A Critical Review of Emergency Simulation Models of Industrial Fire-safety Psychology

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➢ Abstract

Game theory has become an essential tool in the analysis of industrial fire-safety psychology with multiple agents, often with conflicting objectives. This paper surveys the applications of game theory to industrial fire-safety psychological analysis and outlines game-theoretic concepts that have potential for future application. This paper discusses the non-cooperative game theory in static settings. Careful attention was given to techniques for demonstrating the existence and uniqueness of equilibrium in non-cooperative games.

➢ Keywords:

Game theory, non-cooperative, equilibrium concepts, psychology fire-safety

➢ Introduction

Game theory is a powerful tool for analyzing situations in which the decisions of multiple agents affect each agent's payoff. As such, Game theory deals with interactive optimization problems. Games are attached with real life phenomena which are not only zero sum games but also cooperative games and non-cooperative games, in which human behavior is essential part of the study with respect to the obtained payoff from the game. The inclination of study of cooperative games and non-cooperative games are quite different and it gives us mathematical formal way to think and workout over the games which generate quite good results. In the last sixty to seventy years, wide study in the field of game theory has appeared many areas to study. Game theory as a tool is used to develop the other areas like- social sciences, computer, anthropology, anatomy, and biology etc. In decision making, game theory works as a modern applied mathematical tool to understand and resolve the problem, in which players may have cooperative/non-cooperative behaviors. While many economists in the past few centuries have worked on what can be considered game-theoretic models, John von Neumann and Oskar Morgenstern are formally credited as the fathers of modern game theory. Their classic book "Theory of Games and Economic Behavior", von Neumann and Morgenstern [19], summarizes the basic concepts existing at that time. Game theory has since enjoyed an explosion of developments, including the concept of equilibrium by Nash [13], games with imperfect information by Kuhn [10], cooperative games by Aumann [1] and Shubik [16] and auctions by Vickrey [18], to name just a few. Citing Shubik [17], "In the 50s ... game theory was looked upon as a curiosum not to be taken seriously by any behavioral scientist. By the late 1980s, game theory in the new industrial organization has taken over ...game theory has proved its success in many disciplines." Dhingra et al [5] have studied on the utility and applicability of cooperative game theory in an engineering design process which is examined. It is shown how game theory may be used as a tool for solving multiple objective optimization (MOO) problems. Campbell Donald [4] suggested for social choice rules with voters, a lower bound on the number of profiles at which an arbitrary pair of alternatives must be socially indifferent. Gorkem Celik [8] studies an adverse selection problem, where an agent is able to understate his productivity, but not allowed to overstate it. Al-Mutairi et al. [3] study the well-known game of Prisoner's Dilemma, which reflects a basic situation in which one must decide whether or not to cooperate with a competitor, is systematically solved using a fuzzy approach to modeling trust. Prakash Chandra et al. [12] in his research studied "fuzzy payoff of cooperative repeated prisoner dilemma" that the prisoner dilemma game is taken into observation when two players or three players play the game with fuzzy coalition to get the maximum payoff at alfa-level to achieve in repeated play to have an equal share of the output, no player wants to lose his or her payoff due to less degree of membership in the coalition. Many of the useful theoretical tools are spread over dozens of papers and books, buried among other tools that are not as useful in fire-safety Psychology. From the previous literatures, it was observed by the author that no Game theory analysis has been established in industrial fire-safety psychology. In fire-safety psychology studies why employee commits accidents, under what circumstances and what are other contributing facts affecting their behavior or make them accident prone and how such behavior can be corrected to rectify their unsafe actions to achieve the goal of overall fire-safety & occupation health which includes the techniques of accident prevention.

1. Non-cooperative games theory

Non-cooperative game theory is a way of modeling and analyzing situations in which each player's optimal decisions depend on his beliefs or expectations about the play of his opponents. The distinguishing aspect of the theory is its insistence that players should not hold arbitrary beliefs about the play of their opponents. Instead, each player should try to predict his opponents' play, using his knowledge of the rules of the game and the assumption that his opponents are themselves rational, and are thus trying to make their own predictions and to maximize their own payoffs. Game-theoretic methodology has caused deep and wide-reaching changes in the way that practitioners think about key issues in oligopoly theory, much as the idea of rational expectations has revolutionized the study of macroeconomics. This paper tries to provide an overview of those aspects of the theory which are most commonly used by industrial fire-safety experts.

