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Using Concept Maps to Assess Learning of Safety Case Studies: The Eschede Train Disaster

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The Eschede train disaster remains one of the worst railway accidents in Europe in recent years. The loss of 101 lives was caused by a range of factors but was most caused by poor engineering design decisions. The derailment of the high speed ICE train at the town of Eschede in Germany and the subsequent collapse of a bridge on to the train provides an excellent context in which to introduce first year engineering students to the importance of safety in an introductory course. The poor design decisions that led to the derailment and the subsequent collapse of the bridge have been used as a case study in a general first year engineering subject at the University of Melbourne for several years. This paper begins by describing the sequence of events that started with the fracture of a steel tyre on one of the bogies on a passenger coach and that culminated in the collapse of a concrete overpass collapsing onto the train. The key lessons that may be learned from the disaster are then described. The learning around this safety case study is assessed in the classroom using concept maps. An analysis of 84 concept maps prepared by the class 15 weeks after the material had been presented to them provides an insight into how well the students integrated and retained the material from the case study. A method is proposed to analyse the concept maps to assess student and cohort learning of the case study.

Keywords: safety; case studies; concept mapping; Eschede train disaster; assessment

1. Introduction

A sound understanding of the role of the professional engineer in maintaining a high level of personal, design, process and system safety should be included in any professional engineering degree programme. The inclusion of safety in some form is a requirement for professional certification by many bodies including ABET in the United States [1], the Engineering Council UK in the United Kingdom [2], Engineers Australia in Australia [3] and Engineers Ireland in Ireland [4]. The use of real life safety case studies that in some way involve engineering judgement is an effective way to introduce first year engineering students to some of the professional responsibilities that they will eventually shoulder as professional engineers. It is certainly appropriate at an early stage to raise the awareness of engineering students about the importance of safety and their eventual roles in seeking to maintain high safety levels.

If safety case studies are to be described and discussed in lectures, then one way to evaluate student learning is to have the students prepare concepts maps based around the case study [5]. A concept map is a way to visually organize information about a particular topic and the way that the information is understood [6]. Concept maps have been used to analyse student learning in a range of knowledge domains from pulmonary physiology [7] to nanotechnology [8]. Shallcross *et al.* [9] used concept maps to assess the student learning around engineering design.

In this study, a method proposed by Shallcross [5] to assess student and cohort learning of safety case studies is developed further. The method allows the maps to be analysed individually so that the understanding of individual students can be assessed, while the method also provides information on the learning of the cohort as a whole. The technique is applied to the safety case study based around the railway disaster at Eschede in 1998.

2. The Eschede train disaster

At 10:59 a.m. on Friday June 3, 1998 a high speed ICE-1 train of Deutsche Bahn derailed and crashed into a road bridge that spanned the rail tracks outside the town of Eschede in Germany. The bridge collapsed on to the tracks, crushing two passenger coaches and causing the following coaches to crash under speed into the wreckage. More than 100 people were killed in the incident, which was eventually found to have been caused by poor engineering design and decision making [10–11].

2.1 The accident

The ICE trains were introduced into service on the German rail system in 1991, travelling at up to 250 km/h. The trains were seen as an answer to France's TGV high speed train system, which had begun to revolutionise travel within Europe. Each

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train consisted of a power car at each end and twelve coaches. The ICE services across Germany were successful and provided significant competition to the domestic airlines.

In the late 1990s all the ICE-1 trains were fitted with two-piece steel wheels. A steel tyre was separated from the central steel wheel by a thin rubber sleeve that was designed to reduce both the noise and the wear of the wheel. The single-piece monobloc wheels that had been originally fitted to the trains when built had been replaced by the wheel and tyre design after the monobloc wheels had experienced excessive wear. Experience with urban streetcars, which used the wheel and tyre design, suggested that wear would be significantly reduced.

ICE service 884 departed Munich for Hamburg in the early morning and stopped at a number of stations until the last intermediate station at Hanover (Fig. 1). At around 10:30 a.m. it accelerated out of Hanover on its way to its final destination of Hamburg. Approximately 6 km from the site of the accident a tyre on one of the four wheels of the trailing wheelset of the first passenger coach failed, causing the tyre to fracture. The steel tyre's angular momentum caused the somewhat straightened tyre to puncture the floor of the passenger compartment, nearly fatally impaling two passengers at rest in their seats. Rather than pull the emergency handle to stop the train, one of the passengers in the compartment decided to seek the train manager who was further back in the train. On being advised

Fig. 1. The route of ICE Service 884 from Munich to Hamburg.

of the incident in the first passenger coach, the train manager followed company guidelines and decided to examine the wreckage personally before stopping the train. Accompanied by the train manager the passenger returned to the front of the train, but before they could reach the first coach the train derailed.

When the fractured steel tyre had punctured the floor of the compartment, the other end of the steel tyre was hanging just centimetres above the track sleepers. The bottom tip of the suspended steel tyre was lower than the tops of the rail beside which it passed with just centimetres clearance.

Some 600 m before the road bridge there were two sets of points that allowed trains on the parallel track on the left to pass over to the parallel track on the right of the track along which the express train was running. In order to prevent trains derailing when passing through sets of points, guide rails are installed parallel to and just centimetres away from the main running rails.

When the trailing end of the first passenger coach passed over the first of these sets of points at 200 km/h the suspended steel tyre ripped up a long section of one of the guide rails. This section of the guard rail punctured an empty compartment of the second passenger coach with such force that the coach was momentarily lifted off the track. When it fell back the wheels did not land on the rails—it had derailed. The derailed wheels of the second coach caused the points to become set to the diverging track causing, in turn, the following coaches to swing over to the parallel track. The rear of the third passenger coach swung out and impacted the concrete columns supporting a heavy concrete road bridge. As the bridge began to fall, the fourth passenger coach passed beneath it but then left the tracks and rode up and over an embankment beside the railway line. The bridge collapsed on to the rear of the fifth passenger coach, crushing it completely. The sixth coach then careened into the wreckage of the bridge across the tracks driven by the rear power car that was still pushing the train forward. In seconds the rear part of the train went from 200 km/h to being stopped with the six rearmost coaches jack-knifing across the tracks. The lead power car remained on the track, untouched, and came to a complete stop a kilometre down the line. Two Deutsche Bahn employees, who had been on the bridge at the time of the accident, were killed along with 99 passengers and staff on the train. The accident could have been much worse if the train had been running to time as it was scheduled to pass another high speed train coming in the other direction at the bridge site.

