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Effect of Team Replacement Events on Risk Dormancy: Dynamic Probability Model

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Abstract

Today's industrial organizations use multi-team (MT) efforts to achieve effective performance and enhance the quality of their work. MT work is characterized by multiple teams acting concurrently or sequentially to produce a specific outcome over time. This outcome could be in many cases accomplished only by team replacement (TR). MT's may also generate risks. These risks might not cause damage to the team right away, but might possibly create risk dormancy (RD). TR is a crucial interface between teams, and therefore successful TR should consider a set of risk evaluation procedures to avoid accidents. The risks include, but might not be limited to, hazard identification, alert from each other's hazardous activities, etc. The emphasis of this analysis is on the TR, its role, significance and attributes, from the standpoint of risk evaluation and detection, and its effect on RD. A new probabilistic model is suggested. The model is intended to predict the role of TR over the entire RD range. The model can be used to manage the RD as far as TR is concerned. The analysis is, in effect, an extension of the authors' earlier research on the problem of the MT risk dormancy (MTRD).

Keywords: Risk dormancy (RD); Multi-team (MT); Multi-team risk dormancy (MTRD)

Introduction

Modern industrial activities resort to MT effort. Teams are replaced repeatedly in accordance with the work demands and progress. The risks those teams face appear in the course of the work process, depending on the employed tools, uncertain and often harsh environments, and/or from exposures to risks created by the work of other teams on site. This work could be carried out concurrently with the work of the leading team, or by continuing the same objective or a different task. This last scenario was identified and addressed as risk dormancy (RD) in the earlier study of the authors [1]. Here is a brief review of the previous publications in the related fields.

Sasou et al. [2] wrote: "Improving personal skills is important for error prevention. However, today's industrial plants are too large to be controlled by individuals. Teams control power plants, aircraft, ships and the like. However, this produces new problems. It is thought that there are specific causes in team errors that will not be revealed by an exclusive emphasis upon the errors of individuals. This paper has sought to elucidate some of these factors." Hence, the authors have indicated that there is an obvious need for an effort to investigate the risks associated with the MT effort. The shift work or TR was addressed recently also by NASA Safety Center-System Failure Case Studies [3] in connection with the Piper Alpha disaster. The NASA report indicates that "lack of informal "between shift" talks compounded lax communication issues "a failure" that killed 167 workers in the world's deadliest offshore oil industry disaster". The consequences of this disaster were analyzed also by Reason [4] who distinguished between active and latent failure: "for active failure the negative outcome is almost immediate, but for latent failures the consequences of human actions or decisions can take a long time to be disclosed, sometimes many years." Reason J [5] proposed to concentrate, among other facets of accident causation, on the "latent conditions" as major "organizational factors, i.e. the consequences of top-level decision having a delay-action effect upon the integrity of various defensive layers". These conditions contribute to both the "local workplace factors" and to the "unsafe acts" to breach through the defences causing an accident. Reason emphasizes the importance of "what upstream organizational factors could have contributed to" the local condition" by adopting a measured balanced level for both active and organizational factors. One should focus, in his opinion, on hazardous path ways on site. This attitude is wider, in terms of safety actions, and considers the boundaries of the potentially active failures and the interactive activities with other teams in the MT formation. The techniques of identifying organizational factors that cause "latent conditions" contribute to both proactive and investigative actions of the risk management procedure. However, for the TR event it's neither effective nor practical in trying to avoid a "lurking" risk created previously in the wider boundaries of the active failure (e.g. of a failure in the previous team action) threatening to get materialized during the current shift work. Such an attitude provides insufficient attention for TR and its effect on safety. When it comes to the influence on RD time, which is the outcome of MT risk dormancy (MTRD), such an attitude is even more deficient. Mitropoulos et al. [6] call for a "future direction and research needs" and suggest to "developing effective team process for team within and between crews". Mitropoulos et al. [7] identified the taxonomy of accidents that considers the "unrecognized hazard" as "another type of accidents" that "involves situations where the worker is exposed to a "hidden" hazard." The hidden hazard can be a component near its functional limit (such as, e.g., an unsecured deck) or a normal behaviour (such as, e.g., walking on the deck) that might release the hazard. The hidden hazard could be created by an error made by a previous crew. This situation has to do with some issues addressed in the present paper, with an emphasis on the solution for the critical event of TR. An innovative approach to the analysis of the occupational safety was recently suggested based on a holistic perception of MT interactions. The approach is aimed at the means to avoid mistakable actions, which could lead to dormant risks. Farag [1] The term "RD" is identified as "the time delay between the occurrences of a failure (hazard event) in the action of one team (team A) that affects another team (team B) involved in the process" (Figure 1). The authors analyzed the time aspects of RD in MT work and proposed a model for risk evaluation and management based on the assessment of time-dependent probability (TDP) [8].

