The task of determining the matching of actual and planned operation plans in a dispatch control system of the road transport

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Abstract. The article deals with the task of determining the matching between actual and planned operation plans in a dispatch control system of the road transport. The actual route of movement along the transport network is recorded as navigation data in the form of an ordered point set which had been passed through: control points identifiers and time stamps for both arrival and departure times. A new approach is proposed to determining the matching between planned and actual movement routes, which is considered as required for the dispatch control system of the road transport. Determining the matching between actual and planned movement routes is proposed to consider as the task of finding the longest common subsequence of two ordered sets: points of the planned and actual movement routes. In this way, the problem under consideration is scaled down to the classical dynamic programming problem — finding the longest common subsequence of several rows. Based on that the article presents a developed algorithm for solving the problem of finding the longest common subsequence of planned and actual movement route points.

1. Introduction

The traffic control system in road transport plays an essential role in ensuring the quality and safety of the transport process. Modern systems are based on the latest achievements of science, computer technology, mobile communications and global positioning systems (satellite navigation systems). Currently, information dispatch systems are being actively developed and implemented in public transportation, freight transportation, as well as special transport: school buses, ambulances, emergency services, etc. [1-3].

One of the main tasks of the traffic control system in road transport is to control the location of the transport fleet with binding, to established control points. According to the position of the vehicle, its binding to the route gives out three main operational dispatch control models [1]: relay, pseudo-impulse and impulse (digital). The relay model, the information about the vehicle position comes to the dispatcher only after the vehicle arrives at the control point. Currently it is hardly used. The pseudo-impulse and impulse model are similar; in the impulse model, movement is measured not only by control points, but also by the global positioning system (GPS) intermediate points.

In any model, the urgent task is to determine the matching between actual and desired (planned) vehicle location. A number of criteria in the work [4] were considered to determine the degree of matching between planned trips and ones that are done:
• resemblance degree of each planned with actual trip based on the trip’s controlling points match;
• absolute degree of time deviation of each planned trip from completed one;
• sequence of passed control points for scheduled and completed trips.

Therefore, in order to assess the matching between the actual and planned movement, it is necessary to compare the planned and actual sequence of the route passing control points, as well as the time deviations.

2. Meeting the challenge.

The dispatching system in business processes can be described by a sequence of individual discrete events. Currently to model such systems, the discrete event method is widely used. In work [5], where the system under studying is represented as dynamic, asynchronous, transitions trigger events occurring at discrete points in time.

Logical control theory of discrete event systems was first reviewed in the work of Ramadzha and Vonhehma as the theory of supervisory control [6]. The main problem of supervisory control is caused by the “state explosion”: with an increase in the number of system states, the number of model states grows exponentially. This problem can be solved by using Petri network as a modeling tool [7].

Nowadays, the interface between the operator and the control object is provided through the operational dispatch control system and data collection (SCADA - Supervisory Control and Data Acquisition).

By using discrete-event modeling, the functioning system is described as a chronological sequence of event. The event occurs at a certain point in time and causes a change in the state of the system. The event has two coordinates: temporal (t) and spatial. The parameters of the event are determined by spatial coordinate.

The transport fleet movement takes place on the transport network. There are control points along the transport network. Movement is performed along a route, which is described by an ordered set of points. The control point of the transport network is set planned arrival time and (or) departure, for each point of the route. The arrival time and (or) departure time for the route points are strictly set when passengers are transported on regular routes. In special transportations (custom routes), time stamps are usually determined for starting points and some (supporting) intermediate route points.

The actual route of movement along the transport network is recorded as a navigation data in the form of an ordered point set which had been passed through: control points identifiers and time stamps for both arrival and departure times.

Thus, a route is a relative relation \( R(P, T^b, K, T^e) \) with the following attributes: \( P \) – route control point number; \( T^b \) – arrival time at the control point; \( K \) – unique control point identifier; \( T^e \) – departure time from control point.

The route point is a relation tuple (object instance), which is denoted by: \( r(p,t^b,k,t^e) \).