The alarm was raised 4 minutes after the accident, with the first medical staff arriving on the scene 16 minutes after the accident [12, 13].

2.2 The train

Trainset 51, was the first in a second batch of ICE 1 trains to be built in the mid-1990s. The train consisted of two power cars, one at each end of the train, three first class passenger coaches, seven second class passenger coaches, a restaurant car and a service car, which contained second class seating accommodation, a small meeting room and the office for the train manager (Fig. 2). On the day of the accident the train was running with the second class accommodation at the front of the train and first class accommodation at the rear of the train. The train had accommodation for over 740 passengers but carried far fewer at the time of the accident. Power was supplied from overhead catenary through pantographs on each power car. The intermediate cars were unpowered, with all the motive effort being supplied at the ends of the train. In normal operation it was rare for the individual units of the train to be uncoupled and swapped with other units.

2.3 The causes

As already noted, the train wheels on the high speed trains were originally formed as monoblocs, cast as a single piece of steel. However after several months of use the wheels were seen to be wearing at an unacceptably high rate. Metal fatigue and uneven wear on the wheels caused the wheels to go out of round, which in turn caused vibrations.

The Deutsche Bahn railway engineers decided to solve the wheel problem by redesigning the train wheel to feature a steel tyre fitted to an inner section of the wheel. The steel tyre was separated from the main body of the wheel by a rubber sleeve. Steel tyres had long been successfully used on urban trams and streetcars throughout Germany. What the railway engineers did not appreciate was that the trams and streetcars that used wheel sets of an inner steel wheel with a steel tyre usually travelled up to 60 km/h and only over short distances. The high speed trains were designed to operate at speeds up to 250 km/h for extended periods of several hours. The engineers decided that there was no need to conduct extensive tests on the new two-steel piece wheel sets at high speed.

In operation the rail engineers observed that the steel tyres were failing more often than they should have. Every time the wheels turned they were subjected to repetitive dynamic forces that had not been accounted for in the design modelling of the wheel sets. The wheels on these very fast trains turned up to 500 000 times a day. The fatigue cracks that formed were on the inside of the tyres, where they could not be observed. As the tyres became thinner, due to the continuous wear, the rate of crack growth increased [14]. The regular maintenance checks were unable to detect the fatigue cracks. Staff on the train logged issues relating to noise and vibrations from the wheel set containing the failed tyre as many as eight times in

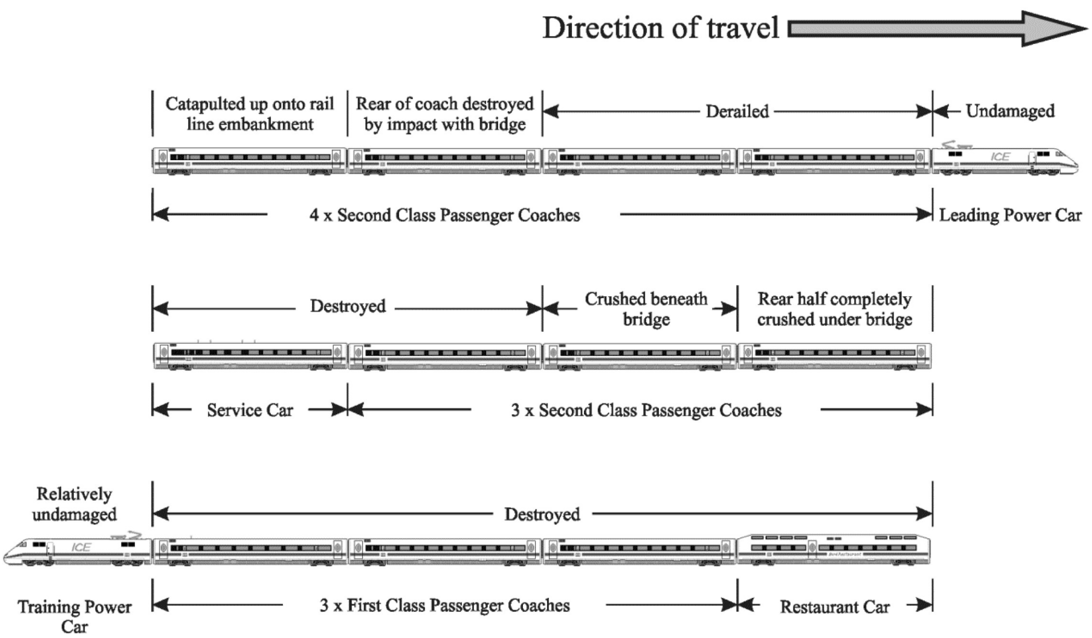

Fig. 2. Composition of the ICE train showing damage to each element. The two power cars as well as the two leading passenger coaches returned to service after the accident.

the two months immediately preceding the failure, however no action was taken. The engineers had designed a wheel set that was not fit for purpose. They had not adequately designed the wheels to meet the severe demands placed on them by the continuous high speed operation of the trains. They took technology that worked for one application and assumed that it would work in a completely different environment.

Two other factors contributed to the severity of the incident: the proximity of the concrete bridge support to the running tracks and the decision to run high speed trains on rail track shared with slower trains.

The concrete columns supporting the bridge were located very close to the running tracks. This gave a small margin for error and increased the likelihood of a major accident should a train derail while passing under the bridge. If the concrete supports had been set further back or if the bridge had been of a design that did not require vertical and vulnerable concrete columns then the consequences might have been less severe with fewer deaths.