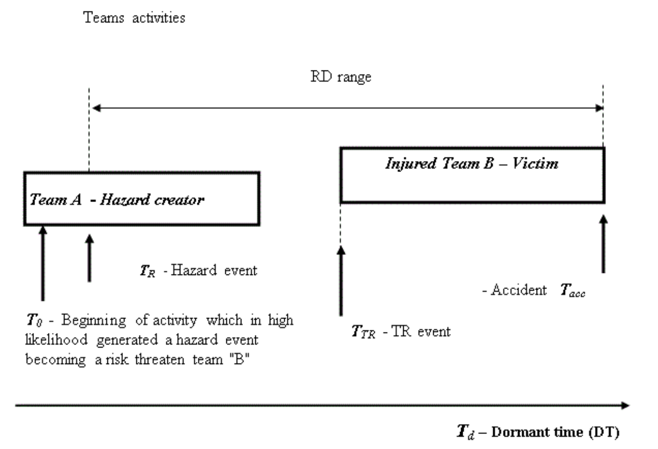

Figure 1: TR event in MTRD pathway.

MT includes various aspects of the processes of teamwork interaction, such as different professions and expertise of the teams on site, with consideration of the periods of time to perform the job. To successfully fulfil a task, teams need to be replaced by shift work system in order to avoid repetition of what they do by other teams. When a team reaches the work site and "assumes command", its first task is to get prepared for the job: assign qualified personal, choose the right tool (s), receive training, get instructions, etc. All these activities are critical to safety. TR event is certainly a crucial safety factor: teams are required to conduct in advance various safety actions, such as, e.g., hazard identification, evaluation and control for all the job stages to insure safe performance. TR risk evaluation applies to all the potentially hazardous situations that might threaten the team members. Such situations include dormant risks generated by previous teams that have been active on site. The RD range is the time interval between hazard creations up to MTRD accident. This time span should contain at least one event of TR. Obviously; any injured by-MTRD-accident team starts either at "workday" beginning or at TR (Figure 1).

The major concern of this study is the effect of the TR event on RD, in a situation, when this team is involved in a MTRD accident. While the teams involved in MTRD accidents have been identified earlier, the TR event occurrence time still needs to be determined. Therefore, an appropriate classification scheme for team's appearance according to their sequence in the RD range is suggested to assist in determining TR types. The MTRD accidents of public utility (PU) are sorted out utilizing the following MT classification criterion. Let us examine the classification of MT formation with regard to TR events followed by several particular and typical examples highlighting their characteristics to understand better the significance of the classification scheme.

MT Classification

Nowadays work is characterized by numerous teams acting on site, i.e., by the MT effort to accomplish the job. These teams are assigned to execute the work in different attendance and in different succession. Although the term "MT" refers to all teams working on site, it should be noted that MT's have different characteristics affected by the particular team duties that contribute to the dormant risk. When it comes to the evaluation of the influence of TR event on the RD, greater attention should be drawn to the characteristic of teams regarding their roles in the MT. Our analysis is intended to assist in the determination of the time of the occurrence of a TR event. This consideration leads to the following classification of the team appearance on site. Three different categories were detected (Figure 2).

