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The Application of TRIZ for Human Safety in the Mina Jamarat Area During a Pilgrimage

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Abstract: Religious events are one of the most over-crowding places in the world that require a lot of processes to keep humans in the safety stage. Moreover, a massive number of accidents occur because of people stampeding. The records have shown several accidents during the Hajj, particularly at Jamarat Bridge in Mina. It is one of the most crowding places in Hajj, where pilgrims come together at a specific time to throw stones. Therefore, this research selects Jamarat as a case study. This study aims to apply a method to reduce crowding problems and improve the safety of humans at crowded events using one of the influential theories that can settle the overcrowding problems known as the TRIZ methodology. TRIZ was invented to solve engineering problems. The study tries to improve the situation related to the congestion at the bridge Mina and the way of pilgrims from Arafat, Muzdalifah and Mina. By using TRIZ, two scenarios apply, and several solutions are generated. After analysis, the principal moving to another dimension and colour changes was the best solution for the first scenario by developing multi-layered bridges to make the pilgrim's movement easier. Also, the colour-changeable signs will guide pilgrims to avoid crowded and improve safety.

Keywords: TRIZ; Human Safety; Hajj; Jamarat; Stampeding; Crowded Places.

1. Introduction

In recent days, it was observed to increase in disastrous accidents in crowded places such as sports events, religious festivals, etc. This is a study into the issues which distress risk and susceptibility relating to a large scale of public gatherings, especially the people in places of worship such as Jamarat bridge near Makkah, Saudi Arabia. This research attempts to find the causes of disasters in such areas using TRIZ theory. TRIZ is a problem-solving, analysis, and prediction toolkit derived from the study of the global patent literature. Genrich Altshuller (1926-1998) developed the "Teoriya Resheniya Izobreatatelskikh Zadatch" as a Russian word named (TRIZ) (Theory of Inventive Problem Solving) in 1950. Its basis is the study of patterns of invention in the global patent literature [1]. Triangle Altshuller

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established TRIZ (the theory of inventive problem solving) as a systematic and organized technique or toolkit that provides a logical strategy for increasing creativity for innovation and innovative problem-solving. TRIZ is a systematic process for solving creative problems based on knowledge. [2]. TRIZ's forty principles provide answers to current trade-offs between opposing criteria. Recently feasibility of using TRIZ in architecture, levels of innovation in architecture based on TRIZ theory, and modelling one accessibility problem have been discussed by authors. It's likewise proposed a novel way to deal with structural issue space surrounding utilizing the TRIZ-based contradiction approach [3].

When a study reveals that the leading cause of mass fatalities is preliminary design, insufficient information, or mismanagement, crowds are frequently blamed. This research aims to identify the crowd places problems and the possibility of applying TRIZ to solve them. The study seeks to revise a crowded place accident for human safety. The case examples have been taken up from Jamarat Bridge near Makkah, Saudi Arabia, to achieve this aim.

2. Literature Review

Money organizations, such as manufacturers, have numerous challenges in the present era, not just in terms of profitability but also in meeting other sustainability requirements such as safety and environmental stewardship [4]. Construction organizations are re-thinking and revising their tactics in response to an increase in safety-related mishaps. The study's main contribution is to explain the Lean TRIZ concept and assess the possibility of using it to solve safety issues. This is because of its complicated and dispersed character; the construction sector requires safer methods. It is possible to design errors and find solutions using the Lean concept. [5].

Depending on the nature of the Hajj and the international part of the event, the epidemic poses a serious threat to public health and global health security during the Hajj. Close contact between pilgrims in crowded places during ceremonies and unhealthy procedures, including travelling abroad, increases the risk of disease outbreaks and epidemics between pilgrims and other Hajj participants [6]. There is a high risk of respiratory diseases such as tuberculosis (TB), influenza, and, more recently, the Middle East Respiratory Syndrome Coronavirus (MERS-CoV) that spreads during the event (MERS-CoV) [7]. During the 1865 Hajj, a cholera outbreak killed nearly 30,000 pilgrims, and a series of global meningococcal disease outbreaks were linked to the Hajj [6].