When the French Government introduced the high speed TGV trains in the 1980s, the trains were only operated at high speed on specially-built high speed rail lines that were not shared with slower rail traffic. When the trains were switched on to slower tracks shared with freight and local services, the TGV trains operated at reduced speeds. In Germany it was decided not to build special, dedicated high speed track but instead to allow the ICE trains to run on upgraded tracks that were shared extensively with the network of slower trains. An unintended outcome of this decision was that the ICE trains had to run over rail networks with very many more sets of points than would be found on the French system. It was while the ICE was travelling over two of these sets of points linking a rail line for slower, local services with the main high speed line that the train derailed. If the train had not passed over two sets of points located one after the other, then the train would not have derailed. There is every likelihood that the train would have come to a safe stop when the conductor had viewed the steel tyre sticking up through the floor of the compartment.

2.4 Lessons to be learned

The key lessons that may be learned from the Eschede rail disaster are as follows.

- Technology that is proven in one set of conditions should not be assumed to be appropriate in a completely different set of conditions—in this case the technology of steel wheels and tyres that worked on slow moving urban street cars should not have been transferred to high speed intercity trains without more extensive study.
- Any design should consider how regular safety inspections may be made—on the ICE train wheels it is impossible to inspect the inside of the steel tyres carefully for the early signs of metal fatigue.
- The bridge at Eschede should have been designed with the view that its support columns could be compromised by the impact of the whole or part of a train.
- Operating high speed trains over points substantially increases the risks of derailment and all possible action should be taken to avoid their use.

3. In the classroom

The factors leading up to the Eschede train accident are used as a case study to introduce first year engineering students at the University of Melbourne to the importance of safety. All students seeking to complete an engineering systems major within the Bachelor of Science degree at the University of Melbourne are required to complete two first year engineering subjects, Engineering Systems Design 1 and 2. Engineering Systems Design 1 is completed in the first semester of their study at the university. The subject introduces students to the engineering profession, engineering problem solving and engineering design as well as topics in safety, sustainability and professional ethics. Each week in the subject students have three lectures and one 3-hour interactive and collaborative workshop. In the first week of the semester, students are given a 50-minute lecture introducing them to aspects of safety and the roles and responsibilities of engineers in ensuring it. In class three case studies are used to illustrate the point: the collapse of two elevated walkways at the Hyatt Regency hotel in Kansas City, USA in 1981 [15], the loss of the Piper Alpha platform in July 1988 [5, 16–19] and, since 2011, the high speed ICE railway accident in Eschede, Germany in June 1998. About 10–15 minutes of the lecture are spent on the Eschede train accident case study using many visual elements including diagrams and photographs of the train and the train wreck.

Being located in the Southern Hemisphere, the academic year at the University of Melbourne typically runs from late-February to late-November each year. Most students enter the University in Semester 1 when enrolments in the subject Engineering Systems Design 1 range from 500 to 700 students. The subject is also offered in Semester 2 to cater for the increasing number of students who come from the Northern Hemisphere to study at the University. Typically 80 to 150 students undertake the subject in Semester 2. In Semester 2 of 2011 a class of just under 100 students completed Engineering Systems Design 1. Of the class, approximately 40% had come to Australia to study engineering from mostly non-English-speaking countries in Asia. In order to assess how much the students had learned of the Eschede train disaster case study, some 15 weeks after the lecture each student was asked to prepare a hand-written concept map with 'ICE Train Accident' as the domain as part of the end-of-semester examination on the subject. The question statement was:

> On June 3, 1998 a high speed ICE train was travelling between Munich and Hamburg when the train derailed while passing under a bridge. The 4th passenger car crashed into the bridge causing the bridge to collapse onto the next passenger car. Prepare a concept map based around the domain 'ICE Train Accident'.
>
> Your concept map should include at least 20 different concepts. You will be marked on the different types of concepts that you develop, on the structure of your concept map and on the understanding that your concept maps demonstrates of the keys aspects of the disaster discussed in class.

The students were also provided with two photographs: one showing an example of the high speed ICE train involved in the accident and the other of the train wreckage.

They were given a single sheet of paper measuring 270 mm by 202 mm, slightly smaller than a standard A4 sheet of paper. Students were given up to 30 minutes to complete the activity.

In the second week of the semester students were given two lectures introducing them to the use of concept maps to break large engineering concepts, challenges and activities into smaller pieces. Examples were presented taken from the first year engineering text book by Brockman [20] showing how concept maps may be used to help to understand an engineering system better. During the semester the students were asked to prepare at least four concept maps on different engineering topics, but not the Eschede train accident. The development of the skill to be able to use concept maps to help understand complex situations is one of the learning outcomes for the subject Engineering Systems Design 1. When the students were asked to prepare concept maps around the disaster some months later in the examination there was an expectation that they would be able to do this. Eighty-four valid maps were prepared by the class.

Concept maps were first developed in the 1970s to depict the knowledge and understanding of particular domains or topics graphically [6, 21]. In a typical map the domain or central concept is written first and then other concepts that relate to it are written around it. These additional concepts are normally no more than three words and are usually enclosed within a rectangle, ellipse or circle. These concepts are linked back to the domain, and to one another if appropriate, using connecting lines labelled with short connecting words or phrases. The link made between any two concepts using the connecting words is a proposition that represents some knowledge or understanding that the map's author has about the domain. As the map develops, more concepts are added: some connecting directly to the domain but more often connected to other concepts. In a well-constructed concept map only the most important propositions are connected back to the central domain. To generate a concept map properly an author needs to organize their knowledge, analysing, synthesizing and evaluating the information that they have in a high level manner, which is not a simple task. A properly constructed map with its many concepts, connecting lines and propositions allow the map's author to demonstrate their understanding of the topic or domain [5].

Consider Fig. 3, which presents a concept map prepared by the author for the domain 'ICE Train Accident'. This map contains 49 concepts other than the central domain. The concept 'Eschede' is linked to the domain by the connecting words 'occurred at' to form the proposition that the ICE train accident occurred at Eschede. Within this map there are 15 loops where different branches link up further away from the domain. For example, a loop exists involving the concepts 'ICE 1 train', 'high speed train', 'Hamburg' and 'Eschede'. There are seven pathways or links out of the central domain and no concept is more than four steps from the domain.