Determining the matching between planned and actual movement routes for two sets \( R \) and \( R' \) is required to find the longest common element sequence, i.e. there is \( R^\prime \) set where: \( R, \) \( R' \) – planned and actual transport vehicle movement route. The longest common sequence is defined as a relative relation \( R^\prime(P, P') \), where \( P, P' \) is the point number in the planned and actual route, respectively. Such a representation of the resulting set allows providing a comparison of the parameters of the planned and actual routes: the control point passing time.

Apparently, there may be several different \( R^\prime \) sets with the same number of members; in this case, it is necessary to choose the implementation that in the physical sense most closely matches the condition of the problem.

The problem-solving conditions will be defined in the most general form.

• Several points of the route could have the same control point identifier of the transport network. In figure 1 an example of route map is shown. The figure shows that points \( r_1 \) and \( r_7, \) \( r_2 \) and \( r_6, \) \( r_3 \) and \( r_7 \) of
the planned route have the same transport network control point identifiers. The transport network control point \( r_4 \) on the actual route may be presented twice, depending on movement conditions: the driver could need to turn around to return. During the maneuver, the vehicle may exit the control point area and then pass through the control point again, which will be reflected on the actual route.

- Planned route points may be absent on the actual route. Such a situation is possible not only because of personnel errors, but because of the actual movement conditions, it is quite possible to change part of the route (for example, due to traffic congestion).
- Time stamps are not present in all points of the planned route. It is clear, that determination of the departure time from the first route point should be required: usually, it is a central station. In addition, the time parameters of the route supporting points must be determined (for example, the time when vehicle is handed to the customer).
- When choosing from several options for solving the problem, preference is given to the implementation, where the actual route point is as closest to the rout’s beginning.

In figure 2 the actual and planned traffic route matching is illustrated. In the figure, the \( r_4 \) actual route point does not correspond to any planned points: the control point of the transport network, which defined in the \( r_2 \) point is not indicated on the planned route. The \( r_4 \) actual route point formally corresponds to the \( r_3 \) and \( r_5 \) planned route points. It is obvious, that in this case, the real movement corresponds to problem solution where the \( r_5 \) point will be chosen.

At the beginning of the movement, the fourth actual route point will be formally assigned to the planned route points \( r_3 \) or \( r_5 \) (Figure 2). It is obvious, that from these solutions, the choice should be the \( r_3 \) planned route point.

![Figure 1. The route map, \( r_1 \cdots r_7 \) – planned route points.](image1.png)

![Figure 2. Matching the planned and actual movement routes: \( r_1 \cdots r_7 \) – planned route points, \( r'_1 \cdots r'_4 \) – actual route points.](image2.png)

Determining the matching between actual and planned movement route will be considered as the task of finding the longest common subsequence of two ordered sets: points of the planned and actual movement routes. Thus, the problem under consideration is scaled down to the classical dynamic programming problem — finding the longest common subsequence of several rows. It has been used to
compare text files, as well as in biology, where it is wanted to compare DNA chains. Quite a lot of different complexity algorithms, which varies in time and computer resources, had been developed to solve it [8].

The classical task is to find the greatest total element sequences (there may be several) for two rows (element sequences) \( x[1 .. m] \) and \( y[1 .. n] \). It is required to find not only the length, but the sequence itself.

The two-row common subsequence is a row that is a subsequence of each of them. A subsequence can be obtained from some last rows, if it is deleted from the last some set its characters. The longest common subsequence (lcs) is the longest common subsequence of the rows \( x \) and \( y \); lcs may be several.

The simplest algorithm is the method of calculating the distance between two rows, based on the dynamic programming method [9]. The lcs calculation algorithm consists of two steps.

1. The longest common subsequence length calculation.
2. Searched subsequence calculated length.

Let \( x \) and \( y \) be two rows; the length of the row \( x \) is \( m \) and \( y \) is \( n \). The longest common subsequence length can be calculated by the following recurrence formula:

\[
\|\text{lcs}(x, y)\| = D(m,n),
\]

\[
D(i, j) = \begin{cases} 
0, & \text{if } i = 0 \text{ or } j = 0 \\
D(i-1, j-1) + 1, & \text{if } x_i = y_j \\
\max(D(i-1, j), D(i, j-1)), & \text{if } x_i \neq y_j 
\end{cases}
\]

Interim results are recorded in the \( a[(m+1)\times(n+1)] \) matrix, which is used to calculate lcs itself. The algorithm running time is estimated \( O(n^2) \), computer memory – \( O(n^2) \). For lcs calculation by filled distance array, the Wagner and Fisher method [8] is used, based on the technique they called the trace.