The application of TRIZ for safety issues in chemical reactors has been discussed in a case study [8], in which 39 engineering parameters for formulating contradictions are condensed into six categories: process disturbance, design, mechanics, human operator, and natural hazard, and materials. The authors of [9] Russian researchers have reported the successful application of TRIZ in developing chemical or bio-chemical products and technologies. The United States became the "seeding ground" for TRIZ because it was easier for Russian TRIZ professionals to travel to the U.S. than in Europe or South Korea. In 2009, Latin American countries such as Brazil, Chile and Columbia began to show interest in TRIZ [10].

The TRIZ approach was used to create a novel way of simulating rainy weather conditions for vehicle lane support systems (LSS). The project's goal was to develop a portable, easy-to-set-up mechanical system capable of distributing a consistent volume of water to a moving vehicle. [11]. Theory and Innovative Problem Solving (TRIZ) is the most influential scientific strategy for creating creative items. The TRIZ approach, as well as creativity and innovation principles, were discussed in this paper. Combining the Six Sigma process and TRIZ is also being developed and has positive results in various industries [12].

TRIZ complies with this criterion more than anything other. However, the application of TRIZ in its traditional form is limited. As a result, we can see how TRIZ is evolving in a new direction, as evidenced by new and updated tools and the organization and structure of TRIT processes [10]. Ebrahim et al. [13] There are numerous debates about the impact of religion on health and society. How to

accommodate religious gatherings that are regarded necessary while adhering to COVID-19's physical separation rules tests public opinion, politics, and public health. The 2020 Hajj was guided by science, with far fewer pilgrims, allowing full compliance with mitigation methods and avoiding the event's cancellation.

The Theory of Inventive Problem Solving, sometimes known as TRIZ, provides tools and strategies for identifying and resolving trade-offs. The methodology was created to conduct a trade analysis of alternative pharmaceutical manufacturing systems. Four primary TRIZ-based tactics have an impact on the effectiveness of these projects. The DEMATEL technique calculates the significance weights of various strategies [14].

3. TRIZ Methodology Problem Solving

The normal problem-solving process is similar to the strategy used by TRIZ to solve problems. Moving from a specific problem to a specific solution is a common problem-solving strategy. However, this strategy may not work in some cases due to inconsistencies or conflicts that prohibit appropriate solutions from being developed. A specialized problem can be generalized into a TRIZ general problem, such as an engineering contradiction, a physical contradiction, a function model, or a substance-field model, as shown in **Figure 1**.

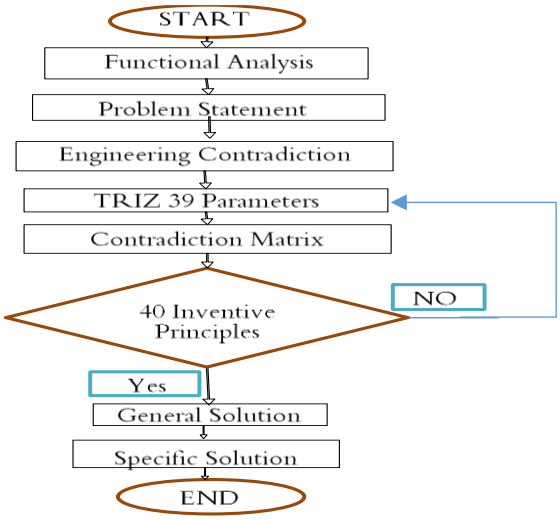

Figure 1: Flowchart of research methodology

TRIZ provides the instrument to resolve this general problem (or model of the problem) based on this general problem (or model of the problem) (e.g. Contradiction Matrix, System of Standard Inventive Solutions). The user must still determine the type of the specific solution required based on the suggested TRIZ general solution, such as 40 Inventive Principles. Because TRIZ is well established in dealing with physical, mechanical, and thermal related problems [15], information technology, building, and construction, we have found that it is instrumental in helping people who work on either technology development or manufacturing sustain in terms of generating innovative solutions.

3.1. Process of TRIZ

Altshuller provides four-step processes for TRIZ problem solutions based on the paradigms above. The first step is to describe the problems. The problem must be clearly defined and its scope analyzed. In this way, TRIZ provides a more comprehensive problem solution. The second step is to compare the general problem with the TRIZ problem. It allows an analyst to identify commonalities between the general problem and TRIZ problems. The third step is finding TRIZ solutions. These solutions can be applied to general problems based on their commonalities. The fourth step is to find an ideal solution

for the issue at hand [12]. It allows to explore various creative solutions and resolve the problem with flexibility.

