Analysis of Errors in Subway Team Cooperation based on Complex Network

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Abstract. Multi-team collaboration plays an important role in subway safe operation. In order to avoid the delay and inefficiency of emergency response caused by multi-team’ errors, this paper built the complex network of subway multi-team’s human factors. The complex network is constructed through thirteen types of subway emergency response. The status of events and equipment represents the node and the behavior of multi-team represents the edge in the complex network. The weight of edge ensured by the probability of a person's failure that be calculated though the VACP model. At last, the importance of node and edge in complex network of multi-team is evaluated based on the complex network theory. So the importance of events and equipment status and team’s behavior in complex networks of multi-team are evaluated and sorted. The analysis results show that the screen, telephones and broadcasts are important equipment and “contacting by phone”, “seeing the screen” and “adjusting the train” are important behavior in the emergency. Some measures are put forward to reduce the human errors in multi-team collaboration operation according to the evaluation results. It is meaningful to improve the safety operation of the subway.

1. Introduction

Subway operation is a huge complex system and its safe operation depends on many teams in their duties and the close coordination between each other. It is of great significance to reduce the number of people caused by multi-team cooperation. The study of human error in the multi-team cooperation is less at present and it’s concentrated in the field of nuclear power, aviation and medicine. The decision-making capacity of the nuclear power plant team is qualitative analyzed in the abnormal state(Sasou,1993,1999). The cognitive error is quantitatively analyzed in nuclear power plant team through CREAM quantitative analysis(Liao,2007). The accuracy of communication is the key to to reduce the mistakes of the team by analyzingthe content characteristics of operating group communication in nuclear power control room(Zhang,2015). Based on the threat and error management (TEM), someone analyzed the flow and influencing factors of the failure of the air traffic control team and put forward the countermeasures to reduce the errors (Lv,2009). Goldfarb and others believe that the individual differences in the team may lead to misunderstanding in the operating room environment further cause surgical errors(Pizzi,Neil,Goldfarb,2001). However, there are few studies on the multi-team in the subway area. Therefore, this paper constructs complex network of multi-team under subway emergencies based on the analysis of human factors and complex network theory. By analyzing the importance of complex network nodes and edge to evaluate the human factors of subway multi - team. It ’s meaningful to analyze and reduce the number of the subway unexpected events from the multi-team aspect and optimize the emergency program.
2. Emergency Response of Multi-Team
Subway incidents refers to all of the accident which effect normal subway operations. The 13 categories of emergencies which often occurred are: Platform Screen Door failure (affect the operation), train failure, turnout failure (loss table), car ATP failure, ground ATP failure (abnormal red), the ground ATP failure (no display), ballast injury (lying rail), lathe fake outbound signal, the train is on fire in the station, the train is on fire in the tunnel (can enter station), the train in the tunnel fire (can not enter station), Platform Screen Door folder people, the train hit the collision. Subway operating system multi-team is mainly related to the cooperation emergency response between the teams. It includes drivers, person on duty at train, master on duty at station, decision-making dispatcher, officer on dispatch duty, passenger dispatcher, staff at signal floor and so on.

The Platform Screen Door failure is regarded an example and the emergency flow chart is as follows.

![Emergency Flow Chart](image)

Figure 1. The emergency response process of PSD failure

3. The construction of multi-team coordination complex network

3.1 "Node" and "Edge" of complex networks
The complex network is constructed based on the complex network theory. The complex network "nodes" and "edges" is ensured according to the emergency response process. The state of events and devices in the emergency response process represents the "nodes" of the complex network. Each node is replaced with number. For example, “1” represents the event of PSD failure. “2” represents the ringing of phone. It is not enumerated a total of 286 nodes. The relationship between nodes is the behavior of the team in the emergency flow chart. It’s the "edge" of the complex network. There is a directional connection between the event and the device and the probability of the group’s behavioral errors is existed. So the complex network of the subway team is the directed and weighted network.

| Number of node | Node            | Edge                           | The linked node |
|----------------|-----------------|--------------------------------|-----------------|
| 1              | The PSD failure | The driver dials the wireless phone | 1 2             |
| 2              | Wireless telephone is ringing | Hear the phone | 2 3             |
| 3              | The wireless phone continues to ring | Train dispatcher picks up the phone | 3 4             |

