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Short Communication

Short Communication: Can Game-theoretic Context Improve the Complex System Safety and Reliability Analysis Methods?[1]

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Keywords

Uncertainty,

Decision-making,

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System safety and reliability

Abstract

In this short communication work, we try to answer the following question if the existing system safety and reliability analysis methods such as fault tree analysis (FTA) are robust and powerful in complex system safety, why they cannot correctly handle the system safety when there are multi number of opposing interests as conflicts. Our simple answer is that the present cannot address such critical circumstances in system maintainability, availability, reliability, and even more resilience. That is what we need to develop probabilistic methods underlying the game-theoretic context. First, the game theory result is based on an optimization model; thus, there is no requirement to validate the model as we have the optimum outcomes. Second, game theory enables decision-makers in system safety to take into account any potential conflicts, either to be direct or indirect. We provide a simple FTA example and show how the new concept can be applied initially.

1. Introduction

One of the main ideas behind the system safety and reliability analysis is improving system safety over time [1–4]. The critical failures, components, basic events, etc., are identified. Then the corresponding intervention actions such as mitigative, preventive, and control actions are performed to be justified system safety to be an acceptable level or ALARP [5–8]. Such system safety and reliability methods are fault tree analysis (FTA) [9–13], event tree analysis (ETA) [14–16], failure modes and effect analysis (FMEA) [17–22], etc. However, there are many situations in the system safety and reliability analysis that

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decision-makers, assessors, safety experts, failure specialists, or relevant individuals to this field may have different and opposing interests. In this case, each decision-maker can decide unilaterally and the integrated decisions of other decision-makers to examine the possible outcomes of the conflicts. Instead of unilaterally moving forward, the decision-makers might cooperate to form a coalition, leading to a Pareto-optimal solution. For both circumstances mentioned above, the game theory can provide an exact and practical language for discussing and explaining the system safety and reliability analysis opposing interest among a group of decision-makers called players. In literature, game theory is defined as mathematical study cooperation and competition, and it highlights "how strategic interactions among players result in overall outcomes concerning the preference of those players. Any player might not have intended such outcomes" [23].

According to the Kaveh Madani [23-29] explanations: "Games are defined mathematical objects, consisting of a set of players, a set of strategies (options or moves) available to them, and specification of players' payoffs for each combination of such strategies (possible outcomes of the game). The payoffs to players determine the decisions made and the type of game being played. If the payoffs sum up to zero or a constant, the players have opposing interests and are playing a zero-sum game or a constant-sum game; whatever one player wins, the other player loses. Non-zero-sum games, in which the sum of payoffs does not equal zero or a constant, have more complications, and sometimes more potential for cooperation" [23,30].

Game theory helps decision-makers in system safety and reliability to have insights by estimating the players' behavior in the game, following their conflicts of interest. In fact, when there is a game among several players, each player tries to be much more intelligent than another by predicting their opponent's decisions. Therefore, the game would be solved due to players' decisions. The game theory is analyzing the players' strategies to maximize their payoffs. In this regard, a game solution suggests that decision-makers should decide the outcome of the games. Game theory was established in 1944 in a book titled "Theory of Games and Economic Behavior" [31], which mainly dealt with quantitative game theory methods. After that, most researchers and scientists have been developed the game theory quantitatively methods, and this trend persists up to this point (see Figure1). Table 1 provides the most cited publications since 2018.