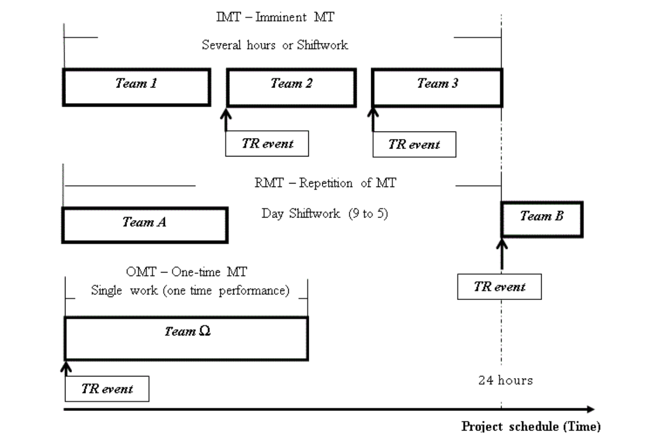

Figure 2: Multi-team (MT) classification.

First, Imminent MT (IMT): Team's work in succession of several hours or in a 24 hours cycle shift-work. IMT is characterized by a task that depends on the same mission with no ability to switch between teams. For example, first of the utility lineman teams performs electrical disconnection, followed by a second team that repairs the electrical component(s).

Second, Repetition of MT (RMT): Teams works in a shift-work schedule at a longer than 24 hours' time span (such as 9- to-5 shift-work schedule), i.e., carries out work that needs more than one shift to accomplish the given job or a particular stage of a permanently repeated work.

Third, One-time MT (OMT): Team's work carried out just once in the project or during a long period of time between certain tasks. For example, teams performing tests, such as grounding test or taking samples during concrete casting, or installation of roller shutter in inner rooms or in factory halls.

Example: An aerial work platform (AWP) is widely used in public utility (PU) in Israel for maintenance and construction of all types of power plants and overhead lines. At a power plant construction site a 70 m long AWP telescopic hydraulic arm is used to provide temporary access for installation of panels to provide closure of air intake filter in a gas turbine. AWP stabilization stage is carried out using four hydraulic stabilizers. One of them was mounted on rubble, which covers the main transformer oil concrete area, assuming that it is a rigid gravel surface. The rubble could not carry the stabilizer pressure, which fell down into the arrest openings. Damage was caused to the

AWP, and the workers who operated it were injured. Two weeks earlier the team that performed the rubble spreading over the arrest openings marked this place with a warning tape, but failed to inform the project manager regarding its instability. An unstable ground risk was neither estimated nor identified, so that MTRD stayed dormant for two weeks. However, the team used the AWP when they started their job at the TR event and was able to identify the risk by conducting job safety analysis (JSA)-risk evaluation procedure. As a result, they could increase the likelihood of correctly identifying this risk by placing a warning tape or by receiving this information from the project manager on site. This example illustrates the importance of managing RD in MT by using TR event as a critical point regarding controlling those risks. This example illustrates the significance of a TR event for safety at a point in time when work slows down, or stops completely for a while, for risk evaluation.

Scope

The reported accidents data of five operational Israel Public Utility (PU) divisions compiled by its safety department during 2004-2011 show as much as 9% of all accidents are of MTRD character showing significance of this type of accidents shown in Table 1.

Division	North District	South District	Logistic	Generation	Construction
MTRD Accidents	5.40%	8.60%	11.90%	8.78%	9.85%

Table 1: RD accidents in MT work.

The RD time span between hazard event created by Team A and accident occurred to Team B is necessarily divided by TR event. Therefore, it's important to analyze the statistics of TR event in this span.

Farag [1], *MTRD: "Teams often operate independently, with no explicit functional linkage between them. In other cases, more or less close professional collaboration is required to perform a particular task. For example, repair work in an electrical utility typically requires involvement of several teams. One team of electricians disconnects the power, another team repairs the damage, and a third team is deployed outside the secluded site, often on a standby basis, to assist, if necessary, the workers inside the worksite. In this example three different teams perform various aspects of the work aimed at a particular mutual goal. A mistake, error or a failure in one team's actions affects other teams involved in sequential large-scale activity, and has a potential to create a hazard. The hazard might remain dormant for some time, but eventually can become or generate a risk. This risk might have an immediate impact on the team member who caused it, and/or threaten another team continuing the job at the given site. This scenario can be identified as risk dormancy (RD). When occurring in a multi-team situation, it becomes multi-team risks dormancy (MTRD)" see also Figure 1.