Non-cooperative game theory models situations in which individuals make decisions unilaterally without consulting other intervening parties. According to Riggs et al., the subject of game theory is situations where "a competitive environment presupposes intelligent opponents capable of exerting influence over our outcomes through their choice of action, while concurrently we choose a course of action that maximizes our returns with respect to the opponents' anticipated activities." Much of the conceptual framework draws on work by mathematicians Von Newman and Nash in the 1940`s and early 1950`s. On one hand, this model demonstrates that effective individual strategies or behaviors do not necessarily create a situation that is best for all. On the other hand, given certain conditions, it confirms that cooperation can exist without formal agreement among the intervening parties. Game theory has been used to understand and organize both human and animal activity. As a decision theory, it helps to explain possible strategic behaviors of individuals without defining the final tactics. Many textbooks cover the topic and its application in varying fields.

2. Basic definitions and assumptions

In this paper, we use the extensive form to represent the finite game as

$$\Gamma = \left\langle \kappa, \mathrm{H}, [(\mathrm{H}_i)_{i \in \mathrm{I}}], \{A(H)_{H \in \mathrm{H}}\}, a, \rho, u \right\rangle \quad (1)$$

where

$\kappa = \left\langle V, v^0, T, p \right\rangle$ is a finite tree with a set of nodes V, a unique initial node $v^0 \in V$, a set of terminal nodes $T \subset V$ (let $D = V / T$ be a set of decision nodes) and an immediate predecessor function $p : V \rightarrow D$ on which the rules of the game are represented, H is the partition of D called an information partition, $A(H)$ is a set of actions available for each information set $H \in \mathrm{H}$ which forms a partition on the set of all actions A, $a : V \setminus \{v^0\} \rightarrow \mathrm{A}$ is an action partition corresponding each node v to a single action $a(v)$, fulfilling: $\forall\ H \in \mathrm{H}, \forall\ v \in H$, restriction $a_v : s(v) \rightarrow \mathrm{A}(H)$ of a on $s(v)$ is a bijection, with $s(v)$ the set of successor nodes of v, $\mathrm{I} = \{1,2,\ldots I\}$ is a finite set of players, 0 is (a special player called) nature, and $(\mathrm{H}_i)_{i \in \mathrm{I} \cup \{0\}}$ is a player partition of information set H. Let $\iota(v) = \iota(H)$ be a single player that makes a move at node $v \in H$, $\rho = \{\rho_H : A(H) \rightarrow [0,1] \mid H \in \mathrm{H}_0\}$ is a family of probabilities of the actions of nature, and $u = (u_i)_{i \in \mathrm{I}} : T \rightarrow \Re^{\mathrm{I}}$ is a payoff profile function.

3. Game setup

Field of fire-safety psychology is applicable to both employer and employee. Accidents are the results of faults of employer and employee. The main responsibility to provide and maintain safe working conditions, safe environment and protective equipments lies upon the employer, however, the practical field of effort for prevention through psychology and use of protective equipments, is applied largely to the employees. The employees being more in number render more chances of human faults. Therefore it is their great, individual and group or collective responsibility to minimize their human faults to prevent accidents and to maintain fire-safety. Present psychological fire-safety problems can be divided in two parts: Employer's problems and Employee's problems. Ultimately they create problems to themselves in terms of health, for society and nation also. Employer's and employee's seek to achieve their respective goals by choosing preferred actions based on inferences about steps that will be taken by the other party. Expectations concerning such actions are based on these hypotheses:

- Each employer's and employee's understand psychological factors affecting human behavior or influencing action and also possesses information on the rules and conditions of the industrial psychology;
- Each employer's and employee's are rational;

- Each employer's and employee's seeks to maximize the anticipated value of their own payoffs, that can be described by an utility function;
- Each employer's and employee's are intelligent.

Since Milgrom et al. [11] have shown that theories based on perfect rationality and adaptability are successful in generating predictions about organizations and their practices, the rationality hypothesis is appropriate, even essential, to the analysis of technical situations. However, the assumption that all individuals are perfectly rational and intelligent may never be satisfied in any real-life situations as claimed by Myerson [9]. Conversely, a prevention program based on irrational behaviors will lead most likely to an ineffective situation.

In this problem, employer's and employee's motivations as well as the variables modulating their choice of actions are well known. Employer's allocates resources in fire-safety psychology as a part of industrial psychology owing to legal obligation, as the result of an economic decision or awareness of problems. Main factors affecting work performance or influencing actions of people are broadly divided as (1) Environmental factors and (2) Human factors. The human factors are due to two aspects (1) Physiological and (2) Psychological. The analysis presented here investigates how psychological factors foster cooperation between employers and employees by using non-cooperative game theory resulting with a compounded effect on industrial fire-safety and occupational health in an organization.