No perfect concept map exists for any domain. Another person familiar with the train accident might prepare a map very different from Fig. 3 with a fundamentally different structure that highlights different concepts and propositions. As noted by Besterfield-Sacre *et al.* [22], the way in which a map is constructed, the concepts that the map's author has chosen to use and the linking propositions that the author has identified as important reveals much about the knowledge and maturity that the author has in that area. To generate a concept map properly an author needs to organize their knowledge, analysing, synthesizing and evaluating the information that they have in a high level manner, which is not a simple task. A properly constructed map with its many concepts, connecting lines and propositions allow the map's author to demonstrate their understanding of the topic or

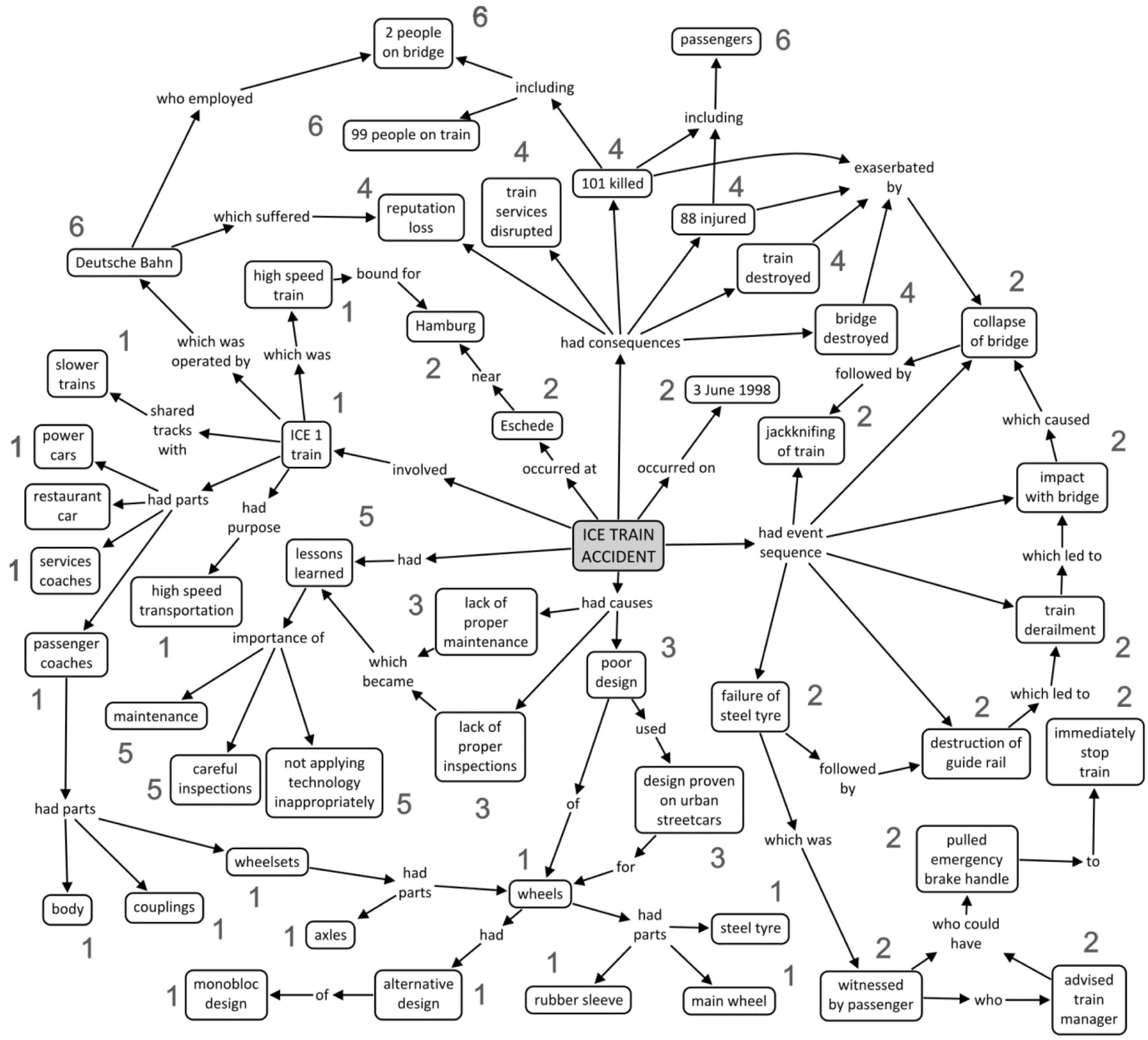

Fig. 3. Concept map around the domain 'ICE Train Accident' prepared by the instructor. This was not circulated to the students.

domain. Safayeni [23], Lourdel *et al.* [24] and Segalàs *et al.* [25] observe that the level of cross-branch linkages, which in turn form loops, usually indicate a better and deeper understanding of the topic.

In the last two decades a number of workers have turned to concept maps to assess the understanding of student cohorts of a range of topics [26–30]. As examples, Daley *et al.* [31] and Williams [32] applied concept maps to explore student learning in nursing education while Mento *et al.* [33] report their application to executive Master of Business Administration program. In engineering education Shallcross [9] used concepts maps to assess student learning and understanding around the design and operation of the Thames Flood Barrier in London and later applied them to assess learning around the loss of the Piper Alpha offshore platform in 1988 [5].

When maps are used for assessment of student learning, the concepts used in the maps may either be generated by the student themselves or the instructor may have provided them for the student [34–35]. When the Engineering Systems Design 1 subject was taught for the first time in 2008, the examiners set a question on the end-of-semester examination that gave students a collection of words as concepts relating to the domain 'bicycle'. The task was designed to assess the students' ability to develop a concept map. The words were simple and included concepts such as 'hub', 'spoke', chain'. Unfortunately many of these words were unknown to the students in the class for whom English was not their first language. As a result the set task became more difficult for non-native speakers and was not equitable. Thereafter students were allowed to choose their own concepts in any maps that they were asked to prepare.

As noted by Shallcross [5], concept maps developed by students may be analysed in several fundamentally different ways to determine the extent of learning and understanding of the topic.

