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IMPROVING INCIDENT ANALYSIS IN THE DUTCH RAILWAY SECTOR

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Abstract - This study set out to examine whether a comprehensive analysis technique for analysing incidents and accidents would provide greater insight in the underlying root-causes of SPAD's. In order to examine whether the current approach to incident analysis provided a sufficiently detailed analysis of the underlying root causes of SPAD's a comparative analysis using PRISMA was performed. The results of the analysis demonstrate that despite the fact there was no significant difference in the numbers of root-causes identified in the re-analysis of the same incident data, there were significant differences in the types of root-causes identified. PRISMA identified significantly more technical and organisational causes and significantly less staff-related root causes. Furthermore, this study revealed that not all information appeared to be used in the analysis, a fact supported by the provisional results of a third analysis where PRISMA was used to collect new information on the causes of very recent incidents. As such, it may be concluded that only when an organisation applies a comprehensive approach to data collection and analysis, will it be possible to state that the real root causes of an incident have been determined.

INTRODUCTION

There are many reasons for investigating an accident or incident. Benner (1980) recognises that each purpose is related to the perceptions the person or group have on the causes of the accident. Within the Dutch railway sector, the main reason is to identify the causes in order to take the most (cost) effective counteractions. The Dutch Railway Inspectorate currently uses MISOS (Anon,2005) to identify the causes and context factors of a wide array of incident and accident types. This database is highly detailed and specific to each incident type and thus prevents a comparative analysis of the causal pathways between different incident types.

The industry is especially concerned with Signals Passed at Danger (SPAD) incidents, where the train driver passes a signal with a red aspect without permission. These can lead to injuries to the public, damage to infrastructure and in the worst case many deaths. In the MISOS system, SPAD's are considered to be antecedents (i.e. causes themselves instead of incidents worthy of further investigation) of accidents (e.g. collisions) and therefore the Dutch Railway Inspectorate has designed a SPAD "bow-tie model" and a separate database to identify the causes and consequences of SPAD's.

The continuing upward trend of occurrence of SPAD's in the Dutch Railways is seen as unacceptable by all involved in the rail sector, whether they be politician, traveller or from the sector itself. For this reason, the sector has set ambitious targets to reduce the number of SPAD's and to reduce their associated risk. Naturally, these reductions can only be achieved if countermeasures are geared to counteracting the dominant types of causes.

The Dutch Railway Inspectorate has expended significant effort in collecting and analysing SPAD incident data using a specific taxonomic classification scheme based on the bow-tie model. The aim of this research was to examine whether the SPAD Bow-tie model provided a sufficiently detailed analysis of the root-causes of SPAD's, or whether a more comprehensive analysis approach would provide additional insight on the root-causes underlying SPAD's. For this purpose, PRISMA (Van der Schaaf, 1992) was chosen as the alternative analysis approach.

CURRENT ANALYSIS APPROACH

The SPAD bow tie model was developed by employees at the Dutch Rail Inspectorate, specifically for examining the relationships between causes and consequences of SPAD's. Its aim is to determine whether combinations or specific groups of causes would lead to individual consequences and thus whether specific countermeasures could be tailored to reduce specific (serious) consequences.

The model comprises ten main categories of causes, which are subdivided into 63 separate sub-categories. A total of ten different outcomes are also included in the model. The main categories and outcomes are depicted in the following figure:

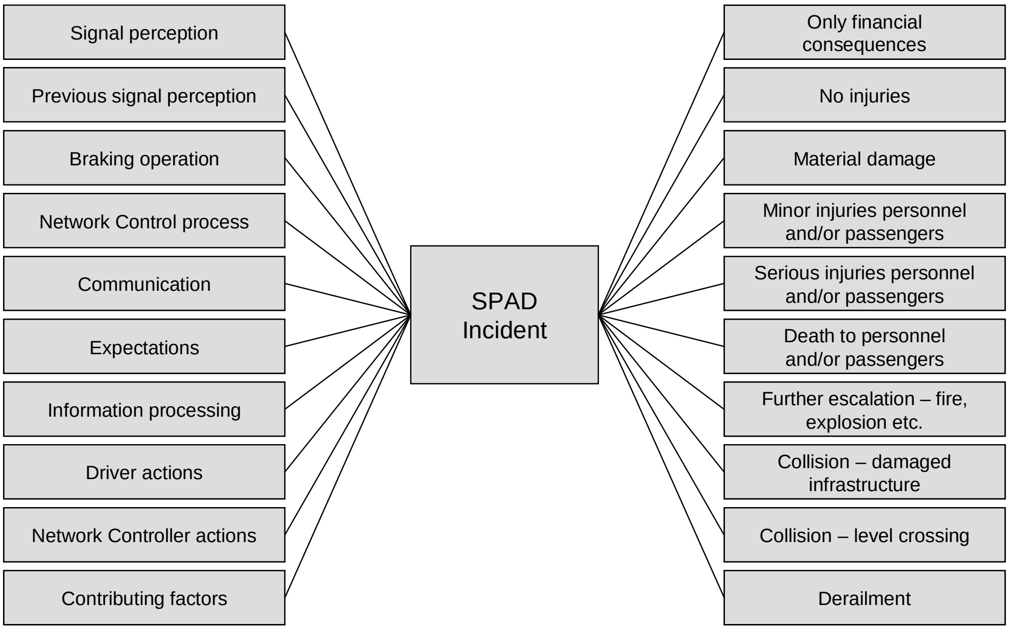

Figure 1: The main components of the SPAD Bow-tie model (IVW, 2005)

Figure 2 provides two examples of the types of subcategories included in the SPAD Bow-tie model, for the main categories Braking Operation and Communication.

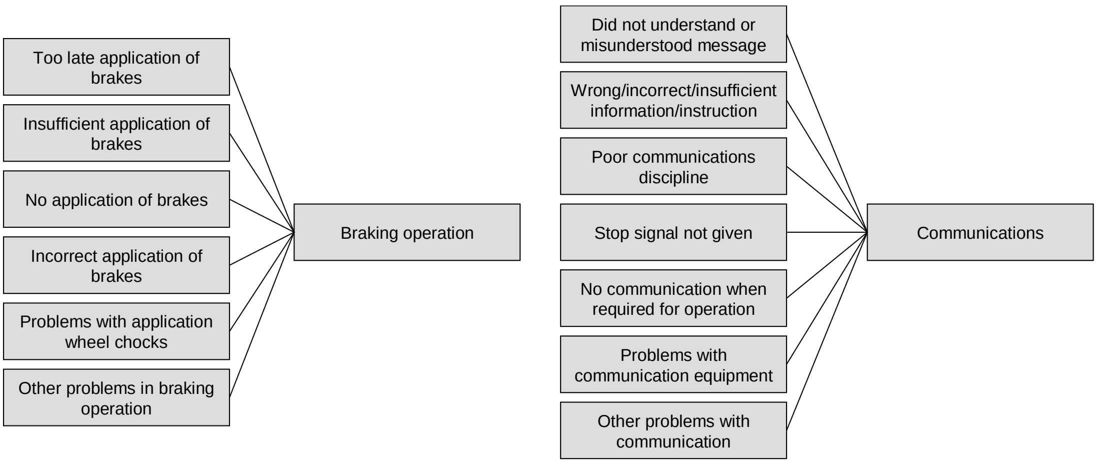

Figure 2: Two examples of subcategories included in the SPAD Bow-tie model (IVW, 2005)

An important feature of the current analysis process is that the analyst using the model can assign multiple causes and multiple consequences for a single incident. However, during incident analysis a gate-mapping approach is applied. Each root cause is classified according to one of the subcategories and that subcategory is then no longer available for the classification of a second root cause. In other words, each subcategory may only appear once in the analysis of an incident.

The sub-categories in the model are seen as the possible root causes of a SPAD incident. During the development of the model, it was recognised that differentiation between several of the root causes was not easily possible. Thus, during the analysis phase it was noted that a number of logical dependencies in the data existed. For example, “braking too-late” and “viewed signal too late” were both coded as root causes, even though one cause might be the direct logical cause of the other cause. This is illustrated in figures 3 and 4:

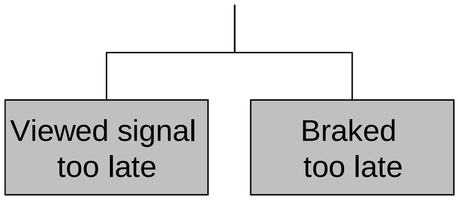

Figure 3: SPAD bow-tie analysis demonstrating the inclusion of logical dependencies

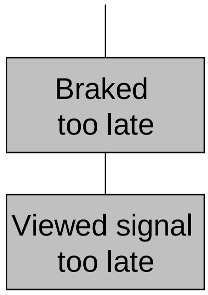

Figure 4: PRISMA analysis of the same data

The Dutch Railway Inspectorate decided not to remove these logical dependencies during the analysis, since an overriding goal was the ease of use of the model. It was believed that this would promote acceptability of the model by all involved and, moreover, an experienced analyst would not have any difficulty in recognising such dependencies.

