | | | 1:00 | |
| 149 | trip to Pickup of order 10781 | Th 17.9.2009 09:00 -- Th 17.9.2009 10:12 | 2,4949 | 41,5933 | R | Th 17.9.2009 08:00 -- Th 17.9.2009 10:00 | Th 17.9.2009 10:12 | | | 1:12 | | :12 |
| 150 | loading of order 10781 | Th 17.9.2009 10:12 -- Th 17.9.2009 11:12 | | | | | | | | | 1:00 | |
| 151 | trip to Delivery of order 10781 | Th 17.9.2009 11:12 -- Th 17.9.2009 15:42 | | | | | | | | 4:30 | | |
| 152 | break of journey | Th 17.9.2009 15:42 -- Th 17.9.2009 16:27 | | | | | | :45 | | | | |
| 153 | continuation of journey | Th 17.9.2009 16:27 -- Th 17.9.2009 19:45 | | | | | | | | 3:18 | | |
| 154 | break of journey | Th 17.9.2009 19:45 -- Fr 18.9.2009 06:45 | | | | | | 11:00 | | | | |
| 155 | continuation of journey | Fr 18.9.2009 06:45 -- Fr 18.9.2009 11:15 | | | | | | | | 4:30 | | |
| 156 | break of journey | Fr 18.9.2009 11:15 -- Fr 18.9.2009 12:00 | | | | | | :45 | | | | |
| 157 | continuation of journey | Fr 18.9.2009 12:00 -- Fr 18.9.2009 15:58 | | | | | | | | 3:58 | | |
| 158 | waiting time | Fr 18.9.2009 15:58 -- Mo 21.9.2009 08:00 | | | | | | | 64:02 | | | |
| 159 | trip to Delivery of order 10781 | Mo 21.9.2009 08:00 -- Mo 21.9.2009 08:00 | 1,0557 | 49,5539 | S | Mo 21.9.2009 08:00 -- Mo 21.9.2009 09:00 | Mo 21.9.2009 08:00 | | | | | |
| 160 | unloading of order 10781 | Mo 21.9.2009 08:00 -- Mo 21.9.2009 09:00 | | | | | | | | | 1:00 | |
| | | | | | | | | ------- | ------- | ------- | ------- | ------- |
| | | | | | | | | 375:58 | 197:20 | 213:38 | 22:04 | 150:30 |
| | | | | | | | | **break** | **wait** | **travel** | **load** | **delay** |
| | | | | | | | | | empty: | 20:03 | | |
| | | | | | | | | | loaded: | 193:35 | | |

**Figure 5.21:** Exemplary results: five-week vehicle tour - scheduling IV

rest period from “Th 20.8.2009 16:45 – Mo 24.8.2009 8:30”, lasting 87:45h, is started.

The subsequent scheduling instructions are of the same type as in the first 22 lines. Therefore, the detailed description is finished at this point. In a next step, **compliance with the general restrictions for International Truck Transportation** is considered.

To simplify the analysis of compliance, the cells of columns 8 to 11 vary in color.

- The *yellow sections* represent the activities performed in a daily driving time interval. They include travel time, break time and load time.
- The *orange sections* contain daily rest periods, and
- the *blue sections* include weekly rest periods.

Exemplarily, the week from *line 100* to *line 132* (Mo 07.9.2009 08:00 until Mo 14.9.2009 15:30) is considered:

- Compliance with *daily driving time restrictions*: There are six travel time intervals with associated total travel times of 8:31h, 9:00h, 10:00h, 10:00h, 9:00h, and 1:47h. Twice (as allowed as a maximum) the total travel time was extended to 10 hours, the remaining *total travel times* stay at or under *a maximum of 9 hours* per daily driving interval.
- Compliance with *weekly driving time*: With a total of 48:18h, the maximum weekly driving time of 56 hours is respected.
- Compliance with *breaks*: All *traveling activities* have a *maximum duration of 4:30h* and are interrupted by “breaks of journey” of at least 0:45h (loading activities are also counted as non-driving periods).
- Compliance with *daily rest period*: The week contains five *daily rest periods*: four of reduced 9-hour length and one of regular 11-hour length. The interested reader may notice that there seems to be one more reduced 9-hour daily rest period, as it is allowed. This, however, can be attributed to the waiting time of 3:44h at *line 103*. This waiting time may be added to the subsequent 9-hour daily rest period (3h+9h splitting option); therefore, the associated 9 hours are counted as a regular 11-hour daily rest period. Hence, there are only three reduced daily rest periods in this week, which conforms to the restrictions.

