Small sized monorail system that provides low cost and ecological effectiveness

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Abstract

The monorail, which is able to share transport space with other road traffic, is generally considered to be one of the most effective transportation methods. Meanwhile, needs to decrease investment costs and respond to worldwide environmental issues are driving the requirement for lower priced and more ecological monorail systems. In this paper, we propose a small sized monorail system, which is realized at a drastically low cost and contributes to a better environment through its low power consumption and high maintainability. The proposed system has several features: 1) a small sized car, 2) a signal mechanism without car detection between stations, and 3) data unified communication using general information technologies.

1 Introduction

The monorail has high climbing ability and a transport space in the air; then its transport space can be arranged freely, and shared with automobiles, which have an enormous transport space. Therefore, it is considered to be one of the most effective transport systems providing better efficiency in urban transport, which is seeing a big increase in traffic in all size of cities [1][2]. In today’s era of mega-competition, the needs to decrease investment costs to strengthen competitiveness is even stronger. Better ecological systems are also desired to respond to the worldwide environmental issues. In response to these situations, we propose a small sized monorail system, which can be realized at a drastically low price and contributes to a better environment through its low power consumption and high maintainability. The proposed system has several features: 1) a small sized car, 2) a signal mechanism without car detection between stations, and 3) data unified
communication using general information technologies. This paper describes these features.

2 Small sized car

Conventional monorails are mainly operated with a composition that allows 400-500 people to be transported. In Japan, there is no monorail whose size is smaller [1][2]. Then, we propose a small sized monorail system, which is capable of carrying approximately 200 people at a time. This small size provides the features which are accompanied by several merits.

1) Required width of tracks is smaller than 18m, and track curvature is also reduced.
2) The railway land needed, and its infrastructures such as track girder, sole bar and station building are small.

Feature 1) increases the possible sites where the monorail can be constructed. With a small sized body, the width of track, which used to be more than 20m, can be cut to less than 18m. This allows construction of monorails in medium and small sized traffic roads besides big ones. Reducing truck curvature from 100m to about 40m, realized by smaller car length, can also contribute to increasing available sites of construction. Feature 2) realizes a lower price. Corresponding to the smaller sized car, railway land needed, track girder, sole bar, station building and etc. are smaller, and that means lower priced construction. Also, small sized cars and station buildings reduce power consumption, which is expected to improve maintainability and provide a better environment.

Though decrease of transport efficiency is considered as a demerit of small sized monorail, the proposed car can transport 3000 people a hour in the case of a 270-second minimum time interval between trains. These features can directly satisfy the needs of medium and small cities, which are increasing worldwide.

3 Signal mechanism without car detection between stations

3.1 Check in-check out signal system

Conventional monorail systems usually use an ATC system[3] as do ordinary railway systems, which realize safety operation as follows. Train detecting devices such as loop coils, and transponders for communication between trains and railway side are set all along the trucks between stations. The equipment realizes safe traffic operations by detecting trains with the loop coils and sending a limiting velocity, which forces only one train to be present in one block section, from the railway side to the train via the transponders. In this paper, we propose a signal system, which reduces investment and maintenance cost drastically by omitting these trains detecting devices and communication devices. The proposed system has several features as listed below.
The check-in check-out method realizes safe traffic operation using only transponders set at stations instead of train detecting devices between stations. This method regards an area between stations which includes one station as one blocking section, and then blocking is done as follows. To confirm there is no train in the blocking section, a train staying at the station which is departing to the next station observes a forward train and checks if it has arrived at the next blocking section, which is the next but one station. This means that there is no train in front until the next but one station. Figure 1 shows a schematic illustration of check-in check-out method. Train $T_i$ staying at station $S_i$, after receiving information (check in) that the forward train $T_{i+1}$ has arrived at the next but one station $S_{i+1}$, receives an aspect, which allows the event (check out) so that $T_i$ can go to the next station $S_j$.

In the proposed system, it is difficult to realize running between stations corresponding to the running schedule, since the running train can not get the limiting velocity from the railway side without the transponders. Therefore, the proposed system provides autonomous running between stations, making the train intelligent by equipping it with a database containing information about each station, distance to the next station and target speed curve. Accurate traffic operation corresponding to the running schedule can be realized by calculating the limit velocity using the target curve and the position calculated by integrating the wheel revolutions, and indicating the limit velocity to the train operator.