The actual analysis and classification of the root causes of the SPAD incident is performed by staff from the Dutch Railway Inspectorate, who are experts in the use of the SPAD Bow Tie model. The classification is based on statements made by those involved in the incident and additional investigation reports.

PRISMA

PRISMA, an acronym for Prevention and Recovery Information System for Monitoring and Analysis, is a near-miss management system first proposed by Van der Schaaf (1992). In developing PRISMA, Van der Schaaf (1992) took several different aspects of incident management into account. He recognised that certain taxonomic criteria needed to be met, such as those proposed by Wright (2002, pg. 83). There is also an important relationship between failure, recovery and context, which needed to be incorporated in the approach. Recovery was important, because it was this aspect which distinguished between an accident and a near-miss. A further reason was that recovery offered an alternative approach to discovering safety improvements. Van der Schaaf and Wright (2005) also note that by introducing conditions which promote or strengthen opportunities for recovery, an organisation may protect itself against initial errors or faults which could develop into adverse consequences.

At the heart of the failure part of the approach is the Eindhoven Classification Model (ECM), presented in Figure 5. This model is based on the concepts of latent failures, introduced by Reason (1990) and the widely accepted taxonomy for classifying human errors which was proposed by Rasmussen (1974).

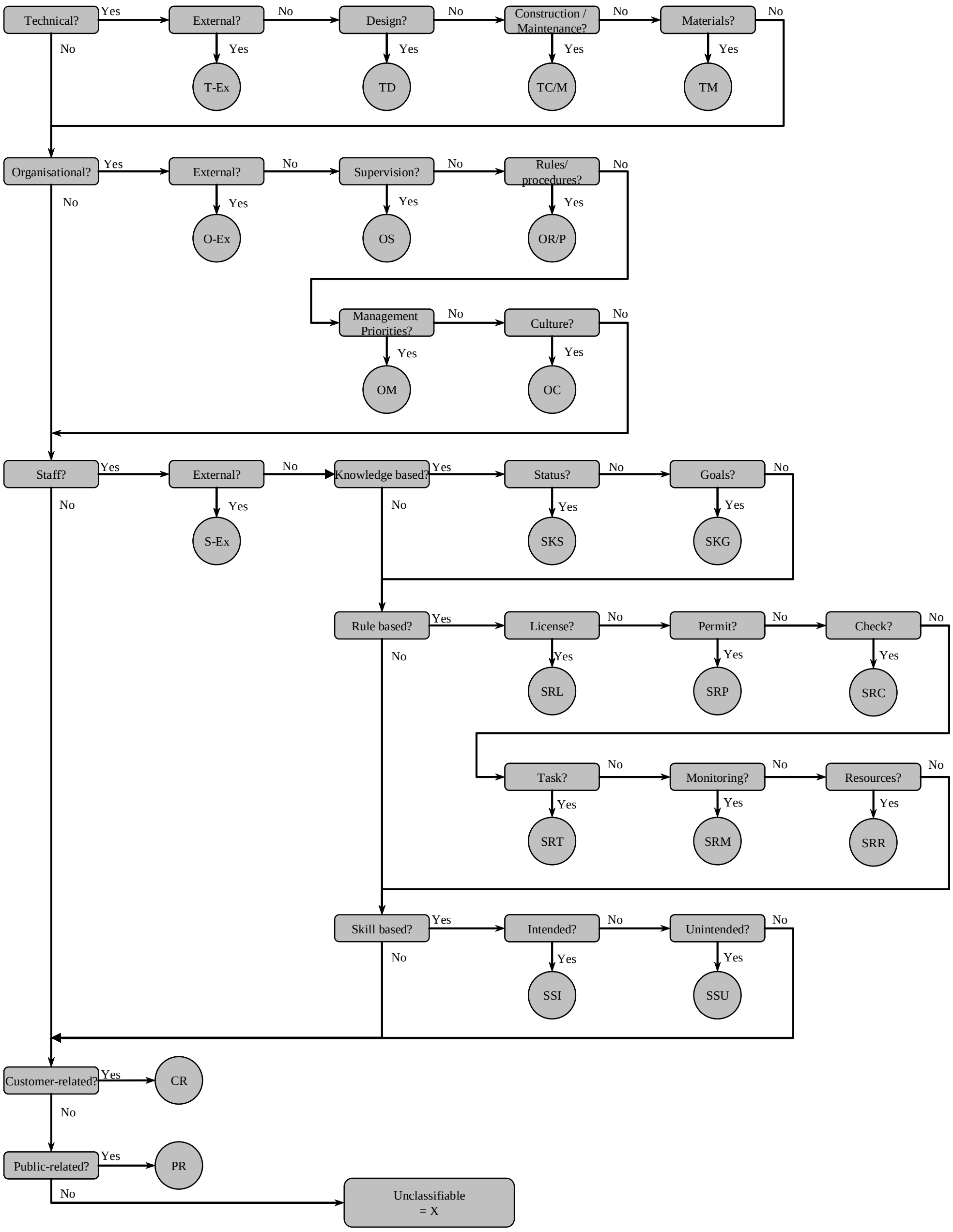

Figure 5: Eindhoven Classification Model for PRISMA Rail (2005)

In order to provide guidance for management in selecting appropriate countermeasures, the 'Classification/Action Matrix' was prepared. The matrix relates five fundamentally different types of intervention to the causal factors for which they would be most effective.

An important consideration is that PRISMA is industry independent. This has been demonstrated in various studies, where PRISMA was applied in as diverse situations as the chemical process industry, steel-making, healthcare, telecommunications and banking information security.

REQUIREMENTS OF A SYSTEM FOR CLASSIFYING (ROOT) CAUSES

Shorrock and Kirwan (2002) assert that the classification of errors in a meaningful way is imperative for recording data which is to be used for detecting trends in incident occurrence or for identifying possible failure modes. Kirwan (1997) states that analysis techniques have three primary functions, namely *identifying* consequences, *quantifying* the chances of occurrence and *reducing* the chance of occurrence. Bearing this in mind, the underlying taxonomy being used to classify the root causes of incidents plays a central role in ensuring that these functions are met.