Problem Definition Tools: These tools are specifically designed to facilitate a problem solver to define the issue appropriately. Once the problem is limited, it becomes relatively easy to identify its solution. Some of the tools used in TRIZ for problem definition include the following:

Solution Tools: The two primary solution tools that TRIZ offers include the Matrix and 40 Inventive Principles and Trends of Evolution. Now we will assess both the tools in the following sections.

3.2. Function analysis

Function analysis analyses the interactions between all of a system's components before looking for problems and solutions. A function analysis aids in the identification of difficult-to-identify difficulties in issues. The understanding of the benefits given by a system is inextricably linked to its functional analysis. This knowledge makes it easier to take appropriate problem-solving steps. Subject-Action-Objects (SaO) is a statement that describes a subject's action on an object. The SaO and other symbols used in function mapping are mapped in the below format (see **Figure 2**).

Figure 2: Function mapping symbols

3.3. Trends of Evolution

Each pattern allows a problem solver to leap from one technological solution to the next while minimizing contradictions, resulting in IFR. The trends are created to demonstrate evolution, and then the direction of development pushes the problem-solver to think about technology in terms of the trends. This method generates solutions to complicated problems [16].

3.4. TRIZ 39 Parameters

The Contradiction Matrix is a TRIZ tool used in conjunction with the 40 Principles to solve the challenges. The matrix comprises 39 properties that improve and deteriorate with time as shown in **Table 1.**

Table 1: 39 Engineering Parameters

1. Weight of moving object	2 .Weight of nonmoving object	3. Length of moving object
4. Length of nonmoving object	5. Area of moving object	6. Area of nonmoving object
7. Volume of moving object	8. Volume of nonmoving object	9. Speed
10. Force	11. Tension, pressure	12. Shape
13. Stability of object	14. Strength	15. Durability of moving object
16. Durability of nonmoving object	17. Temperature	18. Brightness
19. Energy spent by moving object	20. Energy spent by nonmoving object	21. Power
22. Waste of energy	23. Waste of substance	24. Loss of information
25. Waste of time	26. Amount of substance	27. Reliability
28. Accuracy of measurement	29. Accuracy of manufacturing	30. Harmful factors acting on object
31. Harmful side effects	32. Manufacturability	33. Convenience of use
34. Repairability	35. Adaptability	36. Complexity of device
37. Complexity of control	38. Level of automation	39. Productivity

3.5. Contradiction Matrix

TRIZ has been recommended as an effective strategy for solving problems involving a contradiction. The Inventive Principles are essential methods for resolving technical inconsistencies, and their implementation does not require any particular understanding.

Method 1	Method 2
To address the Engineering Contradiction, use the Contradiction Matrix to get a list of proposed Innovative Principles; if none are suitable, look at the remaining 40 inventive Principles.	Learn all 40 Inventive Principles and how to use them alone or in combination to solve the Engineering Contradiction.

Inventor Altshuller developed a contradiction matrix, which abstracts and categorizes the innovative concepts and system parameters that may be used to explain all of the resolved contradictions. For example, in the contradiction, the system parameters are written up in 39 x 39 matrixes. The x-axis represents the parameter that worsens, and the y axis represents the one that improves.

3.6. Engineering Contradiction

An Engineering Contradiction occurs when an attempt to improve one parameter of a system results in another's deterioration (impairment). This can manifest itself as a positively and negatively interaction between two or more components. The focus can quickly resolve the contradiction, which can also be more to r order S to recognize the engineering contradiction. As shown in **Figure 3**, this deterioration of one attribute might take several forms.

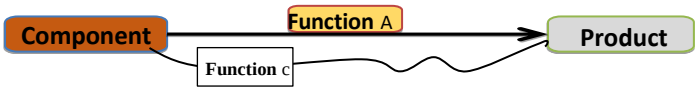

Figure 3: Engineering Contradiction example

3.7. 40 Inventive Principles

TRIZ: Each innovation may be traced back to applying one or more of these principles. Altshuller came up with 40 innovative principles, according to TRIZ. To use the 40 Principles of Innovation, as mentioned in **Table 2**.

