Adaptation of Tracer—Technique for The Retrospective and Predictive Analysis of Cognitive Errors- for Analyzing Indonesian Train Accident Involving Train Dispatcher

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Abstract. Human factors have been as major factors that contribute to many accident in rail industry, including Indonesia. High train accident rate in Indonesia is underlining the importance to develop method in identifying and analyzing human error in rail system in particular for the second most involved in train accident that is train dispatcher. Purpose of this study is to adapt technique for the retrospective and predictive analysis of cognitive errors (TRACer) in identifying human error in Indonesian train dispatcher. Task, sub-task, and cognitive domain analysis of Indonesian train dispatcher is identified through Standard Operation Procedure (SOP)' review and direct observation involving four train dispatchers. Further, TRACer taxonomy including task error, error taxonomies, information taxonomy of Indonesian train dispatcher is determined based on literature review and group discussion among authors and a station master. Performance shaping factors are observed through a questionnaire involving 26 train dispatchers. The adapted TRACer is developed and the application of the adapted TRACer in analyzing one train accident in Indonesia that is validated by Indonesian National Transportation Safety Committee reveals the usefulness of the adapted TRACer. The result revealed that the adapted TRACer is a valuable aid to analyze Indonesian train accident involving train dispatcher and can be used as a basis for further applications in train dispatcher in other countries with necessary adaptation.

1. Introduction
Human error has been mentioned as a major cause of incident and accident within complex system [1,2,3,4,5,6]. Therefore, tools to analyze human error in complex system have been developed for years. To date, there are more than 70 tools for analyzing human error, covering a range of industries [7], for example Human Error Analysis and Classification System (HFACS) and The Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACer). One human error analyze tools that has been used frequently in the railway system is The Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACer). TRACer is developed by [8]. In the beginning, it is used to identify human error in air traffic controller.

TRACer consist of both predictive and retrospective tool. The predictive tool is valuable for identifying and classifying possible errors, whereas the retrospective tool is for post incident analysis. Furthermore, [11] underlined that TRACER was originally developed for aviation and therefore it needs to be modified to include more relevant and comprehensive taxonomies and need further requirement for rail. By the time, TRACer has been modified as a tool for analyze accident involving train driver, referred to as TRACer-Rail, in the UK [2] and in Australia (TRACer-Rav) [2].
In Indonesia, high rate of rail way accident calls for comprehensive methodologies in analyzing human error as well. Indonesian directorate of rail, Ministry of Transportation, stated that there are 283 Indonesian train accidents from year 2009-2013. This number of accident is considering high compared to other countries. Furthermore, Indonesian Ministry of Transportation have been tried to identify causes of Indonesian train accident that are equipment, infrastructure, human resource, external factor, and nature. Among these factors, human factor is contributed to 70% of Indonesian train accident [12]. In the case of railways accident, train driver and train dispatcher is the most involved people.

Research has been focused on the role of train driver in train accidents (see [7, 13, 2, 14] for examples). As far as acknowledge by authors, no study has been conducted in analyzing train accidents involving train dispatcher. Considering that based on Indonesian National Transportation Safety Committee (NTSC) report, four fatal train accidents during 1993-2015 has been caused by train dispatcher error, it is extremely important to adapt and or develop method for identifying and analyzing human error in Indonesian train dispatcher.

The existing TRACEr could not be directly applied in identifying and analyzing train dispatcher error in train accident due to different characteristic among train driver and train dispatcher. As stated by [15], it is crucial to observe condition and characteristic of work and activities of people involved in an accident. Indonesian train dispatcher is characterized by high cognitive demand. Indonesian train dispatcher use many work tools and equipment such as telephone, train route, train signal, and visual figure of train line that very often have been used in the same time, thus requiring multitasking skill that impose high cognitive load.

Purpose of this study is to adapt TRACEr for use in Indonesia to identify human error in Indonesian train dispatcher. First, task analysis is conducted including identification of main, sub task and cognitive demand of train dispatcher. Then, retrospective taxonomy is developed and the proposed adapted TRACEr is validated.