The Psychological factors are Attitude, Aptitude, Frustration, Morale, Motivation, Individual differences etc. Industrial accidents are either due to unsafe conditions (situation or environmental factors) which include mechanical causes (unguarded machinery, defective equipment, dangerous situation etc.), chemical causes (toxic exposure, dust, fume, fire, explosion and variety of ill-effects due to hazardous nature of chemicals, their storage, processes and equipment), and physical causes (physical workload, working hours, heat, light, noise, vibration and working conditions) physiological causes (Age, sex, body-build, posture, physical fitness, health, physical fatigue, nervous strain, sickness etc.) or due to unsafe actions which include psychological causes (motivation, skill, training, carelessness, recklessness, habit, worry, emotional upsets, irresponsibility, poor attitudes etc.). Employees must understand psychological factors affecting fire-safety of them and will be engaged in industrial fire-safety with their personal objectives and their perception of the risks present in their environment. Not to be overlooked, however, are asymmetries of information concerning the occupational health of employees and the risk taking decisions made by social allies. The model must also deal with diagnostic uncertainties, the difficulty in assessing risks present in the workplace and determining what level of risk is tolerable due to the presence of this psychological factors. Employer's and employee's cannot know with preciseness and certainty the value each other has assigned to the different variables modulating their choice of actions, nor the commitment the other makes to Industrial fire-safety. In game theory, this type of interaction can be modeled by games with incomplete and imperfect information. In this paper, we use a game with perfect information (the players know the history of the decisions taken in the past). It is a reasonable hypothesis so long as the tactical factors are not broached. Pervasive asymmetries surrounding information relative to the effort directed at Industrial Fire-safety justify use of a simultaneous, rather than a Bayesian, game.

To break the ground for this section, we introduce basic game theory notation. See texts like Friedman [6] and Fudenberg et al. [7] if more precision is required. Throughout this paper we represent games in the normal form and it consists of (1) each players indexed by $i = 1, 2, \ldots n$, possesses information on the rules, unsafe acts and unsafe conditions, and $N = \{1, 2, \ldots n\}$ is the set of players (2) strategies or more generally a set of strategies denoted by $x_i,\ i = 1, 2, \ldots n$ available to each player and (3) payoffs $\pi_i,\ i = 1, 2, \ldots n$ received by each player. Therefore,

$$\Gamma = \left\langle N, (x_i)_{i \in N}, (\pi_i)_{i \in N} \right\rangle \quad (2)$$

A strategy profile is a combination of strategies that the players might choose

$$x = X_{i \in N}\ x_i \quad (3)$$

In our problem,

N = {1, 2} = {employers, employees}

$x_1 = x_2 =$ {enhance efforts in psychology factors,
sustain efforts in fire-safety psychology as is}

Four outcomes are possible:

$x =$ {(enhance, enhance), (enhance, sustain),
(sustain, sustain), (sustain, enhance)}

Employers' expectation or fear from the employees not only in the way of production targets, but, in the form of attitudes, loyalties and co-operative efforts, is as important to the psychologist as the employers want to know about the resources, desires, motivation and capacities of their employees. Employees' expectation from the employer not only in the form of pay, but in the form of security, opportunity for advancement and protection, is as important to the psychologist as what they want for themselves in the form of self-expression, recognition and acceptable working conditions and environment. The psychological factors (a part of human factors) affecting human behaviour or influencing actions of people for work performance are many. The human attitudes and aptitudes, frustration and conflict, morale, individual differences, acclimatization, skill and training, need and job satisfaction, motivation and aspiration, participation, incentives and job evaluation, fatigue, boredom and monotony, accident proneness, group dynamics, labour policy and turnover, personal selection and classification, problem worker etc. are the main psychological or personal factors affecting human behaviour. The efforts to enhance industrial fire-safety psychology can be considered laborious, costly and not necessarily maximizing the individual utility payoff. There may be situations in which any small private effort in improving industrial fire-safety psychology yields immediate and tremendous returns. But the optimization of efficiency of industrial fire-safety measures depends on the synergy of actions taken by the social allies. Consequently:

- If employees and employers both improve their efforts in enhancing psychology factors, their expected individual utility payoff will incur lower cost.
- If both maintain their efforts in enhancing psychology factors, expected individual utility payoff will prove costly.
- If employees or employers improve its efforts in enhancing psychology factors, which is a very costly individual decision, the other will benefit from these efforts. More precisely, if psychology factors enhancing program goes off-course, or if employees claim it is ineffective, employees may benefit from these efforts but they are very costly to employer. If employees' efforts go unrecognized or are not sustained by the firm, however, the individual payoff is costly to employees while employers benefit (through lower their insurance costs, for example). The following utilities emerge:

π_1 (enhance, enhance) = π_2 (enhance, enhance) = less costly situation
π_1 (enhance, sustain) = π_2 (sustain, enhance) = very costly situation
π_1 (sustain, enhance) = π_2 (enhance, sustain) = beneficial situation
π_1 (sustain, sustain) = π_2 (sustain, sustain) = costly situation

This game may be represented in a tabular form, as represented in Table

		EMPLOYERS	
		Enhance	Sustain
EMPLOYEES	Enhance	less costly, less costly	very costly, benefic
	Sustain	benefic., very costly	costly, costly

Table 1: Game in Tabular Form

Discussion: Equilibrium of the Game

We need to determine where the game leads for both employees and employers in terms of the possible outcomes. In this game, we can identify Nash equilibrium, precisely:

$$\pi^i(x^{*i}, x^{*-i}) \geq \pi^i(x^i, x^{-*i}), \forall x_i \in X_i \tag{4}$$

This strategy seeks to maintain without change efforts in psychology fire-safety. We can also identify a Pareto efficiency equilibrium (the outcome of a game is Pareto efficient if the outcome of a player cannot be improved without diminishing the outcome of others): result $\hat{x}$ dominates the result x if:

$$\pi^i(\hat{x}) \geq \pi^i(x), \forall i \text{ and}$$
$$\exists\, j, \pi^j(\hat{x}) \geq \pi^i(x) \tag{5}$$

The industrial fire-safety psychology game is similar to the Prisoners' Dilemma. The equilibriums found provide a clear indication of how the intervening employees or employers will interact in the real world. In this game, rationally, the stakeholders ought to maintain the status quo in terms of efforts in industrial fire-safety (Nash equilibrium[13]). They ought to avoid the moderate decision, in terms of expected individual payoff, which is to improve efforts in industrial fire-safety (Pareto efficiency equilibrium). Therefore, the rational individual strategies will lead to an outcome that is bad for all stakeholders of company. In this type of problem, we can command effective and efficient co-operation between employees and employers so long as the time span of the game is unknown. This has been demonstrated using genetic algorithms by Axelrod [2] and others.

Analysis of interactions among employees and employers in industrial fire-safety, using game theory, brings us to conclude that if cooperation can be established, it has good chances for survival. There are two important factors in establishing such cooperation [15]:

1. Acting on the costs and benefits of initiatives in industrial fire-safety. Wilde, in his homeostasis theory, points us in this direction:
   - One should reduce the benefits of taking industrial fire-safety risks, which may be done by the use of appropriate legislation or intra-firm politics;
   - One should reduce the cost of making efforts to improve industrial fire-safety, which may be done by modifying the insurance fees or by promoting the use of industrial fire-safety groups;
   - One should increase the benefits making efforts to improve industrial fire-safety, which is the object of different incentive measures and may be done by the use of appropriate training programs and certifications;
   - One should increase the cost of taking risks in industrial fire-safety, which is currently done by legislation.
2. Changing the rules and conditions of interactions by establishing implicit and explicit contracts in industrial fire-safety prevention. In Nadeau [14], It was proposed that an ergonomics intervention approach leading to the establishment of common and objective information on the fire-safety and health. Making explicit contracts and accepting this information binds the social partners and limits the strategic behaviors, increasing the probability of success of the intervention in industrial fire-safety. This implicit contract is one of the conditions under which co-operation will take place without any legal intervention in either the infinite or the indefinite versions of the game.

Our analysis indicates that a range of measures may be employed to encourage and facilitate co-operation which might not occur in their absence.

➢ Conclusion

In this study, we have demonstrated that incompatibility exists in the aims and strategies of the employers and employee with respect to different psychology factors. This situation can prove inefficient or unproductive for all. Management of industrial fire-safety needs to consider the strategic behaviors practiced by intervening employee to introduce measures that are effective as well as efficient. Both implicit and explicit contracts must be constructed to address dominant behavior and to facilitate co-operation on industrial fire-safety issues.

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