### 3.2 System structure and details of logic

#### 3.2.1 System structure

Figure 2 indicates the structure of the proposed signal system. In the conventional ATC system, ATC and interlocking devices are constructed with ad-hoc hardware such as relays to realize blocking, and with a centralized operation system to manage the running control. The proposed system unifies both the blocking and the running control into a centralized operation system since the proposed system has to manage the train running order table, which can be changed dynamically and so is hard to construct with ad-hoc hardware. The centralized operation system has a hierarchy of the running control part and the interlocking part, which
provides structural clearness. The running control part sends the requirement to check the route security to the interlocking part for the train staying at a station which wants to start to the next station. The interlocking part, receiving the requirement, checks if the route to the next station can be secured or not. That is, the interlocking part operates check in - check out logic to communicate the information on the train ID and location between the train and the railway side. It sends back the result to the running control part, and when the route to the next station is secured, it sends the aspect to the train waiting for departure. In terminal stations, turning points and a car shed, the interlocking part switches the turnouts and locks them corresponding to the route security, to realize blocking. In the following sections, we discuss the basic logic of the interlocking part using the check in – check out method to realize blocking in ordinary stations, terminal stations and car shed. Since the logic in turning points is almost same as in the terminal station, we omit the former discussion.

3.2.2 Logic for ordinary stations
Ordinary stations are coupled by a one-way railway (Figure 1). The interlocking part which has received the route security requirement uses the transponder to check if the train ID detected at the next but one station (S_i-1) is equal to the forward train (T_{i+1}) ID. If so, it gives the aspect to the train waiting at the station(S_i-1) via the transponder. These operations realize blocking of the route security to the next station. On the other hand, it is necessary to know exactly which is the forward train for complete blocking operations. Therefore, the interlocking part prepares the train running order table, which describes the order trains are running in on the railway, and this allows the forward trains to be identified.

3.2.3 Logic for terminal stations
Terminal stations have turnouts, which enable the trains to reverse direction. Figure 3 shows the structure of a terminal station which has a typical turnout. The terminal station can be accessed by more than one train while the ordinary station can only be accessed by a single train. Therefore, the same approach as for the ordinary station is not enough, and we introduce the idea to block the
Figure 3: Structure of the terminal station.

station directly. In order to manage the blocking of terminal stations, we propose a flagging operation, which distinguishes whether the terminal station is occupied by a train or not by a flag (SOFlag: Station Occupied Flag) ON = occupied and OFF = not occupied. There are two kinds of basic conditions to secure the route, that have to be satisfied, one is the forward train's arrival at forward stations (which is the same as for the ordinary stations), and the other is that the turnouts are locked and the SOFlag is OFF. After satisfying these conditions, operation system locks the turnouts and sets the SOFlag ON. The condition by which the turnout gets unlocked is that the train which has ordered the locking has arrived at the target station, and the condition by which the SOFlag is set OFF is that the train which has occupied the terminal station has arrived at the other station. Unless these conditions are satisfied, the locking and block of the terminal station is never set free. Several concrete conditions to secure the route are listed below, and operations supposed to be executed when the conditions are satisfied are described.

**Condition to secure the route from platform \(S_2\) to the terminal station**

The arrival of forward train \(T_{i+1}\) at station \((S_2\) or \(S_3\)) where train \(T_i\) is not proceeding or at \(S_3\), is confirmed. The turnout are free, and SOFlag is OFF.

**Operation when the condition is satisfied**

Set SOFlag ON, and order the turnout to be switched and locked. Confirm the state of the locked turnout, then allow the train \(T_i\) to depart.

**Condition to secure the route from the terminal station to \(S_5\)**

The forward train has arrived at \(S_6\), and the turnout is set free.

**Operation when the condition is satisfied**

Order the turnout to be switched and locked. Confirm the state of the locked turnout, then allow the train \(T_i\) to depart.