Analysis

This analysis is aimed to provide a statistical assistance to safety manager to pay attention for the following stages around TR event: (a) increased probability of hazard creation and (b) zoon of increased likelihood of MTRD accident.

TR effect analysis

TR in RD range: The TR event that appears at the RD range between creations of a hazard event by Team A to its realization is crucial for Team B regarding the required treatment. The reason is that a certain MTRD accident might lead to an injury. An analysis of the RD path with respect to TR event reveals the following stages leading to an accident refer Figure 1:

T_0 -Beginning of activity which in high likelihood generated a hazard event becoming a risk threaten team "B".

T_R-Hazard event

T_{d}-Continues dormant time

T_{TR}-TR moment

T_{acc}-RD time at accident

Here the DT-T_d, eq (1), is a random variable extending between the beginning of Team an activity T_0, which could possibly generate a hazard event T_R, and the accident RD time at accident-T_{acc}. Thus, the entire RD range can be expressed by DT-T_d. This analysis addresses the effect of TR event on RD and proposes an effective model for the TR distribution, treating TR as a random variable. In this context, classification criteria for RD are related to risks generated by MT activities.

Probabilistic analysis of TR effect

TR event distribution: Two intervals of DT extend along the RD range until an accident takes place. Firstly, the DT interval extends from a hazard event creation until TR event-T_{TR}. In the following analysis it is limited to $T_0 < T_d \leq T_{TR}$. Secondly, the DT interval extends from TR event until the accident-T_{acc}. In the following analysis it is limited to $T_{TR} < T_d \leq T_{acc}$. Start and end times T_0 and T_{acc} of the RD range are known in advance [1]. Accordingly, the team affected by the accident and the accident time, as well as the team that generated the risk (risk-causing team) and the time of an activity, when the risk was actually generated, are determined. Moreover, once the MT work sequences of events are established including the affected team, the time when these teams start working can be determined (Figure 2). One can therefore calculate the occurrences of TR events that occur within the RD range between T_0 and T_{acc}.

Example: Linemen team from North District start working at TR 10 AM, average DT-dormancy time is 4 hours. The first interval of increased hazard creation by team of electricians whom disconnect the power is around 07:30 AM while the second interval of increased accident probability is around noon (12:00).

Considering MT layout of an organization or a project, multiple TR events will take place in a continuous DT (Figure 3 and 4)

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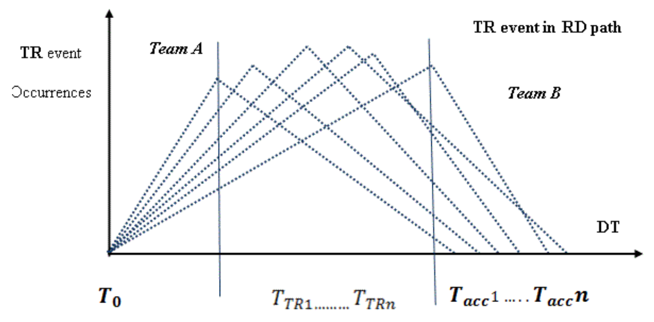

Figure 3: Distribution models for single TR events.

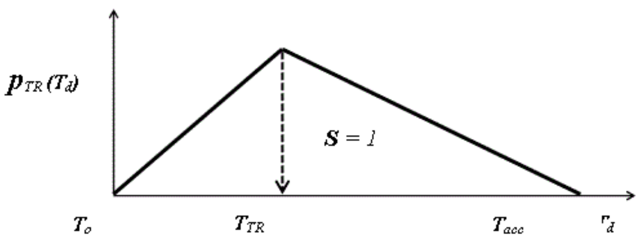

Figure 4: TR event pdf over RD range.