1. The structure of the map may be studied by determining the total number of concepts included in the map, the total number of propositions, and the maximum number of generations that any concept is removed from the central domain [36].
2. The content of the map may be studied by categorising every concept included in the map into one of several categories according to some taxonomy [5, 9, 24–25].
3. The quality of the map may be assessed in a more subjective manner giving scores for comprehensiveness of the topics covered by the concepts taken as a whole, the correctness of the propositions contained in the map and the structure of the map considering the extent of links between different branches [22].
4. The overall quality of the map can be assessed by comparing it with a map prepared by an expert in the domain [37].
5. All valid propositions, cross-link between different branches and examples are identified and assigned a given different number of points to derive an overall points score for each map [27, 31, 38].

In this present study the maps are analysed using the first three methods. For each map the following characteristics of each map are identified:

- total number of concepts other than the domain;
- total number of propositions;
- number of pathways leading out of the domain;
- maximum number of generations that any concept is away from the domain.

Next, each of the concepts featured in a map are classified into one of the six categories proposed by Shallcross [5] to analyse student learning around the loss of the Piper Alpha safety case study. The six categories applied to the Eschede railway disaster are:

Category 1—Context—Description and purpose of the train including its major components

Category 2—Incident description—What went wrong? The key steps or events in the case study

Category 3—Causes—What caused the incident?

Category 4—Consequences and aftermath—Short, medium and long term consequences

Category 5—Lessons learned—What could have been done better or differently?

Category 6—Actors and stakeholders—People and institutions, including companies and government

These six categories were selected to cover broadly all the concepts that might be expected to be included in any concept map relating to a case study of a safety incident such as the Piper Alpha disaster. The taxonomy was found to be effective in the Piper Alpha disaster case study and so is applied here. Table 1 lists the six categories, together with typical concepts that might be assigned to them. The six categories were not disclosed to the students ahead of the preparation of the maps to ensure that they were not unduly influenced in their thinking.

The number of categories chosen for the classification process is an important consideration in designing the method used to analyse the concept maps: too few categories and the value of classifying the concepts is diminished with unrelated concepts lumped together; too many categories and it becomes difficult to accurately assign each concept to the appropriate group. With ten or more categories there is a greater need to assign the concepts to the most appropriate categories subjectively. Lourdel *et al.* [24] used a taxonomy of six categories to classify the concept maps in their study on sustainability. Later Segalas *et al.* [25] proposed a taxonomy of ten categories for analysis of concept maps of the same domain, by sub-dividing some of Lourdel *et al.*'s categories. While at first inspection it appears that the use of ten categories is worthwhile for gaining more detailed insight into areas covered by a concept map, it comes at the cost of introducing

Table 1. Example concepts for each of the six categories

Category	Example concepts
1. Context	Passenger train, wheels, motor, power car, parallel tracks, bridge, steel.
2. Incident description	Wheel failure, Hamburg, Eschede, cracks in steel tyres.
3. Causes	Metal fatigue, design flaws, ignorance, carelessness, unethical behaviour, vibrations, responsibility, wheel design, bridge design.
4. Consequences and aftermath	Death, injuries, bridge collapse, loss of life, loss of property, bridge collapse, loss of income, loss of reputation.
5. Lessons learned	Maintenance, testing.
6. Actors and stakeholders	Driver, train manager, passengers, engineers, staff, management, railway company, contractors, government, emergency services.

more errors into the analysis by having to make more subjective judgements as to which categories some of the concepts should belong. Shallcross *et al.* [9] used seven categories to classify the concept maps, considering the design and operation of the Thames Barrier. In the present study, it was decided to define six categories to encompass the concepts that might be expected to be around the domain of the train disaster. Six was chosen as the number of categories as being an appropriate balance between gaining a useful insight into the distribution of the concepts amongst the categories, and the need to reduce the number of subjective decisions that must necessarily be made when the concepts are classified.

For each concept map all the individual concepts were classified into one of the six categories. Where a concept did not obviously fit into one category or another it was assigned to the one closest in meaning. Occasionally it was necessary to study the surrounding concepts to properly classify a concept. As Lourdel *et al.* [24] note, classifying words into any set of categories implies a certain level of subjectivity in analysing the meaning and intent behind the words. Some concepts could equally fit into more than one category and in such cases the context developed amongst the surrounding concepts was used to make the assignment.

Not surprisingly the author's own concept map for the ICE train accident includes concepts from all six categories. The numbers written beside each of the concepts in Fig. 3 indicate the category to which the particular concept has been assigned. In this example, 18 concepts have been assigned to Category 1, 13 to Category 2, four each to Categories 3, 5 and 6, and six concepts to Category 4.