2. Methodology

Three main steps had been conducted in this study. First, task analysis is conducted using Applied Cognitive Task Analysis (ACTA) to describe cognitive demand for train dispatcher’ tasks. The task analysis including main task analysis, sub task analysis, and cognitive demand identification. The main and sub task analysis is conducted based on documents’ review (e.g., Standard Operation Procedure’s review) and direct observation. Direct observation is conducted to four train dispatchers who have complete train controlling task. For every sub task that is observed, cognitive demand identification was done by matching the sub task with Simple Model of Cognition (SMoC) [16] that consist of four cognitive domains: (i) perception, (ii) memory, (iii) decision making, planning and judgments, and (iv) action. The result of main and sub task analysis, as well as cognitive demand identification are confirmed to and validated by station master.

The second step is developing TRACEr’s retrospective analysis taxonomies including task error, error taxonomies (i.e., Internal Error Modes (IEM) and Psychological Error Modes (PEM)), information taxonomy, and Performance Shaping Factors (PSF) taxonomy. Task errors are determined from all sub tasks from each main task of train dispatcher that contribute to train incident and accident. The similar sub tasks are grouped into one kind of task error. Error taxonomies - IEM and PEM taxonomy-, developed by RSSB for train driver (see [17] for further review) as the result of extensive review of human factors in the rail area, was adopted for train dispatcher because the variables in the taxonomy is related with train dispatcher activities. Information taxonomy for train dispatcher is adopted from information taxonomy for ATC proposed by [10] with several adjustment based on train dispatcher task. The determination of task error, error taxonomies, and information taxonomy are conducted through group discussion among authors and station master.

PSF taxonomy developed for human performance in railway system in UK, proposed by [18] is adopted. The PSF are including personal, dynamic personal, task factors, team factors, organization, system factors, and environmental. A questionnaire was developed based on factors in [18] for confirmatory process. Explanations for every factor in the PSF taxonomy were adapted to Indonesian,
following back translation procedure (see [19, 20] for a further review). The questionnaire consist of 43 questions with nominal scale was given to train dispatchers from all classes of station. There are 6 station classes in Indonesian railway management. Purposive sampling was used to provide sample from every classes. In total, 26 train dispatchers were involved. Figure 3 shows the sample for PSF taxonomy for confirmatory process. Additional factor was given by the train dispatcher respondents in an open question in questionnaire related to PSF for Indonesian train dispatcher, that is distance of home to the station.

The last step is validating and evaluating the developed method. Face validity was conducted for validating the model. Subject Matter Expert (SME) was appraising whether the model could be used for analyzing train dispatcher’s human error on a train accident. SME is also evaluating the developed method using [9] criterion. The criterions are comprehensiveness, consistency, theoretical validity, usefulness, resource, document ability and acceptability. A rail accident investigator from Indonesian National Transportation Safety Committee (NTSC) became the SME to conduct the validation and evaluation. A questioner was developed to see its validity and the value of the method in [9] criterion.

3. Result and Analysis

Task analysis

Based on interview result and observe documents, the main tasks of Indonesian train dispatcher are: arranging train to enter the station, dispatching train to exit the station, controlling train crossover, controlling change in train arrangement, and train launching. For each main task, sub tasks are determined based on the observation. There are 8 sub task for arranging train to enter the station, 8 sub task for dispatching train to exit the station, 28 sub task for controlling train crossover, 28 sub task for controlling change in train arrangement, and 9 sub task for train launching. In more detail, Table 1 shows the example of sub task as well as cognitive domain for each sub task of arranging train to enter station.