Table 2: 40 Inventive Principles

No.	Inventive principle	No.	Inventive principle
1	Segmentation	21	Skipping
2	Taking out	22	Blessing in disguise
3	Local quality	23	Feedback
4	Asymmetry	24	Intermediary
5	Merging	25	Self-service
6	Universabrationlity	26	Copying
7	Nested dol1	27	Cheap short-living
8	Anti-weight	28	Mechanics substitution
9	Preliminary anti-action	29	Pneumatics and hydraulics
10	Preliminary action	30	Flexible shells and thin films
11	Beforehand cushioning	31	Porous materials
12	Equipotentiality	32	Colours changes
13	The other way around	33	Homogeneity
14	Spheroidality	34	Discarding and recovering
15	Dynamics	35	Parameter changes
16	Partial or excessive actions	36	Phase transitions
17	Another dimension	37	Thermal expansion
18	Mechanical vibration	38	Strong oxidants
19	Periodic action	39	Inert atmosphere
20	Continuity of useful action	40	Composite material film

The next problem-solving stage in the TRIZ technique is to look for viable general solutions outlined in the TRIZ 40 Inventive Principles, based on the identified improving and worsening factors and the ideal result to be obtained. A list of 40 innovative principles can be found here.

A solution that is relevant to the issue at hand. There are forty (40) solution keywords for any technological challenge that can be used to generate solution ideas. The list was compiled based on reviewing current patents and solution principles [17]. Segmentation, taking out, and localization are some of the general solution principles covered quality, as well as merging the general solution is next evaluated to get a specific solution.

4. Result and Discussion

4.1. Problem overview

As shown in Figure 4(a), the general map of Jamarat place is taken by Google earth that includes five sub-places reflected in the area of pilgrim temporary staying.

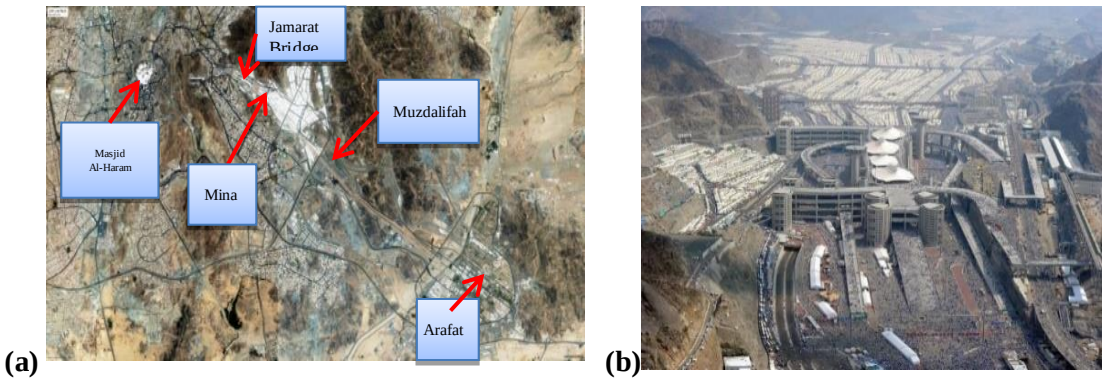

Figure 4: (a) General Map for case study place (source: Google earth), (b) Jamarat bridges consist of four floors

First of all, Arafat place is the beginning point for the pilgrim, which does not have the power of being crowded. Next, the pilgrim assembly to Arafat gates and run to Muzdalifah with big groups to collect the stones of Jamarat that will be affected negatively and create jams in the Muzdalifah-Mina roads.

Figure 4. (b). The Jamarat bridges consist of four floors with a few bridges. Moreover, it illustrates the difficulty of the topography around the Jamarat area, which is in a narrow valley and contains some hills and mountains.

4.2. The Nine windows

The system's structure (system, subsystem, and super-system), as well as its temporal growth, are described at various levels (past, present, and future) [19]

Table 3: The Nine windows

	Past	Present	Future
Super-System	Saudi Authority	Saudi Authority, Ministry of Hajj.	Saudi Authority Ministry of Hajj, Hajj Agency.
System	Jamarat is overcrowded and not safe	Jamarat is not 100% affected and safe	Effect and safe Jamarat bridge.
Subsystem	Road & Jamarat Pillar	Bridge Jamarat Pillar & Pillar Surrenders.	Bridge Multi-layer Escalator.