### 3.2.4 Logic for car shed

The structure of a typical car shed is indicated in Figure 4. Since a station (control station), which is connected to the car shed, is accessed with plural trains, we apply the method of blocking for the control station as well as the terminal station. In the car shed, entering and departing from the car shed cause changes in the train running order in the railway. Therefore, the train running order table, which is important for realizing safe traffic operation in the proposed system, has
to be treated carefully. The basic concept of modifying the train running order table is that, on entering the shed, the table will not be modified until the train's arrival at the shed is confirmed, and on departing from the shed, the table will be modified when the departure signal, which allows the train to depart from the shed, is indicated to the train. Applying this logic, even though the entering and departure operations fail, that is, for entering the shed, the train which was supposed to be in the shed remained in the railway, and for departing from the shed, the train which arrived at the railway was not detected, contents of the table are modified to prevent crashes. Therefore, fail safe operation is expected. Several concrete conditions to secure the route, in passing the station, entering and departing from the shed, are listed below, and operations which should be executed when the conditions are satisfied are described. Besides, we describe the condition to set the turnout and station free.

**Condition to secure the route entering to the control station from another station**

Train $T_i$ is present at station $S_{j-1}$, and train $T_{i-1}$ has arrived at station $S_{j+1}$. Besides, SOFlag of the control station $S_j$ is OFF.

**Operation when the condition is satisfied**

Set SOFlag of $S_j$ ON, and allow the train $T_i$ to depart.

**Condition to set the route free**

SOFlag of the station $S_j$ is ON, and the train $T_i$ is present at the station $S_j$.

**Condition to secure the route departing from the control station to another station**

Train $T_i$ is present at station $S_{j-1}$, and train $T_{i-1}$ has arrived at station $S_{j+1}$. Besides, SOFlag of the control station $S_j$ is ON, and turnout $TO_i$ is free.

**Operation when the condition is satisfied**

Order the turnout $TO_i$ to be switched and locked. Confirm the state that the turnout $TO_i$ is locked, then allow the train $T_i$ to depart.

**Condition to set the route free**

SOFlag of $S_j$ is ON, and the train $T_i$ is present at the station $S_{j+1}$.

**Condition to secure the route entering the car shed**

Train $T_i$ is present at station $S_j$, and train $T_{i-1}$ has been ordered to enter the row $j$ of the car shed. Row $j$ is vacant, and SOFlag of the control station $S_j$ is OFF, and
turnouts TO₁, TO₂ are free.

**Operation when the condition is satisfied**

Order the turnouts TO₁, TO₂ to be switched and locked. Confirm the state that the turnouts are locked, then allow the train Tᵢ to depart.

**Condition to set the route free**

The train Tᵢ is present in row j of the car shed.

**Other operation when the condition is satisfied**

Modify the train running order table.

**Condition to secure the route departing from the car shed**

Train Tᵢ has been ordered to depart from the car shed. A train parked in the top line, where the train Tᵢ is supposed to be parked, is the train Tᵢ. SOFlag of the control station Sⱼ is OFF, and turnouts TO₁, TO₂ are free.

**Operation when the condition is satisfied**

Order the turnouts TO₁, TO₂ to be switched and locked. Confirm the state that the turnouts are locked, then set SOFlag of the control station Sⱼ ON, and allow the train Tᵢ to depart. Finally, modify the train running order table.

**Condition to set the route free**

The train Tᵢ is present at the control station Sⱼ.

3.3 Realization of safety

3.3.1 Scope of consideration

Failures in the traffic operation system can be mainly classified into two situations.

a. Failure of the centralized operation system

b. Failure of the sensors

In this paper, we discuss safety when these failures occur. To realize safe and stable traffic operations, definite and immediate detection of the failure is required, however, we will discuss this elsewhere. We discuss, instead, how to realize safety on the assumption that the failures are detected correctly.

3.3.2 Failure of the centralized operation system

When failures are detected, basically, all trains are automatically stopped. Operations executed by hands or ad-hoc hardware to restart the running immediately are described in Table. 1. Departure to the next station, which is difficult to do automatically because of lack of information about the location, will be operated manually. In the terminal stations, the same operation can be applied as for the ordinary station. That is, running between the ordinary station and the terminal station means that the route security has been realized, and the turnouts have been locked, and that the safety of movement to the next stations has been confirmed.