| Main task               | Sub task                                                                 | Cognitive Domain                          |
|-------------------------|---------------------------------------------------------------------------|-------------------------------------------|
| Arranging train to enter station | Do communication between stations                                          | Perception (hearing) Action execution      |
|                         | Prepare the railway and make sure it is free from obstacles               | Decision Making Action execution           |
|                         | Stop all launching movement that heading to the railway                   | Decision Making Action execution           |
|                         | Make route for the train                                                  | Action execution Perception (visual)       |
|                         | Anounce of train arrival                                                  | Memory Action execution                    |
|                         | Execute 1st signal (Train dispatcher ready to receive train arrival)and make sure 21st signal (last carriage sign) is complete | Perception (visual) Decision Making       |
|                         | Ensure launcing is stop and not crossing the border                       | Perception (visual)                        |
|                         | Record train arrival time                                                 | Memory                                     |
|                         | Give information of train arrival to the preceding station                | Decision Making Action execution           |

In relation with task error, there are 16 types of task error identified in train dispatcher’ activities and accident. Task errors were obtained by classifying similar sub task from previous step. This part explains what kind of sub task that could fail to perform satisfactory. Based on those task errors, Internal Error Modes (IEM) and Psychological Error Modes (PEM) for train dispatcher are developed. IEM describes what cognitive function failed or could fail and in what way [11] and PEM describes the psychological nature of the IEMs, the cognitive biases that are known to affect performance [11]. Information taxonomy that describes the subject matter or in what area the error could occur is developed. This taxonomy related to IEM. Performance Shapping Factors (PSF), factors that could influence
performance and aggravating occurrence of errors [11] is developed as well. After the development of taxonomies, Adapted TRACEr was proposed. Figure 1 shows a proposed conceptual model for developed TRACEr.

![Figure 1. The adapted TRACEr](image)

The adapted TRACEr is assessed and evaluated by Indonesian NTSC. Based evaluation criterion proposed by [9], the adapted TRACEr is evaluated as having high comprehensiveness, moderate consistency, moderate theoretical validity, moderate resource, moderate document ability, and high acceptability.

**Application of adapted TRACEr**

A report by Indonesian NTSC about a crash between train number 34 and train number 144 in Purwosari station in 2010 is analyzed. The accident was happened when train 144 was instructed to stop and wait for train 34 that would pass through Purwosari station. Yogyakarta operation control gave an instruction to Purwosari station’s train dispatcher that train 34 would pass the Purwosari station’s without stopping in track 2. Train dispatcher was instructed to arrange arrival of train 144 to enter track 1. Train 34 was permitted to enter the station on track number 2 with certain speed as the sign that was given by the Purwosari train dispatcher. However, since the last carriage of train 144 still on track 1, the last carriage of train 144 was hit by train 34. One passenger was killed and 4 passengers were injured in this accident.

From NTSC’ investigation report, it was stated that the contribution factors to the accident were:
1. Purwosari station’s train dispatcher was not ensuring by himself that the train was not exceeding the border.
2. The lamp as the sign of the last carriage of train 144 was off.
3. Track number 1 on Purwosari station has never been used by train so that train dispatcher was not experienced and familiar with track 1.

The adapted TRACEr is applied to analyze the accident. Based on Cognitive Task Analysis, the cognitive domain that is used dominantly for ensuring the train so that the train was not violating train border is visual perception. As the train dispatcher may see the wrong sign, Internal Error Modes (IEM) in this case is mis-perceiving the situation. Another important factor is the psychological reason why IEM happened (i.e., Psychological Error Mode/PEM). In this case, train dispatcher act that not ensure by
himself that the train was not exceeding the border, mean that he has expected what he seen was right things (i.e., wrong expectation). The next step is identified the subject matter of the error. From the train dispatcher point of view, there are duties/activities that were not performed satisfactorily. Although there may another reason that causing the accident, the main reason is there is an activity not performed satisfactory, and so the subject matter of the error or information taxonomy is train dispatcher activity. At last, there several factors that may influence the train dispatcher performance (i.e., performance shaping factors/PSF). From the analysis of the report, it has been concluded that the PSFs, in this case, are familiarity, interpretation, and visibility.

Based on the adapted-TRACEr analysis as the adapted-TRACEr is focused on retrospective analysis, to avoid similar type of train crash, identified errors can be minimized or even avoided in the future, by taking several steps to anticipate those errors.