In her dissertation, Wright (2002, pg. 82) presents seven minimum criteria, which any prospective taxonomy must meet in order to enable an effective analysis of the root causes of an incident.

These criteria are, that the taxonomy:

1. is based on a suitable underlying theory of human behaviour
2. includes technical, behavioural, organizational and management factors
3. is reliable, such that independent analysts arrive at the same conclusions
4. is comprehensive, in that it can describe incidents and near-misses and can describe both failure and recovery
5. is quantitative, whereby it is possible to collect and compare the results of numerous incidents
6. suggest methods of improving and recovery based on identified root causes
7. can differentiate between direct causes and root causes.

The following table illustrates which of the taxonomic criteria are met by the SPAD bow-tie model and PRISMA:

Table 1: comparing which taxonomic criteria are met by the bow-tie and PRISMA methods

Taxonomic criteria	SPAD Bow-tie model	PRISMA
1. Underlying theory		✓
2. Tech./org./human factors	+/-	✓
3. Reliable	✓	✓
4. Comprehensive		✓
5. Quantitative	✓	✓
6. Recommendations		✓
7. Differentiation		✓

In its application, the SPAD bow-tie model has been shown to be reliable and quantitative. Unfortunately, it does not meet any of the other minimum requirements of a taxonomy. It is SPAD specific and does not allow comparison with other incident types (e.g. SPAD's in the UK have been found to have commonalities with station overruns). With respect to technical, organisational and human factors, the SPAD bow-tie model focuses primarily on the human factors aspect; only limited attention is paid to the role of technical and organisational factors. In previous studies, PRISMA has demonstrated its ability to analyse many different types of incidents using the same basic set of root causes.

METHOD

In order to compare the effectiveness of the analysis process, it was vital to ensure that both analyses would make use of the same data. Furthermore, it was important that the incident data be complete. Since there was a possibility that incident data from 2004 could still be incomplete, it was decided to use information from incidents which occurred in 2003. A further benefit of using this information was that it had all been analysed by one and the same bow-tie analyst.