When solving the problem of determining matching between actual and planned route based on the algorithm above, the following two sets will be reviewed: \( R \), \( R' \) – planned and actual route of the vehicle. It is required to determine the \( R' \) set - the longest common element subsequence for sets \( R \) and \( R' \). Route points (planned and actual) are compared by the transport network control point identifier, i.e. route points are considered equal, if \( k_i = k_j \). To store interim results, the three-dimensional matrix \( a[m+1,n+1,2] \) will be used, where the point number of planned and actual vehicle’s movement route will be written down at the intersection of row \( i \) and column \( j \).

An algorithm solving problem:
A. The length of the longest common subsequence calculation.
A.1. \( D(i, j) = 0 \) for \( i = 0, j = 0 \); \( i = 0 .. m, j = 0 \);
A.2. For \( i = 1 .. m, j = 1 .. n \) calculate:

\[
\text{if } k_{i-1} = k'_{j-1} \\
D(i, j) = D(i-1, j-1) + 1 \\
a(i, j,1) = i - 1 \\
a(i, j,2) = j - 1
\]

otherwise:

\[
\text{if } D(i-1, j) > D(i, j-1) \\
D(i, j) = D(i-1, j) \\
a(i, j,1) = i - 1 \\
a(i, j,2) = j
\]
In this algorithm, it is assumed that the numeration of elements set which constituting the route starts from 0. As a result of calculation, in \( D(m,n) \) the length of the longest subsequence will be written.

B. Search for the subsequence calculated length.

B.1. The subsequence determination begins with the last element, i.e. \( z = D(m,n) \), \( i = m \), \( j = n \).

\[
\begin{cases}
D(i, j) = D(i, j - 1) \\
\text{otherwise} \quad \begin{cases}
a(i, j,1) = i \\
a(i, j,2) = j - 1
\end{cases}
\end{cases}
\]

otherwise: \( D(i, j) = D(i, j - 1) \)

In this algorithm, it is assumed that the numeration of elements set which constituting the route starts from 0. As a result of calculation, in \( D(m,n) \) the length of the longest subsequence will be written.

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\begin{cases}
D(i, j) = D(i, j - 1) \\
\text{otherwise} \quad \begin{cases}
a(i, j,1) = i \\
a(i, j,2) = j - 1
\end{cases}
\end{cases}
\]

otherwise: \( D(i, j) = D(i, j - 1) \)

 otherwise:

if \( a(i, j,1) = i - 1 \) and \( a(i, j,2) = j - 1 \)

\[
\begin{cases}
i = i - 1 \\
j = j - 1
\end{cases}
\]

otherwise:

if \( a(i, j,1) = i - 1 \) and \( a(i, j,2) = j - 1 \)

\[
\begin{cases}
i = i - 1 \\
j = j - 1
\end{cases}
\]

B.3. If \( i = 0 \) or \( j = 0 \), the calculation is complete, the relational set \( R'(P, P') \) contains a list of matching points of planned and actual route.

Otherwise, go to step B.2

3. Results analysis

The algorithm for determining matching between planned and actual vehicle’s movement route is implemented in the dispatch control subsystem of the BusTrafficManagement information system, which is used to organize and manage the passenger transportation along the bus routes of the Krasnoyarsk Krai. The system operator OAO «Avtokolonna 1967» (Krasnoyarsk city) is one of the largest passenger carriers in the Siberian region. In table 1 one of the custom route parameters is shown. The table shows that the planned and actual movement route points do not correspond largely. There are network control points on the actual route that are not fixed on the planned route. The planned route points are formed in such a way to ensure effective dispatching traffic control: not all transport network control points, which the traffic passes through, are entered into it. On the other hand, in the actual route may be missed some control points from the planned route due to personnel errors in planning or changing the route during movement. In this example, on the actual route there are no control points from planned route No. 7 (control point ID 1437), No. 14 (ID - 1307) and No. 15 (ID - 1328).