By using this tool in **Table 3,** they will be able to consider the problem in space and time. Several ideas and insights started to be offered by the participants.

4.3. Engineering Contradiction

The pilgrims walk from Arafat to Mina, but they have to stop at Muzdalifah to collect the stones for throwing the Evil; after that, they face congestion.

Engineering Contradiction: "**If** the pilgrims walk from Arafat to Mina, **then** it is easy for them to stop at Muzdalifah, **but** it creates danger due to congestion."

Parameters involved: Improving Parameters: Easy operation (Parameters #33), Length of moving object (Parameters #3).

- Worsening Parameters: Harmful factors acting on an object (Parameters #30).

Solution: Based on the Contradiction Matrix (Appendix-A), the suggested Inventive Principles are shown in **Table 4.**

Improving Parameter #33 versus Worsening Parameter #30 gives rise to suggested Inventive Principles #2 (Taking out or extraction), #25 (Self-service), #28 (Replace a mechanical system), #39(Inert environment).
Improving Parameter#3 versus Worsening Parameter#30 gives rise to suggested Inventive Principles#1(Segmentation), #15(Dynamism), #17(Moving to another dimension), and #24(Intermediary).

Table 4: Extract of contradiction matrix.

	Worsening Feature →	Harmful factors acting on the object
⇩	**Improving Feature**	30
3	Length of moving object	1, 15, 17, 24
33	Ease of operation	2, 25, 28, 39

4.4. General Solution

When using TRIZ, Altschuller's TRIZ allows users to specify and solve any problems. The starting point for the TRIZ technique is the problem scenario. After that, the user examines and characterizes the procedure to determine the actual problem. Finally, the general problem's available solutions must be determined. There are many solutions that we get from TRIZ inventive principle as general solutions for this case shown in **Table 5:**

Table 5: The suggested Inventive Principles

	No.	Principle	Principle Suggestion solution
Parameter (3 / 30)	1	1 Segmentation	It has divided the roads into different paths for pedestrians, cars, and buses
	2	15 Dynamism	Renting vehicles from one place and delivered elsewhere.
	3	17 Moving to another dimension	Jamarat Bridge and roads consist of many floors.

Parameter (33 / 30)	4	24 Intermediary	The use of disabled vehicles and traceable.
	5	2 Taking out or extraction	Prevent pilgrims from the acquisition of holdings during the Hajj
	6	25 Self-service	Sun Auto shades and Fire super-automatic.
	7	28 Replace a mechanical system	Use escalator multi-layer for the whole distance between Mina and Muzdalifah
	8	39 Inert environments	An environment is free of tension at Hajj.

Following are detailed descriptions of the above list of the suggested inventive principles as a general solution:

Principle 1: Segmentation

By erecting barriers to divide the crowd into different portions, segmentation can be employed to address the crowd problem. The barrier will prevent crowds in each sector from interfering with the others. The evacuation of persons in a segmented area will take longer because the evacuation path will be narrower and more complicated. TRIZ principles can be used to think about and address this new situation [20]. **Figure 5**.

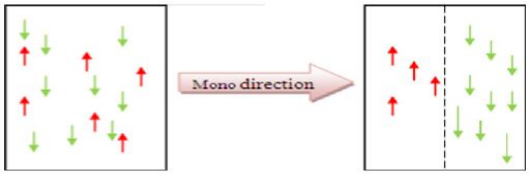

Figure 5: Illustration of turning bi-directional flow to mono-directional flow.

Principle 02: Taking out or extraction

Prevent pilgrims from acquiring property during the Hajj ritual. Remove an object's interfering part or parcel or isolate the object's only necessary component. If pilgrims bring their belongings during Hajj, they would be hampered by traffic congestion, which has resulted in disaster.

Principle 15: Dynamism

The Ministry of Municipal and Rural Affairs has set aside several electric vehicles at the Jamarat Facility for pilgrims with special needs, patients and the elderly. As a result, about 70,000 pilgrims will be served by electric vehicles each year throughout the Hajj season. On the other hand, the Ministry of Municipal and Rural Affairs has set aside many electric cars at the Jamarat Facility for pilgrims with special needs, patients, the elderly, and women to make the Hajj ritual of tossing pebbles easier for them [21].