Table 1. Nodes and Edges in Subway multi-team complex networks
4. Train dispatcher knows the PSD failure  
5. The phone is in its original state  
6. Train dispatcher finds the PSD failure  
7. Dispatch telephone is ringing  
8. Dispatch telephone continues to ring  
9. Train dispatcher knows the PSD failure  
10. Dispatch telephone is in its original state  
…  
286. Train dispatcher knows the train hit person

| Event | Description |
|-------|-------------|
| 4     | Train dispatcher knows the PSD failure |
| 5     | Train dispatcher hangs up the phone |
| 6     | Train dispatcher checks big screen |
| 7     | The phone is in its original state |
| 8     | The person on duty at station calls to the train dispatcher |
| 9     | Dispatch picks up the phone |
| 10    | Hang up the phone |
| …    | … |
| 286   | Hang up the phone |

3.2 VACP model and the weight of edge

The VACP model argues that operational tasks can be accomplished by resources such as vision, hearing, cognition, and movement. It defined the level of requirements for information processing resources of pilots (Mccracken, Aldrich, 1984). The higher the level of the behavior, the greater the difficulty and the more prone to mistakes. Therefore, this model is introduced into the subway emergencies. The VACP resource requirements level values the weight of the "edge" in complex networks. The complex network is constructed. The main groups of each team due to the probability of failure in Table 2.

Table 2: The probability of multi-team’s human errors

| Behavior / Action | VACP Level / The Probability |
|-------------------|------------------------------|
| The driver / train dispatcher calls the wireless phone to the train dispatcher / driver | 5.8 |
| Train dispatcher calls to the overall dispatcher / electromechanical dispatcher | 4.2 |
| Train dispatcher / driver / the person on duty at train / overall dispatcher calls to hear the phone | 4.6 |
| the person on duty at train / train dispatcher calls to train dispatcher / the person on duty at train | 6.5 |
| The person on duty at train / train dispatcher calls and answers phone | 2.2 |
| Train dispatcher / overall dispatcher / lifts / hangs up / the person on duty at train / train dispatcher / the person on duty at train | 5.0 |
| Job announcements / inquiries / answers and so on | 4.9 |
| Train dispatcher / overall dispatcher / lifts / hangs up / the person on duty at train / train dispatcher / the person on duty at train / orders recitation (code, memories) | 5.3 |
| Driver / station guard / the person on duty at train presses button | 2.2 |
| PSD is opened manually and so on | 4.6 |
| Driver / station personnel guides passengers | 6.8 |
| The person on duty at train contacts with master on duty at station | 1.0 |
| Maintenance workers rush to the point of failure | 3.7 |
| Repair the PSD | 4.0 |
| The station manager calls 119,120 | 4.6 |
| Get off at the station | 1.2 |

3.3 multi-team collaboration complex network

The 286 "nodes" and "edges" of the complex network are determined. The direction between the two nodes and the weight of the edge are ensured by analyzing the emergency response process. Using NetworkX to build the complex network of the subway group.

4. subway multi-team complex network assessment

The importance of event and equipment status and multi-team cooperative behavior in complex network are evaluated through six evaluation indexes according to the importance evaluation method of complex network theory and the NetworkX software.
4.1 Importance of node assessment

The "node" in a complex network model of a complex group represents the status of each event and equipment. In the study of node importance, the evaluation indexes are degree centrality, the betweenness centrality and clustering coefficients.

The degree centrality reflects the impact of various types of emergencies and equipment in the network. The greater the degree of the node, the greater the importance of it. The betweenness centrality represents the control of the network traffic. The shorter the path through a node, then the more important of the node. The clustering coefficients indicates the tightness of each node in the network. The analysis results of degree centrality for complex network nodes in Table 3. The node importance is sorted as follows Table 4.

| Number of node | Node sorts by edge-betweeness | The meaning of node | Sorting |
|----------------|-------------------------------|---------------------|--------|
| 15             | 0.12631578947368421           | The dispatch phone is restored to its original state | 1      |
| 10             | 0.11228070175438597           | The dispatch phone is restored to its original state | 2      |
| 05             | 0.09473684210526316           | The phone is restored to its original state | 3      |
| 53             | 0.09473684210526316           | Resume operation    | 4      |
| 12             | 0.07719298245614035           | The dispatch phone continues to ring | 5      |
| 11             | 0.06666666666666667          | The dispatch phone rings | 6      |
| 7              | 0.06315789473684211           | The dispatch phone is ringing   | 7      |
| 8              | 0.06315789473684211           | The dispatch phone continues to ring | 8      |
| 20             | 0.06315789473684211           | The phone is restored to its original state | 9      |

| Sorting | Node sorts by edge-betweeness | Node sorts by the edge's meaning | Node sorts by the network efficiency |
|---------|-------------------------------|---------------------------------|-------------------------------------|
| 1       | The dispatch phone is restored to its original state | 15                               | 51                                 |
| 2       | The dispatch phone is restored to its original state | 10                               | 10                                 |
| 3       | The phone is restored to its original state | 05                               | 05                                 |
| 4       | Resume operation               | 53                               | 16                                 |