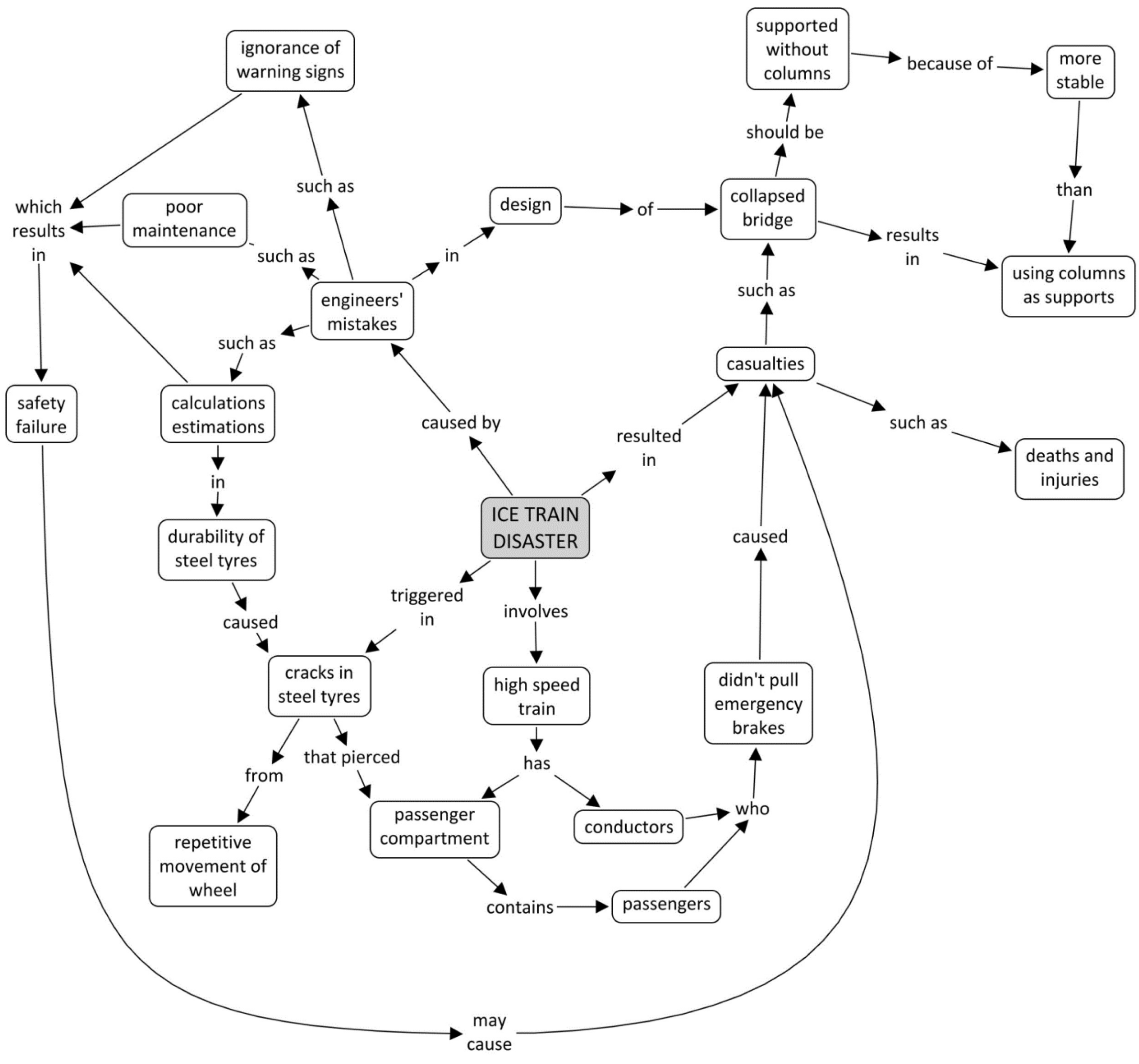

Fig. 4. Concept map of 20 concepts prepared by a first year engineering student (Student 1). The hand-drawn map has been redrawn by the author for legibility but preserving the structure and features of the original map.

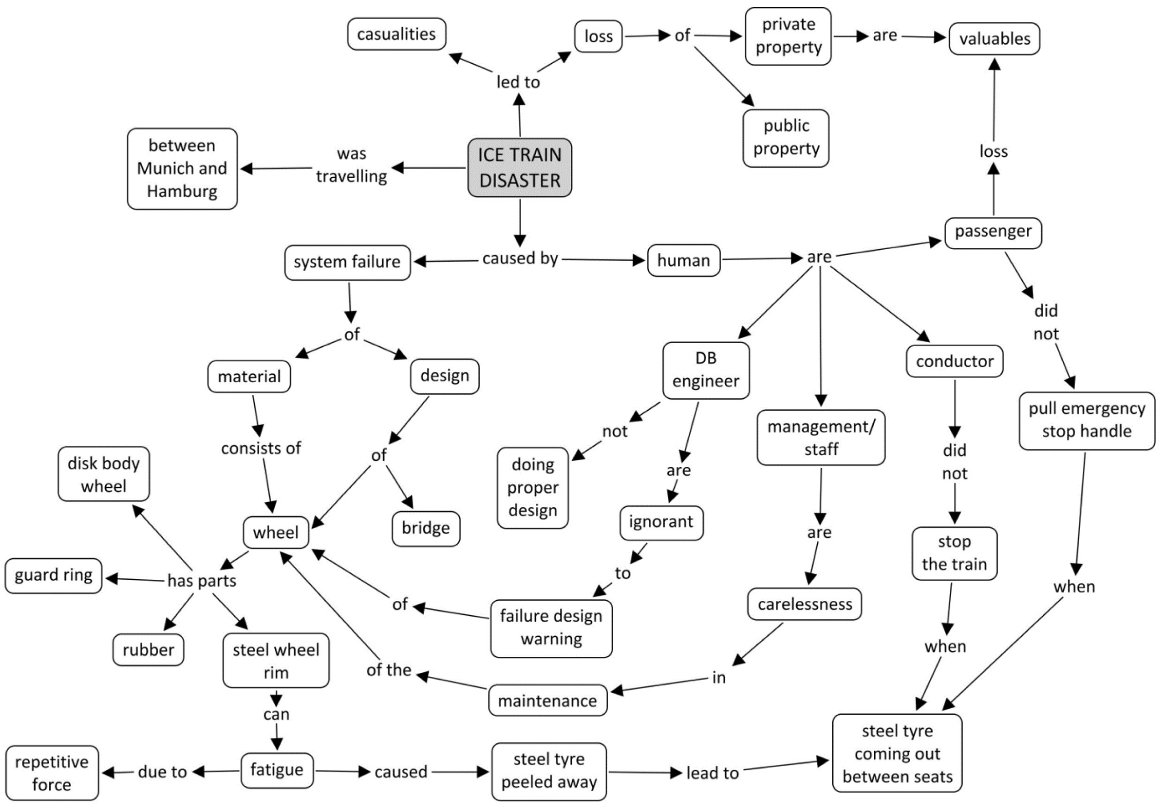

Fig. 5. Concept map of 31 concepts prepared by a first year engineering student (Student 2). The hand-drawn map has been redrawn by the author for legibility but preserving the structure and features of the original map.

The number and distribution of concepts across the six categories allows conclusions to be drawn on which concepts the students considered most important and how the students linked the key concepts together. It is not expected that all categories would be equally represented even if time were not a constraint.

The concept maps prepared by the first year engineering student cohort are represented by Figs 4 and 5. The first map (Fig. 4) contains 20 concepts with representatives drawn from all the concept categories. The second map (Fig. 5) has 31 concepts and has no concepts that could be related to Category 5 (Lessons learned). Figure 5 contains substantially more detail about the separation of the steel tyre from the wheel due to metal fatigue than Fig. 4.