4. Discussion

The adaptation of TRACEr to analyzing Indonesian train accident involving train driver is conducted because TRACEr cannot be used directly to identify train accident involving train dispatcher because the different context of work. In addition, it is conducted in order to simplify TRACEr in analyzing a train accident where train dispatcher is involved. As stated by [21], TRACEr was considered too difficult and requires a lot of resources and energy and requires a greater effort if HTA is not available [21, 22]. Therefore, such adaptation is crucially needed.

TRACEr was selected as a base for Indonesian train accident analysis involving train dispatcher as this tool is available online and appeared to be the most frequently used HEI in the UK [11]. In addition, TRACEr is designed with hierarchical form for the taxonomy, thus minimizing the cognitive demands for the analyst [23], so that it has a good consistency and comprehensiveness. It should be noted that there is also a tool having similar taxonomy as TRACEr that is Human Factor Analysis and Classification System (HFACS) [24]. HFACS consist of four components that interacting each other that are organizational influences, unsafe supervision, precondition for unsafe acts, and unsafe acts; so that all the problems in every level can be well understood. Unlike the HFACS, TRACEr focuses on how an accident can occur and what factors affect it. From these differences, [25] conclude that TRACEr has a better mechanism of accident analysis than HFACS.

In determining task error, error taxonomies, information taxonomies, and PSF taxonomies, literatures review was conducted before group discussion. For example, in reviewing IEM taxonomies, IEM proposed by [26, 10, 17] were reviewed. All of these IEM have different context in use. [26] develop IEM for used in maritime area, [10] develop IEM for used in ATC and [17] develop IEM for rail area. For this reason IEM of [17] was used. In addition, IEM of RSSB is chosen due to its quite comprehensive taxonomy.

For Information taxonomy, taxonomies proposed by [10] and [26] was reviewed. Both have different perspective. [26] said that error information deals with the equipment involved in the error, while [10] stated that the information error categorizing not only equipment involved with the operator task but also there are external variables such as aircraft information variable, time and location used in this information error. Therefore, information taxonomy proposed by [10] was used in this research.

On the determination of PSF, beside PSF proposed by [18], PSF for pilot and ATC proposed by [10] was reviewed as well. [10] proposed nine dimensions of PSF that are traffic and airspace, pilot/controller communication, procedures, training and experience, workplace design, ambient environment, personal factors, social and team factors, organizational factors. However, due to practical reason that PSF proposed by [10] is applied in aviation and based on discussion between authors and station master, the PSF proposed by Kyriakidis is chosen.

This study represents first attempts to adapted HEI tools, in particular TRACEr, in analyzing Indonesian train accident involving train dispatcher. This study gives valuable contribution for Indonesian railway management in analyzing and reducing Indonesian train accident involving train dispatcher. Moreover, the adapted TRACEr-rail has been validated by Indonesian NTSC and has been
used to identify recent Indonesian train accident in 2016. Authors also have been requested to develop TRACEr manual for guidance of Indonesian NTSC.

This study has several limitations. First, the TRACEr that has been adapted is limited to retrospective method, while the predictive method has not been further adapted. This is because a limited number of Indonesian train accidents that has been officially reported by Indonesian NTSC which involve train dispatcher. More train accident reports and in-depth analysis are needed. Second, validation of the adapted TRACEr is conducted through face validity and confirmation by Indonesian NTSC. Restricted cognitive analysis capability of Indonesian accident investigator is rendering more validation process of the adapted TRACEr. More rigorous validation method is suggested to strengthen the validation of the adapted TRACEr.

5. Conclusion
This present study is aimed to adapt TRACEr for analyzing Indonesian train accident involving train dispatcher as an effort to reduce train accident in Indonesia. The adapted TRACEr that has high comprehensiveness, moderate consistency, moderate theoretical validity, moderate resource, moderate document ability, and high acceptability is particularly important to ensure the widespread use by not only incident investigators, but also designers, trainers, risk analysts, procedure writers, and ergonomist.

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