However, as the incident data had been analysed by one analyst this necessitated that a reliability trial be performed to ensure that the analysis was free from bias. Three raters from the Railway Inspectorate were asked to independently classify twenty randomly selected SPAD incidents using the SPAD bow-tie classification model.

The result of this trial was a Kappa of 0.49, which according to Landis and Koch (1977) is moderate agreement. After discussing the results and determining the reasons for certain categories being chosen, a second trial was performed using 20 new randomly selected incidents. The result of this second trial was a Kappa of 0.69, which is substantial agreement.

ANALYSIS USING THE BOW-TIE MODEL

After providing instruction in the use of the Eindhoven Classification Model, the Railway Inspectorate analyst was asked to construct an algorithm, whereby each of the 63 sub-categories in the SPAD bow-tie model was assigned one or more PRISMA categories as they saw applicable. Where more than one category was deemed applicable, the analyst was asked to estimate the relative weight of each PRISMA category.

Since the construction of the algorithm could also introduce bias into the comparison, three other experts in the use of PRISMA or the SPAD bow-tie model were also asked to independently prepare an algorithm. This led to a Kappa of 0.69 being determined at the PRISMA main category level, which is substantial agreement.

A random sample of 70 incidents was selected from a population of some 250 incidents reported in 2003. One incident was later dropped from the sample when it was discovered that the original analysis was based on incomplete information. These 69 incidents were then converted to PRISMA main categories using the algorithm developed by the Railway Inspectorate analyst.

ANALYSIS USING PRISMA

In the reanalysis of the same 69 incidents, causal trees were constructed using the same incident data as the Railway Inspectorate analyst used in the classification by means of the SPAD bow-tie model. The causal factors were then classified using the Eindhoven Classification Model.

A reliability trial was performed to ensure that the construction and classification of the causal trees was free from bias. Ten incidents were randomly selected from the 69 incidents and analysed by a separate rater. A Kappa of 0.69 was calculated at the main PRISMA category level, which represents a substantial level of agreement between the raters.

RESULTS

The average number of root causes identified in the Bow-tie analysis was 3.2 while the PRISMA analysis identified an average of 3.3 root causes per incident. Using the Wilcoxon Signed-rank test, PRISMA *did not* identify a significantly greater number of root causes than those found using the bow-tie model (P=0.188).

The percentages of technical, organisational and staff-related root-causes, identified in the Bow-tie analysis and the PRISMA analysis, are presented in Table 2, and illustrated in Figure 6.

Table 2: Overview of the distribution of root causes per PRISMA main category

	Technical	Organisational	Staff	Customer & Public	Unclassified
Bow-tie	3%	0%	90%	0%	6%
PRISMA	17%	12%	64%	0%	7%