TR event distribution over RD range: Once the TR event nature has been determined (in accordance with the previously conducted analysis), a probabilistic model can be developed by taking into account the TR moment of time-TTR that is expressed by the continuous random variable DT-T_d. We suggest a triangular distribution with maximum at an actual TR moment as a proper model for this pdf-pTR(Td) as shown in eq. (2).

$$pTR(Td) = 2Td/TaccTTR \quad 0 < Td \leq TTR + 2$$
$$/Tacc\ [(Tacc - Td)/(Tacc - TTR)] \quad TTR < Td < Tacc \rightarrow (2)$$

Here:

pTR (Td) is the probability density function (pdf) of the random TR event

T_d-Dormant time

T_{TR}-TR moment

T_{acc}-RD time at accident

The pdf function as shown in eq. (2) is for a single TR event. However, to create an experimental function for a plurality of TR events and to adequately fit all data, a Procrustes' procedure is applied for relative DT as a continues variable - τ:

$$fexp(\tau, Tacc, TTR) = 2(\tau Tacc/TTR)\ \tau \leq TTR/Tacc \quad \text{Here } \tau$$
$$+ (1-\tau)/(1 - TTR/Tacc) \quad TTR/Tacc < \tau < 1 \quad \rightarrow (3)$$

= Td / Tacc is the relative dormant time

To represent maximal sample statistical data for TR an averaging procedure over all available events could be used:

$$\bar{f}exp\ (\tau, Tacc, TTR) = \sum i = o,n\ fexp[\tau, Tacc, TTR]i\ /n \rightarrow (4)$$

Results

Results of five cases (five divisions of the PU) where fitted using Beta distribution:

$$f(\tau, \alpha, \beta) = \Gamma(\alpha + \beta)\ /\ \Gamma(\alpha)\Gamma(\beta)\ \tau\alpha - 1\ (1 - \tau)\beta - 1 \rightarrow (5)$$

The fitted parameters for the five public utility (PU) divisions are shown in Table 2.

Division/Parameter	α	β
North District	1.78	2.37
South District	1.83	2.34
Logistics	1.95	2.1
Generation	1.93	1.93
Construction	1.86	2.325

Table 2: Fitted distributions parameters.

The data are well described by Beta distribution and the computed data are shown in Figures 5-9.

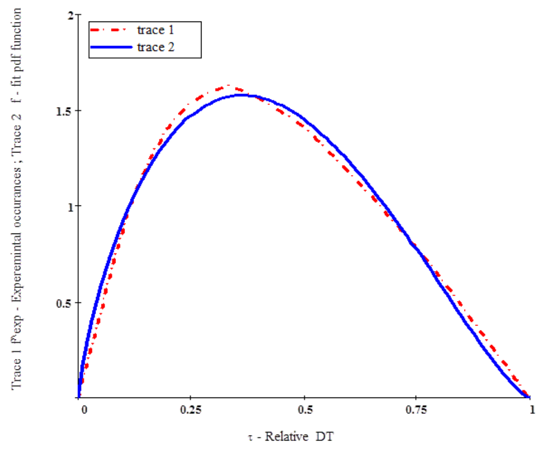

Figure 5: Pdf of North division.

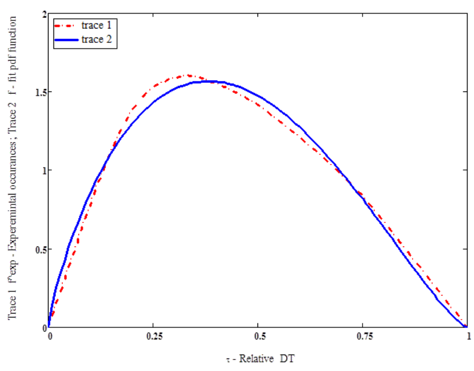

Figure 6: Pdf of North division.

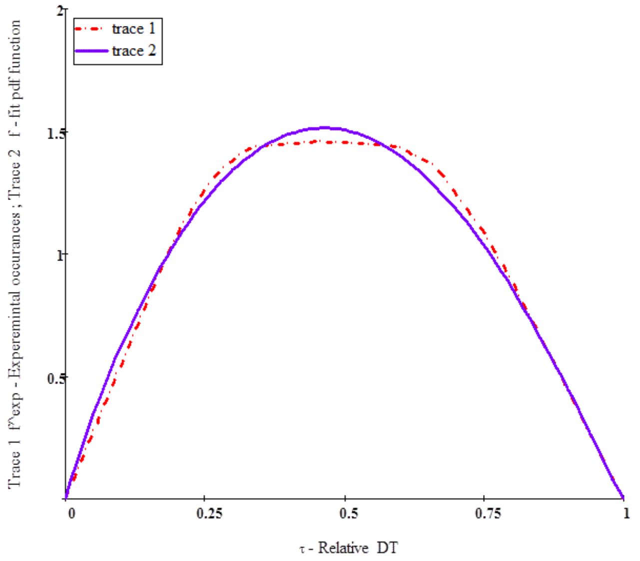

Figure 7: Pdf of logistic division.