  Another interesting aspect occurs in *line 108*: the vehicle starts a daily rest period, even though it has only reached a total traveling time of 8:31h in the respective travel time interval. The maximum travel time restriction would allow for 29 additional minutes. In this case, however, the restriction “daily rest period has to be taken within 24 hours after the last daily rest period (*24-hour rule*)” comes into effect. At “Mo 07.9.2009 23:00” the end of the last daily rest period (here: weekly rest period) is exactly 15 hours ago. Thus, it is the last possible time to start a daily rest period (which in this case even has to be a reduced 9-hour one) to fulfill the 24-hour rule.
- Compliance with *weekly rest period*: In the scheduling, there are five weekly rest periods with the lengths of 87:45h, 32:30h, 85:48h, 67:43h, and 64:02h. Four weekly

rest periods reach the minimum regular duration of 45 hours, the second weekly rest period *(line 71)* is reduced to 32:30h and needs a 21-hour compensation. This compensation is accomplished directly with the subsequent weekly rest period, where 85:48h of weekly rest period are scheduled. Hereby, the required 45h+21h=66h are more than fulfilled.

- Compliance with *Sunday traffic ban*: No activities are scheduled on Sundays.

The investigation of the exemplary five-week vehicle tour has provided some more insights into how a solution of the MNS procedure looks. The next subsection presents the final results that have actually been achieved with the best MNS parameter settings.

### 5.5.3 Final Results

The overall solution quality of the investigated real-life problem is clearly dependent on several aspects, especially empty travel time and delay, but also waiting time and total operating time. Unfortunately, an *antithetic behavior* was detected for the objective function criteria *empty travel time* and *delay*. There is no explicit specification how to relatively weight both factors. There is only the preference to weight reduction in empty travel time higher than reduction in delay and reduction in delay higher than reduction in waiting time.

Therefore, it is not possible to present "one" best result. Instead, it makes sense to present a choice of good solutions with different weighting of the preferences. The results are generated with the best parameter settings of Section 5.5.1 for the three promising penalty cost combinations: (40,8), (30,5) and (40,5). Detailed results for the objective function criteria empty travel time, delay, break/wait, and overtime are outlined in Table 5.9. The percentage deviations from the manual planning benchmark are visualized in Figure 5.22.

In the first case, a solution is presented that allocates improvements quite equally between empty travel time and delay. This solution is generated by the penalty cost setting (40,8): empty travel time is reduced by 3.9%, delay by 6.0% and break/wait by 1.6%. The empty-to-all ratio which was 11.2% in the manual planning benchmark is reduced to a level of 10.8%. Since there is a stronger reduction in delay as in empty travel time, some additional "improvement" may be shifted from the reduction of delay to the reduction of empty travel time which is – according to the given preferences – the primary focus.

| penalty costs | **empty traveling** | **delay** | **break/wait** | **operating time** |
|---|---|---|---|---|
| 40,8 | 24808 | 150122 | 488489 | 741140 |
| 30,5 | 23936 | 156915 | 485434 | 737213 |
| 40,5 | 22750 | 186175 | 485486 | 736079 |

**Table 5.9:** Final results for best parameter and penalty cost settings (in hours)

This is achieved in a second scenario with penalty cost setting (30,5): here, a reduction of empty travel time of 7.3% is generated. Simultaneously, delay is improved by 1.7% and break/wait by 2.2%. The empty-to-all ratio decreases to a level of 10.5%.