In figure 3 the result of determining the matching between planned and actual route is shown, with the parameters which are given in table 1. The calculations for determining the matching of routes in the information system are carried out in real time dispatch control. As a result, we can conclude that the proposed algorithm in this article has a good working capability, which allows it to be effectively used.
Table 1. Example of planned and actual route.

| No.  | Control point | Arrival time | Departure time | No.  | Control point | Arrival time | Departure time |
|------|---------------|--------------|----------------|------|---------------|--------------|----------------|
| 1    | 1300          | 28.02.19     | 6:00           | 5089 | 1300          | 26.02.201    | 9:15:43       |
|      |               |              |                |      |               |              | 5:53          |
| 2    | 1298          | 28.02.19     | 9:57           | 5105 | 1417          | 28.02.201    | 9:5:57        |
| 3    | 1299          | 28.02.19     | 6:01           | 5109 | 1434          | 28.02.19     | 6:01          |
| 5    | 1400          | 28.02.19     | 6:05           | 5119 | 1299          | 28.02.19     | 6:05          |
| 6    | 1428          | 28.02.19     | 6:09           | 5123 | 1316          | 28.02.19     | 6:09          |
| 7    | 1437          | 28.02.19     | 6:36           | 5126 | 1400          | 28.02.19     | 6:36          |
| 9    | 1402          | 28.02.19     | 6:43           | 5139 | 1428          | 28.02.19     | 6:43          |
| 11   | 1437          | 28.02.19     | 6:54           | 5149 | 1402          | 28.02.19     | 6:54          |
| 12   | 1428          | 28.02.19     | 7:01           | 5152 | 1364          | 28.02.19     | 7:01          |
| 13   | 1400          | 28.02.19     | 7:01           | 5155 | 1402          | 28.02.19     | 7:01          |
| 14   | 1307          | 28.02.19     | 8:58           | 5170 | 1326          | 28.02.19     | 8:58          |
| 15   | 1328          | 28.02.19     | 9:23           | 5182 | 1437          | 28.02.19     | 9:23          |
| 16   | 1300          | 28.02.19     | 9:30           | 5189 | 1324          | 28.02.19     | 9:30          |
|      |               |              |                |      |               |              | 9:37          |
|      |               |              |                |      |               |              | 9:42          |
|      |               |              |                |      |               |              | 10:07         |
|      |               |              |                |      |               |              | 10:07         |
|      |               |              |                |      |               |              | 10:07         |
|      |               |              |                |      |               |              | 11:49         |
|      |               |              |                |      |               |              | 11:49         |
|      |               |              |                |      |               |              | 11:51         |
|      |               |              |                |      |               |              | 11:51         |
|      |               |              |                |      |               |              | 11:54         |
|      |               |              |                |      |               |              | 11:54         |
|      |               |              |                |      |               |              | 11:59         |
|      |               |              |                |      |               |              | 15:31         |
| 1    | Avtokolonna 167 | 10:00 | 11:59 | 5191 | 1248          | 3:30          |

1 point number in sequence order of planned control points
2 point number in sequence order of actual movement on transport network

Figure 3. Planned and actual route matching of a custom route.
4. Conclusion
In the article, a new approach is proposed to determining the matching between planned and actual movement routes, which are considered as required for the dispatch control system of the road transport. Determining the matching between actual and planned movement routes is proposed to consider as the task of finding the longest common subsequence of two ordered sets: points of the planned and actual movement routes. In this way, the problem under consideration is scaled down to the classical dynamic programming problem — finding the longest common subsequence of several rows.

On this basis, the article presents a developed algorithm for solving the problem finding the longest common subsequence of planned and actual movement route points.

The proposed algorithm has been tested in the information system of the bus traffic dispatching control subsystem BusTrafficManagement. The practical experience implementation lead us to conclude that the algorithm has a good working capability, which allows it to be effectively used in practical application in the dispatch control system.

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