3.3.3 Failure of the sensors

We discuss the safety at ordinary stations, terminal stations and car shed in the case of sensor failures.
Table 1. Operations in the centralized operation system failures.

<table>
<thead>
<tr>
<th></th>
<th>between stations</th>
<th>at station</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Failure on the car side</td>
<td>Restart the system, and move the train to the next station manually.</td>
<td>Restart the system, and get information about location and train running order table.</td>
</tr>
<tr>
<td>2) Failure on the railway side</td>
<td>Move the train to the next station manually.</td>
<td>Stay at the station. After the arrival of all trains at stations, get information about location and modify the train running order table.</td>
</tr>
</tbody>
</table>

3.3.3.1 Safety at ordinary stations
Using the check in-check out method, the safety can be realized even for sensor failure occurrence since the following train is not allowed to depart without the detection of the forward train which can only be realized with normal sensors.

3.3.3.2 Safety at terminal stations
Plural trains can access terminal stations, therefore, the check in-check out method is not enough to satisfy the safety, and complete blocking of the station is required. With the proposed method, once the block is arranged, the block is never set free unless the train which has occupied the terminal station is detected to have arrived at the other station. That is, when the sensors are damaged, the arrival at stations can not be detected, and the block of the terminal station is never set free. Thus, the system avoids the dangerous situation that the block, which is occupied by a train, is set free and a train crash is caused.

3.3.3.3 Safety at the car shed
a) Event of departing from the car shed. In the case that sensors at the control station fail, where a train departing from the shed is never detected at the control station, safety can be realized since the train running order table is modified when departure from the shed is allowed, and a train starting from another station to the control station is never allowed to depart until the train departing from the shed is detected. In the case that sensors at the car shed fail, departing the shed is never executed.
b) Event of entering the car shed. In the case that sensors at the control station fail, entering the shed is never executed. In the case that sensors at the car shed fail, the system considers that some train stays at the parking place where the failed sensor is located, and entering the shed is never executed.

4. Communication system
The communication system, which consists of telecommunication between stations, visual monitoring on the platform, railway compound broadcasting,
guide displays on the platform, etc. are constructed by ad-hoc communication tracks, which are separated corresponding to the purpose and also the data type such as voice, picture and ordinary data. Ad-hoc communication tracks used to be a cause of high product prices, and the situation that a large number of communication tracks for different purposes and data types cause huge bundles which consequently lead to enormous investment and maintenance costs.

The proposed system unifies the communication tracks, which are prepared separately corresponding to the purpose and the media, and translates the information by a big transmission line. That is, using an off-the-shelf communication method such as IP, the system synthesizes plural media, which are data, voice and picture, with the same protocol, and translates these data with the optical fiber, which has a large bandwidth.

Figure 5 shows a schematic illustration of the proposed communication network. We attempt to use the off-the-shelf technologies as much as possible, for decreased investment cost and better maintainability. Communication in the railway compounds are realized by LAN, and the railway compound LANs are connected with each other by a giga bit ethernet of optical fibers. Using the giga bit ethernet, several merits, such as sufficient bandwidth (1000Mbps), which carries visual data easily, small cost of router, and easiness of connection with a conventional ethernet, are expected.

Figure 6 indicates the structure of the railway compound LAN. Managing all data, such as ordinary data, voice and pictures, with off-the-shelf protocol IP, which also realizes a small number of transmission lines, is expected to decrease the development and maintenance costs. To realize communication by voice and moving pictures, VoIP (Voice over IP) technology is used, and QoS (Quality of Service) technology, such as RTP, RSVP, DiffServ provides real time communication, which avoids time delay and discontinuous service. Using the proposed system discussed above, we realize lower development cost by using off-the-shelf technology, and reduce investment costs by using a unified transmission line. High maintainability can be expected.
5. Conclusion

To develop a low priced and environmentally responsible monorail system, we proposed small sized car, a signal system with no train detection devices between stations, and a data unified communication system. Logic for the check in-check out signal system was described. Also, safety of the operation system and safety during sensor failure occurrence were discussed, and finally, possibility of safe traffic operation was indicated.

References