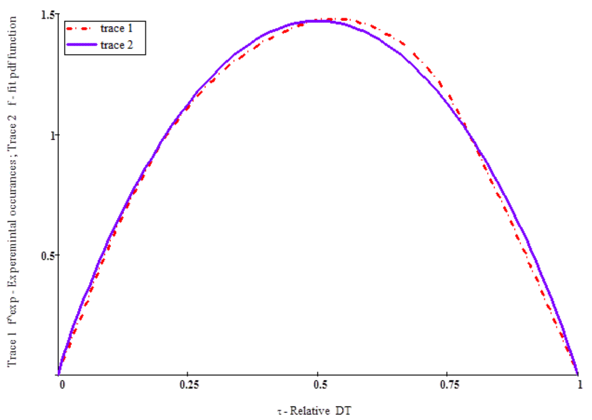

Figure 8: Pdf of generation division.

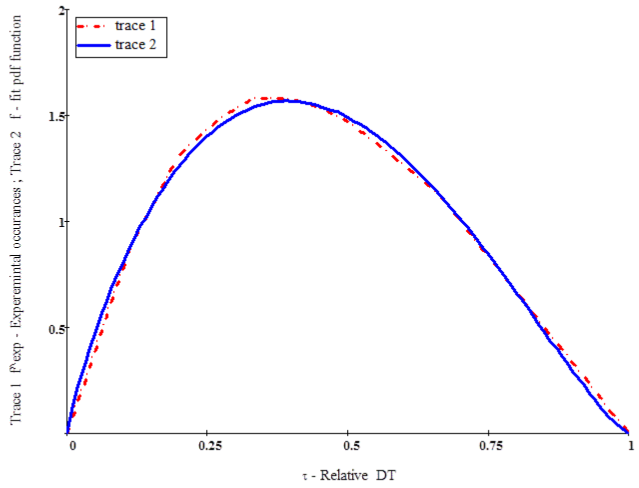

Figure 9: Pdf of construction division.

Discussion

Modern industrial projects are based on involvement of teams. More teams mean more TR events. These events cause slowing down the work and even sometimes stopping it as part of early new team preparation and the risk evaluation at the work site. Therefore, TR is an event that should be considered critical. It is a sort of an "Achilles' heel" of safety compliance. The following considerations seem to be crucial.

MT work emphasizes the roles of the team, which created the risk, and the affected (injured) team after TR. Once a potentially hazardous event is created and identified, the likelihood that it will actually occur within the RD range, the TR should be addressed and their likelihood is quantified.

TR events are interfaces between the working teams and have a key effect on the risk and the likelihood of its successful and trustworthy evaluation. It is important that the TR events are quantified as critical safety factors. In the RD range at least one TR event occurs between a hazard event created by one team and accident that harmed another.

The TR event that takes place within the DT range is described in our analysis using triangular pdf. Note that Johnson [9] indicated that the TR event over RD interval is limited by two points-T_0 and T_{acc}. Normalization of the dormant time range is done in our study by using Procrustes procedure and setting a new scale spread between 0 to 1 instead of T_0 to T_{acc} one [10].

Once a model for the single TR event is determined, averaging was conducted over all events. This continuous distribution can be fitted with beta distribution.

Conclusion

The following are the main finding of this paper: firstly, in the modern MT work over the RD range, a TR event represents a potentially risky point to safety. Secondly, The analysis of the fitted beta distribution reveals that pdf maximum (mode, most likely value) appears at the time T_{TR}, where TR event located at approximately 40% of DT dividing the DT in proportion of 2:3.

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