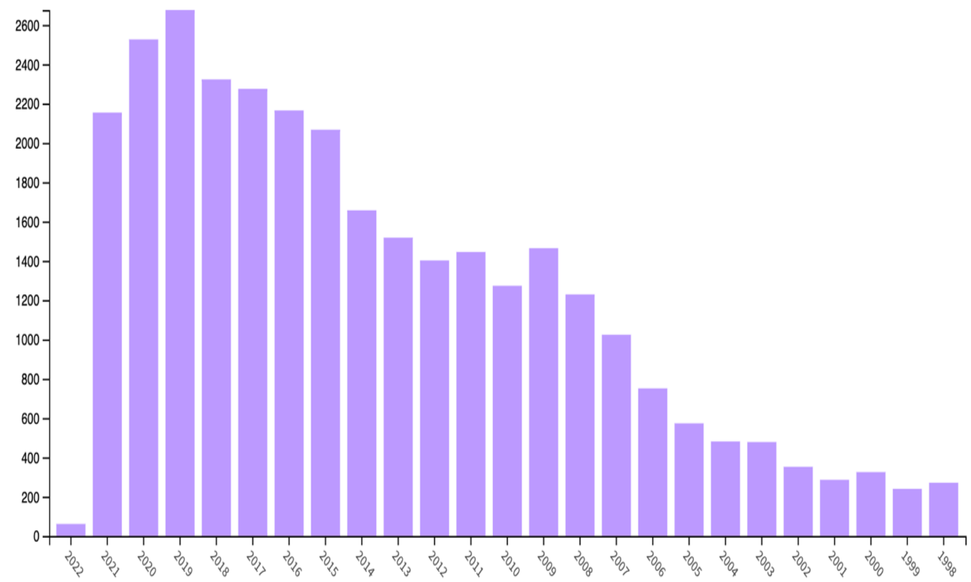

Figure 1. The number publications with keywords "game theory" since 1998) reference from web of science database, access 9th December 2021)

Table 1. The most cited papers since publications with keywords "game theory" among almost 10,000 documents (reference from web of science database, access 9th December 2021)

Row	Title	Total Citations	Average per Year
1	"Generative Adversarial Networks"	1113	556.5
2	"A Tutorial on UAVs for Wireless Networks: Applications, Challenges, and Open Problems" [32]	508	169.33
3	"From local explanations to global understanding with explainable AI for trees" [33]	369	184.5
4	"Peer-to-Peer energy trading in a Microgrid" [34]	274	68.5
5	"A Survey on Consensus Mechanisms and Mining Strategy Management in Blockchain Networks" [35]	201	67
6	"Imperfect Information Dynamic Stackelberg Game Based Resource Allocation Using Hidden Markov for Cloud Computing" [36]	197	49.25
7	"AC-POCA: Anti-coordination Game Based Partially Overlapping Channels Assignment in Combined UAV and D2D-Based Networks" [37]	192	48
8	"Bilateral Contract Networks for Peer-to-Peer Energy Trading" [38]	165	55
9	"Peer-to-Peer Energy Trading in a Prosumer-Based Community Microgrid: A Game-Theoretic Model" [39]	161	53.67
10	"Current research on Internet of Things (IoT) security: A survey" [40]	138	46
11	"Smart transactive energy framework in grid-connected multiple home microgrids under independent and coalition operations" [41]	138	34.5
12	"Energy Demand Side Management within micro-grid networks enhanced by blockchain" [42]	132	33
13	"On-Demand Service Platforms"	127	31.75
14	"Evidential Supplier Selection Based on DEMATEL and Game Theory" [43]	125	31.25
15	"Particle Swarm Optimization Based Solar PV Array Reconfiguration of the Maximum Power Extraction Under Partial Shading Conditions" [44]	124	31

In the next section, a simple example is illustrated to show how the concept of game theory can be applied in the system safety and reliability analysis.

2. Illustration of an Example

This section assumed a system safety and reliability analysis unreal example to show how game theory can be applied to such a problem. Let us assume that in a process-based industry, the system safety and reliability policy signed by higher management indicates that the system safety performance should be improved annually.

Based on the bathtub curve (number of failures), we also know that the system's reliability decreases as the failure probability increases over time (see Figure 2). Therefore, to keep the system reliable to an acceptable level, it is required to perform intervention actions [45-47].

In addition, there are four units, as electrical, mechanical, utility, and fire station, that should improve their performance, facilities, employees' education in a single year to satisfy process-based industry policy as system safety performance. The units are the players in the game, and conflicts of interest are that none of them can have the perfect performance to satisfy process-based industry policy due to budget limitations. In fact, each player was willing to ask for more budget, even it was much less than their needs. Therefore, here would be the points the players have opposing interests.