The 84 valid concept maps prepared by the class were analysed and found to contain on average 23.0 concepts other than the domain and 29.0 propositions or links indicating that on average there were an average of 6.0 interlinks between different branches of the maps. The distribution of concepts across each of the six categories is presented in Fig. 6. This indicates that the students had a very good appreciation of the incident and its causes but had little to note on the lessons learned. Concepts from Categories 2 and 3 accounted for nearly half of all concepts considered important enough by the class to be included in their maps, while two-thirds of the class did not include any concepts from Category 5. Two students prepared maps with fewer than 12 concepts, while one student prepared a map of 52 concepts. Just three of the 84 maps were purely hierarchical, featuring no crosslinks between different branches of the maps.

The dashed curve of Fig. 6 shows the distribution of concepts across each of the six concept categories for the Piper Alpha case study, which has been discussed elsewhere [5]. This shows that the students in the Piper Alpha case study cohort were unable to place into context the disaster as well as those who participated in the Eschede train disaster but that the students were able to retain more information regarding lessons learned from the loss of the offshore platform than the students did for the train accident.

The third method used to assess the maps employed a scoring rubric based upon that developed by [22]. In the method proposed by Besterfield-Sacre *et al.* each map is scored either 0, 1 or 2 against three dimensions (Table 2):

- *comprehensiveness*—a student's ability to define the domain and the knowledge in terms of both depth and breadth of the topic area;
- *structure*—an ability to arrange the concepts systematically with appropriate links between concepts across the entire map including linkages between different branches and different levels;
- *correctness*—an ability to present concepts relating to the domain with accuracy and without the presence of misconceptions.

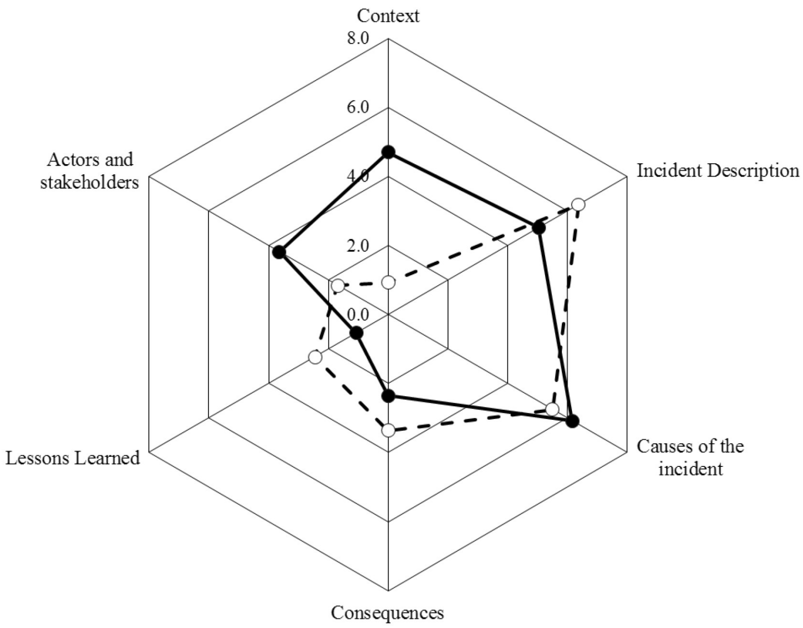

Fig. 6. Distribution of average number of concepts in each of six categories for all student concept maps. Solid line refers to the present study for the ICE Train Disaster, while dashed line refers to the Piper Alpha case study [5].

Table 2. Concept map scoring rubric considering the four dimensions of concept map construction (based on [22]).

Scoring rubric	0	1	2
Comprehensiveness A student's ability to define the domain, and the knowledge in terms of both depth and breadth of the topic area	The map is incomplete, missing many key concepts indicating a lack of knowledge or understanding of the map's domain. The map barely covers some of the qualities of the domain.	The map contains most of the concepts relating to key aspects of the domain expected to be found in the map.	The map's concepts taken together define the domain well, indicating an awareness of nearly all the key aspects of the domain.
Structure An ability to systematically arrange the concepts presented with appropriate links between concepts across the entire map between different branches levels	The map is strictly hierarchical with few if any links between different branches. The thinking behind the map development is linear. Obvious links between concepts are not included.	The map is well structured with appropriate links across the map between different branches and sub-braches. All obvious links between the concepts are made.	The key concepts are systematically arranged with well-defined links at all levels. The map also includes sophisticated branch structures, suggesting the thinking is holistic.
Correctness An ability to present concepts relating to the domain with accuracy and without the presence of misconceptions	The map contains many errors or inappropriate concepts and/or links indicating a poor or naïve understanding of the topic.	The map contains some inappropriate concepts or links but most are fundamentally sound.	The map contains no, or very few, errors. All concepts and links included in the map are appropriate and sufficient, indicating a sound understanding of the topic.
Map elements An ability to prepare a properly-constituted concept map containing all the necessary features.	Propositions linking the concepts are absent and the directions of the links are missing. The domain is not clearly defined.	Propositions or directions are not indicated on the links between concepts. Concepts and propositions are not clearly distinguished.	The map contains all the elements of a proper concept map including a clearly defined domain. All links have the direction indicated and all propositions are included.