52, 112, 125, 136, 162  Shunt to large spacing line to fill the car / find a large screen with red light / find a large screen without red light / train dispatcher orders to follow-up train to be withholding / broadcast information to passengers

18, 86, 124  The driver gets the broadcast information / Train dispatcher determines the number of online trains / Person on duty at train reports that signal has been repaired

32  The dispatch phone is restored to its original state

49, 154, 177  The phone is in the original

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4.2 Evaluation of edge importance

The evaluation of edge importance is analyzed the importance of the behavior of the group of people. There are three kinds of evaluation indexes of "edge" importance: edge-betweenness, edge-betweenness centrality and network efficiency. Edge-betweenness refers to the number of shortest paths passing through the edge. The larger the number of edges, the more times the number of nodes in the network passes through the edge. It can be used to describe the impact of team behavior on emergencies. The edge-betweenness centrality is the ratio of the number of paths of the network to the number of paths passing through the center point. The greater the number of sides passed, the greater the edge-betweenness centrality, the more important the edge. Network efficiency refers to the sum of the weight of all edges and the ratio of the shortest path length. The amount of reduce of network efficiency after deleting an edge is regarded as an indicator for evaluating the importance of connecting edges in weighted networks. The following Table 5 is a result of the analysis of the complex network edge of the subway team.

Table 5. The analysis results of edge for complex network

| Sorting | Edge sorts by edge-betweenness | Edge sorts by edge-betweenness centrality | Edge sorts by the network efficiency |
|---------|-------------------------------|------------------------------------------|-------------------------------------|
| 1       | 10-154 Train dispatcher sees CCTV | 151-7 Person on duty at train calls the dispatch phone | 113-114 Person on duty at train detects track; Fire fighters check for danger |
| 2       | 5-167 Driver presses the radio button 10-53 Train dispatcher adjusts the train | 68-51 Train dispatcher adjusts the train 69-7 | 10-53 68-63 Train dispatcher adjusts the train 60-61 |
| 3       | 5-154 Train dispatcher adjusts the train | 71-11 Person on duty at train calls to the line train dispatcher | (Direct driver) fault car back to the garage 49-53 32-51 |
| 4       | 20-51 Train dispatcher sees CCTV 15-16 Train dispatcher to call the driver | 69-71 Train dispatcher calls to the person on duty at train | 133-7 Train dispatcher adjusts the train 271-272 |
| 5       | 15-16 Train dispatcher to call the driver | 10-133 Train dispatcher sees CCTV | Person on duty at train calls to the train dispatcher |

4.3 Evaluation results and application analysis

The node importance assessment indicates that “The phone is restored to its original status” “The status of screen” and “The broadcast” in the complex network occupy important positions. The entire
network will be paralyzed once these points are removed. So the status of phone, screen and broadcast should be noticed. The edge importance assessment indicates that “View CCTV”, “Press the radio button” and “Train dispatcher adjusts the train” are the important behavior of stuff. These behavioral errors are more likely to lead to accidents. "Detecting orbit" plays a decisive role in the ground event of ground ATP failure. Some corresponding measures are proposed to reduce human error:

1. Workbench buttons of dispatch team should be designed reasonably. Train dispatcher’s workbench is complex and each button has a different function. Train dispatcher needs to contact each team by phone when an emergency happens in the subway. So the phone buttons which be in common can be set reasonably to prevent the wrong button to extend the emergency response time. Such as dispatch phone, driver phone, etc. For example, person on duty at train as the only team can be linked with the Train dispatcher, so the phone should be set in the place at their fingertips.

2. The screen design takes into account human visual. Train dispatcher and person on duty at train can pay attention to the screen when the emergency happens. Then they could determine the type of event in the first time and take reasonable emergency measures to avoid more serious consequences.

5. Conclusion

(1) The relationship among the teams in subway emergency showed a complex network structure. Building and quantifying the multi-team collaboration complex network in subway emergency according to the emergency response process and VACP model to calculate the probability of human error. "Node" indicates the status of event and equipment, and "edge" indicates the behavior of each team.

(2) According to the six indexes of complex network’s importance assessment, the status of events and equipment and multi-team cooperative behavior are evaluated and sequenced. And then the effective measures are put forward to reduce the number of human mistakes after analyzing.

(3) Due to the distribution of the team duties in subway is similar, the multi-team cooperation complex network proposed in this paper has universal adaptability. It is of great significance to reduce the failure of the subway team.

Conflict of Interest
The author confirms that this article content has no conflict of interest.

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