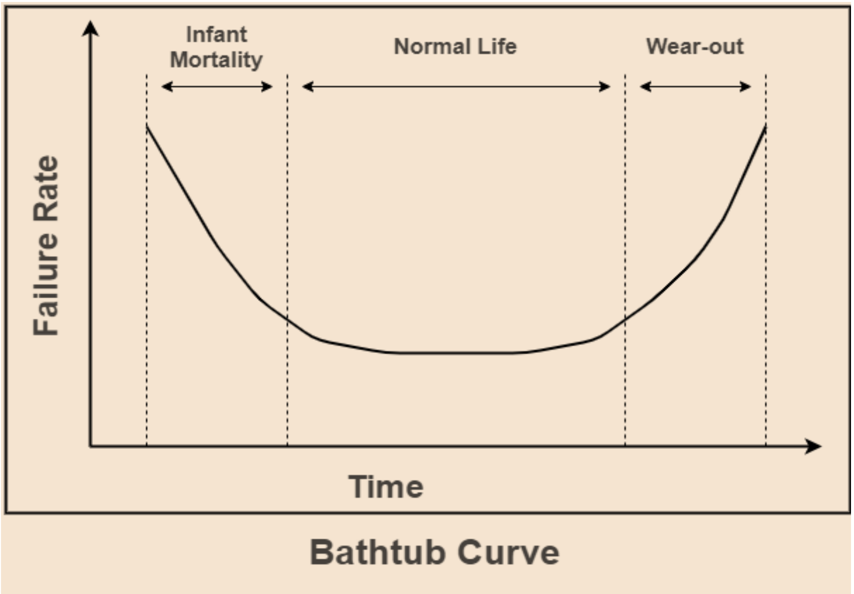

Figure 2. In the first period, the failure rate decreased in the bathtub curve. In the second period, the failure rate is constant; however, the system's reliability decreases. In the last period, the failure rate increased [2].

Let consider that the unit cost in the form of qualitative terms is the following: VL (1), L (2), M (3), H (4), and VH (5). Besides, the budget of the process-based industry is 12-unit cost. The aim of game theory here is optimally allocating the budget to the four units to satisfy process-based industry policy. To seek simplicity, it is considered that all units have almost the same contributions to the system's system safety performance, in which up to 25 %. Therefore, for allocation budget in unit cost, the system safety performance would be improved as VL (5%), L (10%), M (15), H (20%), and VH (25%). However, this performance varies for the four units.

```
sets

i unit number /1*4/
j cost index /1*5/
;

table
p(i,j) Cost per system safety performance efficiency program
          1    2   3    4    5
1         5    10  15   20   25
2         5    10  15   20   25
3         4    4   10   16   18
4         5    7   13   18   24
;
parameters

c(j) cost of costindex j /1 1,2 2,3 3,4 4,5 5/
;

binary variable x(i,j)  if unit i costs j for us;
free variable z;

equations

e1,e2,e3
;

e1..                 sum(i,sum(j,p(i,j)*x(i,j)))=e=z;
e2(i)..              sum(j,x(i,j))=e=1;
e3..                 sum(i,sum(j,c(j)*x(i,j)))=l=12;

        model
Production /all/;

         solve
production using MIP maximizing z;

         display
x.l , z.l ;

```

Figure 3. The mathematical programming code (using Gams Package for Mac, https://www.gams.com)

Table 2. The allocating budget and their system safety performance

Row	Unit 1	Unit 2	Unit 3	Unit 4
VL (1)	5	5	4	5
L (2)	10	10	4	7
M (3)	15	15	10	13
H (4)	20	20	16	18
VH (5)	25	25	16	24

To resolve this problem, it seems that it would be a simple optimization problem, as it is. However, the constructed game theory based on optimization provides insight to take into account the opposing interest of players and limitations that the system has. In the following, the mathematical programming is modeled [48,49], the feasible and optimum outcomes are presented, and the corresponding codes are depicted in Figure 3. The results show that the maximum system safety performance is 59% with Unit 1 (VH), Unit 2 (VH), Unit 3 (VL), and Unit 4 (VL).

3. Conclusion

We believe that the game theory has considerable potential to resolve the system safety and reliability analysis opposing interest between a group of players. The game theory-based problem is applicable in such problems due to the fact that it does not necessarily require objective information considering reliability data or subjective opinions in the conventional system, safety, and reliability analysis tools. In addition, game theory can provide a reasonable prediction of players' behavior in specific circumstances, in which rational behavior of players would be understood adequately with their objective maximization.

However, it is required that game theory be applied in different system safety and reliability problems by classifying the problem, as game theory cannot be practical and with more minor advantages when there are no conflicts of interest among the players. Therefore, the author decided to provide a better reflection of game theory in a book chapter that will be published in the book titled "Advanced decision-making methods and applications in system safety and reliability problems".

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Conflict of Interest Statement

The authors declare no conflict of interest.

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