NB: data rounded to nearest decimal

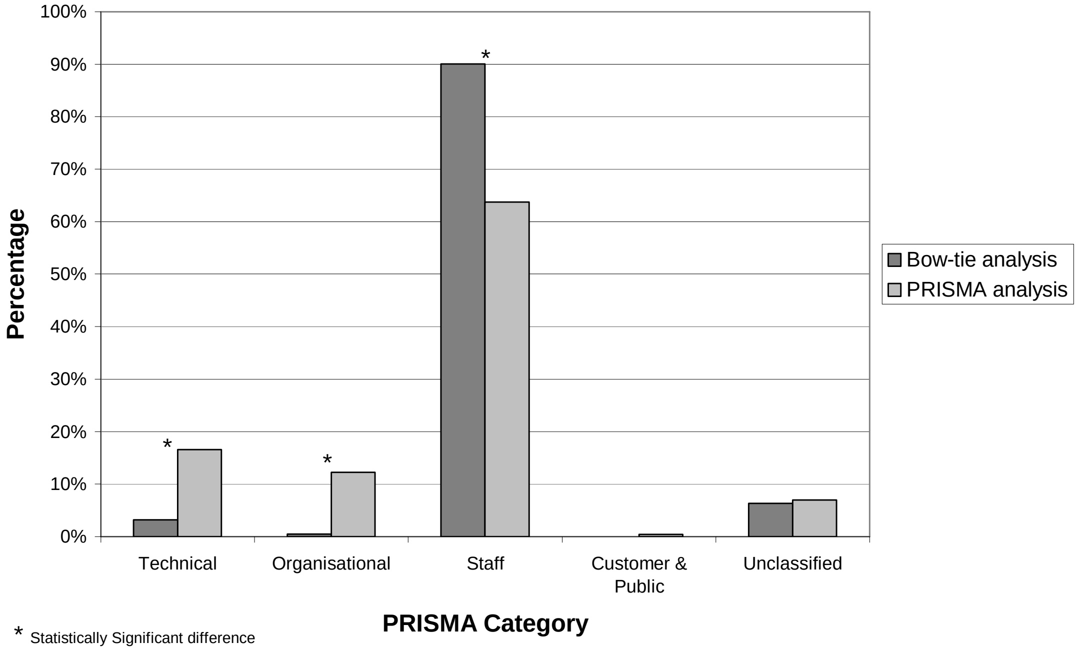

Figure 6: Comparison of root causes at the main category level

Using the normal approximation to the Wilcoxon Signed Rank Test, it was possible to determine whether significant differences occurred in the percentage of technical, organisational or human factors. The results are as follows:

- *Technical factors:* PRISMA identified a significantly greater number (P = 0.000)
- *Organisational factors:* PRISMA identified a significantly greater number (P = 0.000)
- *Staff-related factors:* PRISMA identified a significantly smaller number (P = 0.005)
- *Customer & Public:* no significant difference was identified (insufficient data for P-value)
- *Unclassified factors:* no significant difference was identified at the 1% level of significance (P=0.045)

DISCUSSION

In performing the PRISMA analyses of SPAD's, the primary question was whether the current data analysis procedure was sufficiently comprehensive. More than just an examination of the analysis philosophy, the two analyses made it possible to establish whether effective use was being made of all available data in the analyses of the root causes of SPAD's.

The results of the statistical tests demonstrate that in analysing SPAD's, the factors identified by PRISMA are significantly different to those identified by the bow-tie model. Where the current analysis method primarily examines staff-related causes, PRISMA enables a more complete analysis to be carried out. This is illustrated by the fact that in the PRISMA analysis, using the same (subset) incident data as in the Bow-tie analysis, significantly more technical and organisational causes were identified. Consequently, significantly less staff-related causes were identified.

These results are supported by Amalberti (2001), who states that "…mistakes made by individuals must be repositioned in a more systemic or sociologic framework to correctly analyse how they contribute to safety." Furthermore, Amalberti states that "… it is necessary to reconsider the entire contribution of individuals to systems operation." In other words, only investigating the role of the train driver in SPAD incidents will not lead to optimal reductions in the numbers of incidents. The role of technology and the organisation also needs to be included in the investigation if significant improvements are to be realised.

The statistical tests support the impression that not all information is effectively used in the current analysis process. A significant difference in the factors identified in the PRISMA analysis as compared with the Bow-tie analysis, lends weight to the argument that the current analysis procedure only examines what Reason (1997, pg. 10) terms ‘active errors’. Further support for the limited depth of analysis of information in the incident dossiers, is provided by the fact that the researcher (i.e. the first author) was able to achieve a good overall agreement with other Railway Inspectorate analysts when using the bow-tie model. This was achieved, despite the fact that no formal training in the use of the model or analysis procedure was provided.

The explanation for this good agreement was that a process of gate-mapping was applied. Instead of analysing what the relationship was between root causes and causal factor, an analyst using the SPAD Bow Tie model would classify each possible causal factor using the bow tie taxonomy. The classification of each factor is achieved by examining which main category and then which subcategory would be applicable. One the subcategory has been chosen, the next causal factor is examined. As such, each subcategory is applied a maximum of one time only. By comparison, if in a PRISMA analysis the same root cause was linked to two different direct causes, then the root cause category would be included twice in the analysis.

What is further interesting is that the differences between the *types* of root causes being identified did not result from an increased *number* of root causes being identified! Indeed, there is no statistically significant difference in the number of root causes identified in the PRISMA analysis versus those found in the Bow-tie analysis. The difference in the complexity of the analysis is illustrated in Figure 7.