Principle 17: Another dimension

This idea indicates that we consider altering the structure's dimensions. As a result of this principle, the notion that comes to mind is to divide the crowd into multiple floors (vertically) rather than a single floor (horizontally), as seen in Figure6. This dimension difference allows more people to be accommodated without impacting the building's footprint. However, the total area is raised as a result of multiple structural dimensions.

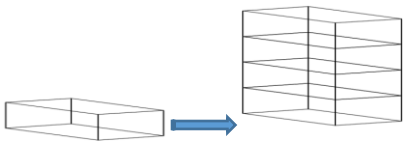

Figure 6: Illustration of changing a building's dimension.

Principle 24: Intermediary

Use a carrier product or a method that acts as a middleman. This idea can be applied in Hajj when disabled individuals use and return disabled vehicles.

Principle 25 Self-service

Sun Auto shades work automatically when the sun shines in the Hajj areas. These Shades comfort and protect the Pilgrims from the direct burning sun rays. It helps make Pilgrims calm and not start pushing each other to run away from Sun heat. These shades are manufactured with sensors that sense sun rays and work as stealth.

Principle 28: Replacement of a Mechanical System

This principle guides us to use escalator mechanics for all distances between Muzdalifah and Mina. This includes using a horizontal and different height escalator for bridge multi-layer; if they use this action, it will be easier and safer for pilgrims to perform Hajj rituals.

Principle 39: Inert Environment

After proofing a tent's surface, the tent's temperature can be reduced by 5 to 7 degrees Celsius. As a result of the heat insulation, the amount of energy used by the air conditioner is reduced. Mina campers might apply new paint to insulate heat transfer.

4.5. Specific Solution

The final phase is solution selection. This is when the best and most appropriate solution is selected from various ideas and tailored to the specific situation. As a result, the final stage in the procedure is to choose a solution. In addition, we look for inconsistencies in the context of crowd management and assess which of TRIZ's category solutions may be applicable.

The path from Muzdalifah to Mina can be developed to be A multi-layer path that makes the movement of pilgrims easier by using the horizontal electric escalator. Jamarat Bridge consists of four floors, but it is a one-floor construction that still needs at least another three floors (**Figure 7)**.

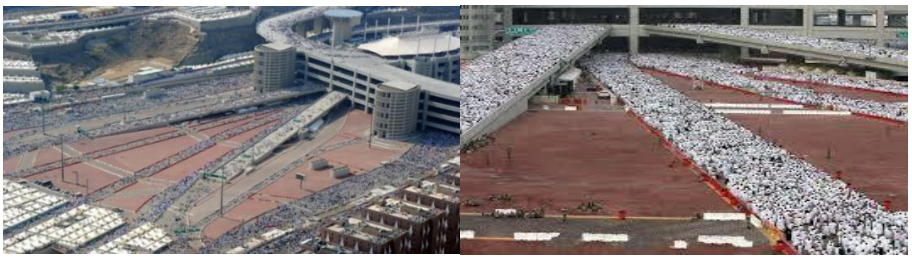

Figure 7: Crowded pilgrims on the paths from Muzdalifah to Mina and Mina bridge

5. Conclusion and Future Enhancement

In conclusion, this study focused on human safety in crowded places such as religious gatherings. These crowded places led to many accidents; as a case study, the fundamental research has taken the Jamarat bridge area in Mina, Saudi Arabia, to study how we can improve human safety by applying TRIZ theory. During the pilgrim's returns from Arafat to Mina, they have to stop at Muzdalifah to

collect the stones. During the collection of stones, congestion occurs. The use of colour-changeable signs will help the pilgrims keep updated about the crowded flow while moving. Therefore, the principle 32# colour changes are considered adequate for this scenario's problem.

TRIZ innovation development in greater depth-component in Mina and Makkah. Foremost, the researcher believes that applying TRIZ to Hajj in many regions and paths will aid in the interrelationship of the various difficulties and the discovery of general answers. As a result, in the context of crowded human safety, it is proposed that TRIZ be applied to all Hajj paths. There are specific issues indicated for additional investigation in large-scale gatherings, developed positions for safety management and engineering: The degree to which users of large-scale gatherings facilities are satisfied with crowd safety management—the likelihood of enforcing the crowd dynamics building safety code.

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