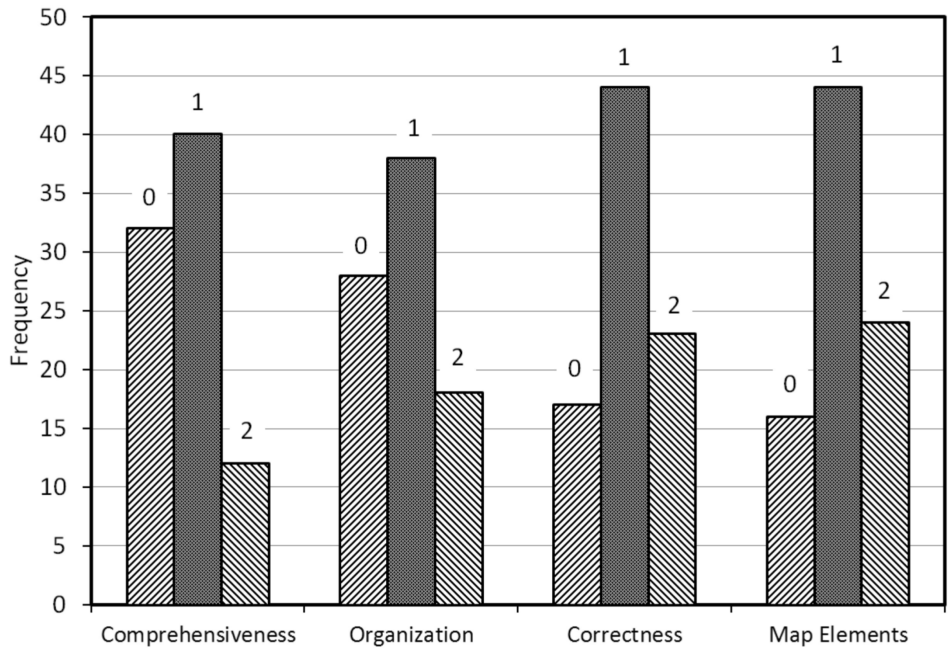

Fig. 7. Distribution of scores across the four dimensions of Comprehensiveness, Organization, Correctness and Map elements.

To this rubric, this study adds a fourth dimension relating to map elements. This considers the ability to prepare a properly-constituted concept map that contains all the necessary elements such that all links have joining words and direction indicated. This fourth element is added in this study as the student's ability not only to prepare an accurate and comprehensive map is being tested by the assessment task but also the ability to prepare a concept map properly containing all the appropriate elements.

In the present study each map was scored 0, 1 or 2 against the four dimensions of the rubric. Figure 7 shows the distributions of scores across the four dimensions for the 84 concept maps. From this data we are able to conclude that a third of the class were unable to display a comprehensive understanding of the domain, their concept maps lacking in key areas. However what they did present was usually correct with most of the propositions being fundamentally sound. Looking at the scores for 'Organization', the information presented in the maps could have been organized better with more valid crosslinks between different branches of the map. Most maps possessed the required elements expected in a map.

By adding the scores for the four dimensions a total score for each concept map may be derived. The distribution of these scores is presented in Fig. 8. While it may be argued that the four individual components of the total score should not be equally weighted with greater emphasis perhaps being given to the dimensions of 'Comprehensiveness' and 'Correctness', in this example the four constitutive scores are considered equally.

4. Concluding remarks

The rail accident at Eschede in Germany is an excellent case study in the importance of safe engineering design. The sequence of events from the point when the steel tyre peeled away from the wheel until the impact of the train into the bridge supports engages the students. The key design decisions made by the railway engineers to apply a wheel design proven for low-speed urban street cars to high speed intercity expresses and to allow the trains to run at high speed on lines shared with slower trains can generally be presented so that students can understand the concepts well.

Concept maps have been demonstrated to be useful tools in assessing learning, not only of the individual students, but of the cohort as a whole. The scoring rubric presented here allows each map to be scored and given a numerical grade. When the maps are analysed by assigning each concept to a particular category then a different type of picture may be built up of the cohort's understanding and learning of the train disaster. This type of analysis allows us to identify which areas of the case study were well understood and which areas were less

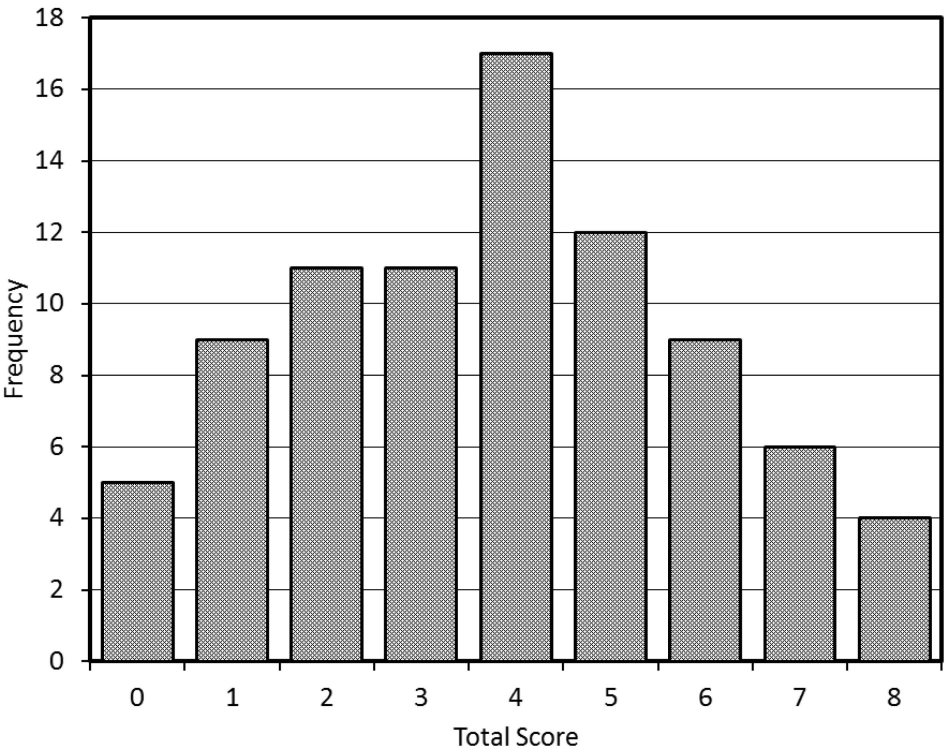

Fig. 8. Distribution of the total concept maps scores by summing the individual scores across the four components.

understood. In this case, students included few comments relating to the types of lessons that could be learned from the case study. They also did not engage well with concepts around the consequences of the case study.

It is also found that concept maps are generally easier and quicker to assess than conventional essays in which students might be asked to write on a particular topic. Misconceptions that students might hold around a topic can be more readily identified in a concept map than in an essay. Concept maps are powerful tools for assessing student and cohort learning.

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