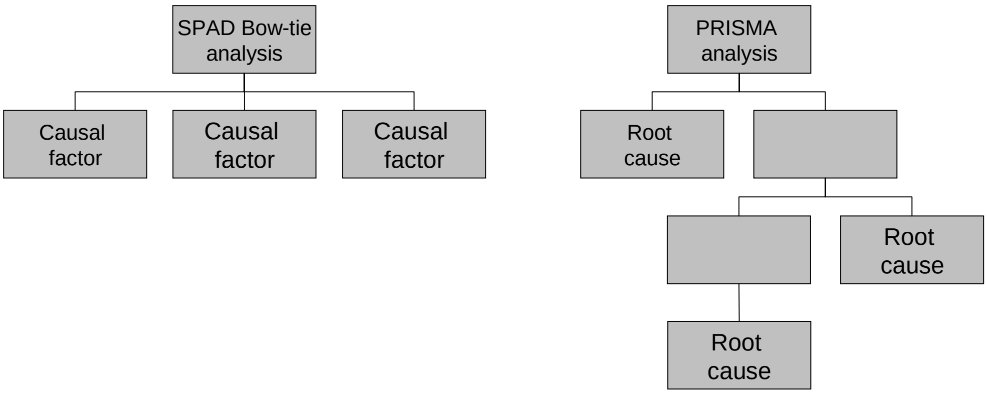

Figure 7: example of a SPAD analysis: left using the bow-tie, right using PRISMA

The analyst responsible for entering data into the Railway Inspectorate database acknowledged that data was further interpreted, and that factors which were not specifically mentioned in the incident reports were also being included in the database. An example of such further interpretation is the combinations “did not see signal” and “did not brake.” If “did not see signal” was included in the report, but “did not brake” was not included, the analyst would include both codes in the analysis, under the assumption that the driver “obviously” did not brake for the SPADed signal.

Furthermore, even if both statements would be included in the accident report, it would be incorrect to include both as root causes of the SPAD incident, since one cause is dependent on the other. There are undoubtedly other reasons for the driver not seeing the signal, such as “being distracted”, which in its turn is also included in the model as a root cause.

Finally, in a third analysis, there was an opportunity to analyse new very recent incident data, whereby drivers were interviewed by the first author on the factors which contributed to the SPAD incident. Although only a small number of incidents were collected (10 incidents), using the PRISMA method to help guide the investigative process as well as analysis of root causes, and average of more than 5.5 root causes per incident was identified. Thus, it can be tentatively concluded that the data that the Railway Inspectorate use in their SPAD analysis is limited by a method and taxonomy which restricts itself to mainly human causes.

LIMITATIONS OF THE STUDY

An important limitation of this study was that it focused only on failure root causes. Though in many of the incidents re-analysed as part of analysis 2, recovery or attempted recovery was evident in the statement made by the driver or network controller, this fact was ignored in the development and classification of the causal trees because no equivalent information was available in the bow-tie model. As such, the full potential of the PRISMA method has not been used in this study.

During this study there was no further examination of the specific consequences of SPAD's. Though several incidents were identified where drivers made the incident potentially worse by their further actions (e.g. reversing the train over points without permission), these aspects were not included in the causal tree. The incident analysis stopped at the moment that the driver passed the signal at danger. This limitation stemmed partly from the chosen research assignment. More importantly, in order to compare the Bow-tie model with PRISMA, the same focus needed to be chosen. The IVW analyst made it clear that the current approach only examined the causal factors of the incident up to the point that the SPAD occurred.

The information used in the two analyses has been analysed differently to the approach that a PRISMA researcher would normally follow. As such less information is in the dossiers than would be preferred, which has affected the construction of the causal trees. This is obvious when one examines the percentage 'unclassified' in the PRISMA analysis, which is slightly greater than what would be expected if it were possible to perform a comprehensive PRISMA analysis, where the additional information was available.

A final more general limitation is the fact that the researcher was limited by the accuracy of the information in the dossiers. Since these limitations affected both analyses, it is not expected that they would alter the significant differences found between the technical, organisational or staff-related factors.

CONCLUSIONS

The results of this research demonstrate that the current analysis process within the Dutch Railway sector is not as effective as it could be. The current analysis process primarily identifies staff-based causes, and does not effectively examine other possible causes. Though the SPAD bow-tie model enables multiple causes to be incorporated in the analysis data, the results of this study demonstrate that including multiple causes is in itself an insufficient guarantee for ensuring an effective analysis of the root causes of incidents.

Only when the analysis process is properly structured and only when the underlying taxonomy for analysing the root causes meets a minimum set of criteria will it be possible to truly state that the root causes of an incident have been clearly established.

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