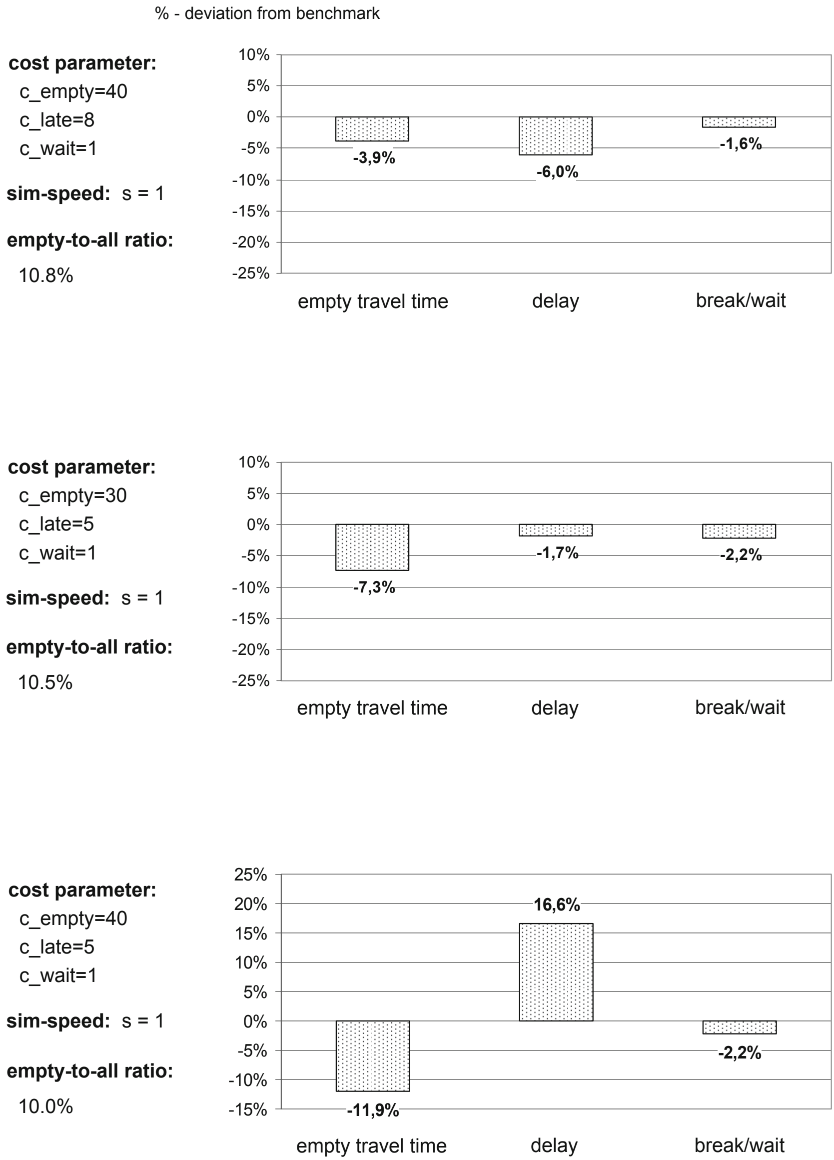


**Figure 5.22:** Final results for cost parameters (40,8), (30,5) and (40,5)

In a third penalty cost setting (40,5), we try to achieve even further improvements of empty travel time. And indeed, an improvement of 11.9% in terms of empty travel time compared to the manual planning benchmark is produced. The empty-to-all ratio decreases to a level of only 10.0%. However, this improvement comes along with a significant worsening in category delay (16.6%), while break/wait stays at a constant level in comparison to the previous setting (-2.2%). Due to the worsening in delay, this penalty cost setting seems to be only recommendable in situations with very strong preferences for reduction of empty travel time (in relation to reduction of delay).

In total, the second solution with penalty cost setting (30,5) seems to fulfill the required preferences for a “good solution” in the most suitable way: improvements are achieved in comparison to the manual planning benchmark for all objective function criteria, with highest improvements in category empty travel time and second highest improvements in category delay. In the following, we will refer to this second penalty cost setting and the associated results.

### 5.5.4 Discussion

The final results show that the application of a computer-based real-life planning system is capable of producing planning results with significant reductions in empty travel time and in delay. In the following, the *pros and cons* of an implementation of such a planning system are discussed. An overview is given in Table 5.10.

In a first step, the **possible benefits** are summarized.

- In the five-week test horizon, *1,880 hours of empty travel time are saved* compared to the manual planning benchmark (scenario with penalty cost setting: 30,5). With the assumed average speed of 72 km/h, this equates to 135,360 kilometers. Projected to a whole year with 52 weeks, a saving of approx. 1.4 million empty kilometers would be generated.

- Furthermore, there is an *increase in customer service*: total delay is reduced by 1.7% compared to the manual planning benchmark (scenario with penalty cost setting: 30,5). This corresponds to a weekly reduction of delay of approx. 546 hours.

- In addition to the saving of empty kilometers and to the improvement in service quality, the introduction of a computer-based Decision Support System for the dispatching of an international truck fleet will also cause a *reduction in manual planning effort*. Such a dynamic Decision Support System, however, is not capable of replacing a human dispatcher, it just supports human dispatchers with planning proposals. Some unsystematical data errors or unexpected planning situations will always require the final approval of a human. Nevertheless, the time that a dispatcher needs to perform the planning tasks considered in this work may be reduced. This, for example, allows for a higher number of vehicles to be supervised per dispatcher or for the taking on of other productive work in the freed up time.

- Independently of the quantifiable savings, the implementation of such a project initiates a general improvement process (e.g., for the input data quality and consistency), which may also result in general positive feedback for other parts and planning tasks of the freight forwarding company.

| costs | | benefits |
|---|---|---|
| **implementation costs** | **operating costs** | **reduction in empty traveled distance** of 7.3% |
| - guarantee of general and on time data availability | - staff, to keep the system running and for maintainance | five-week horizon: 1,880 h · 72 km/h = 135,360 km |
| - measures, securing input data quality and consistency | - energy, hardware | → year-long horizon (approx.): 1.4 million km |
| - acquisition/development of planning software | - ... | |
| - acquisition of sufficient hardware resources | **imponderabilities** | **reduction in delay** of 1.7% |
| - management of data interfaces | - remaining real-life restrictions, not considered | **reduction in manual planning effort** |
| - training of the dispatchers | - user incompliance | - time for other productive work |
| - ... | - ... | **general improvement process** |
| | | - positive feedback for other tasks |

**Table 5.10:** Implementation of a dynamic Fleet Management System: costs and benefits

In a second step, the **costs and risks** that have to be set against the potential benefits are outlined: initial implementation cost to acquire the new planning system and to get it running; recurring operating and maintainance costs; and also imponderabilities (risks), which may decrease the extent of actually generated savings.

*Implementation costs*:

- In the beginning, it has to be ensured that all information that is needed for the planning process is digitally available (*general data availability*). Possibly, the existing information system has to be backed up with additional information. Hereby, an on time data collection process is crucial (*on time data availability*). These preliminary aspects may cause first introduction costs.

- Furthermore, *measures for securing the input data quality and consistency* are needed. This is because a computer based planning system is not capable of finding unsystematic errors in the input data by itself. Undetected data errors may render the planning results partially useless. Such measures may include the installation of automatic checks of input data and also the raising of quality awareness of the people who manually enter the input data (perhaps with a gratification system for error free data handling).

- Introduction costs, furthermore, include the *costs for acquisition/development of planning software*. A freight forwarding company will not usually have the resources to build up a Decision Support System on its own. Hence, a planning solution should be bought from a professional software provider. This provider should have sufficient experience in the freight forwarding sector and also a skilled workforce that allows for customer specific adaptations and prompt service in case of difficulties. However, to avoid paying all the generated savings to the software company, the freight forwarder should have own employees available who understand the planning program and who are able to perform program adaptions themselves.

- *Appropriate hardware equipment* is needed for the planning software. It was shown in this study that even a conventional PC is able to perform the planning of a large problem instance. Thus, the hardware costs should only be moderate.

- Some financial effort is also necessary to establish real time links between all existing databases and the new planning system (*management of data interfaces*). With regard to this, it could be advantageous to introduce a dynamic planning system from the software company providing the associated database and information systems.
- Finally, there are introduction costs for the *training of the dispatchers*. This is not only necessary in order to enable people to use the dynamic planning system, but also to create general acceptance of the new planning system.

*Operating and maintainance costs*:

- In addition to the introduction costs, there are also some *recurring operating and maintainance costs* for the planning system that have to be considered. These costs specifically occur for the company's own staff which keeps the planning system running and performs necessary program adaptations. Furthermore, permanent energy costs or costs for the replacement of hardware resources must be accounted for.

*Possible imponderabilities (risks):*

- There may be the problem of user in-compliance. As explained in Section 3.5, the usage of a computer based planning system may be significantly reduced if too many (correct) computer suggestions are manually overwritten by human planners. The only way to cope with this problem is the endeavor to create general acceptance of the software by the human dispatchers.
- Furthermore, it should be mentioned that despite the adapted MNS procedure is including many real-life restrictions, there are some aspects remaining that have not been covered: e.g., explicit planning of driver exchange or further sources of dynamism. The additional consideration of these aspects in a real-life planning, may result in a less significant reduction in empty traveled distance.

After estimation of all savings and cost values, one approach of assessing the advantageousness of an investment in a dynamic planning system could be the calculation of the resulting net present value. Such a detailed quantification, however, is very company specific and therefore shall not be a part of this work.