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Ground Exploration and Location Detection (G.E.L.D) and Its Influence on the Optimization of Incident Response in Confined Spaces

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The construction boom has driven our country's growth by 6.02% in 2022, according to INEI data. This development extends not only upwards but also downwards, encompassing the construction of basements and tunnels. According to the MTC (Ministry of Transport and Communications), the construction of underground roads is currently underway in the city of Lima in 2023, which will soon become part of our daily lives. Fires and accidents are not uncommon in these places. Once a fire breaks out in a tunnel, occupants face a confined and dangerous environment and need to evacuate before reaching untenable conditions. Failure to evacuate in the event of a fire will cause serious injuries and fatalities due to toxic smoke and high temperatures, as many past fire accidents have taught us. The objective of this research is to determine how G.E.L.D. influences the optimization of disaster response in confined spaces such as tunnels and basements. Through Lean Manufacturing tools, to measure its influence on operations, response times, and implement an improvement proposal according to the characteristics and needs of our national territory.

Keywords: Tunnel fires, Lean Manufacturing, G.E.L.D., confined spaces, fire prevention and control.

1. Introduction

The construction boom in Peru has driven the country's growth by 6.02% in 2022, according to INEI data. [1] This growth extends not only upwards but also downwards, encompassing the development of basements and tunnels. Throughout history, the use of tunnels for various purposes (hydraulic, transportation) has intensified worldwide [2]. In the past two decades, a growing number of Latin American countries have recognized the importance of developing higher-capacity public transportation systems in their major cities. Lima Metro Line 1 was first identified in studies completed in 1972, which recommended building a metro line linking strategic points in the city [3].

The increasing population in the capital has led to the collapse of urban land transportation routes, creating the need for alternative routes to decongest traffic. The construction of underground roads has been an effective solution throughout history, despite requiring a significant investment of time and money. Underground tunnels offer advantages such as reduced travel times, less visual and environmental impact, and continuous traffic flow. These tunnels require auxiliary facilities such as lighting, ventilation, and fire protection systems to ensure the safety of their users [2].

According to the Ministry of Transport and Communications (MTC), underground road construction projects are underway in Lima, including metro lines 2, 3, and 4, which will connect Lima and Callao over 69 km. Additionally, the large tunnel for the Yellow Line, which passes under the Rímac River, has been completed. However, these spaces are not without risks, especially in the event of fires. Tunnels can magnify the consequences of a fire due to the oven effect and smoke generation. Table I presents relevant data on highway tunnel fires since 1949, compiled from PIARC in 1999 and other sources. It is crucial to consider these risks when planning and managing safety in underground roads [4].

Table 1. Data on the most relevant fires that occurred in road tunnels

YEAR	TUNNEL	Wounded	Poisoning	Death	Grand/Total
1949	Netherlands (N.V.USA)		66		66
1974	Chesapeake Bay (United States)		1		1
1976	Porte de Italie (France)		12		12
1978	Velser (Netherlands)	5		5	10
1979	Nihonzoka (Japan)	3		7	10
1980	Kajiwara (Japan)			1	1
1980	Sakai (Japan)			5	5
1982	Caldecott (California, United States)			7	7
1983	Frejus (France)		1		1
1983	Pecorile (Italy)			8	8
1986	L'Arme (France)			3	3
1987	Gumefens (Austria)			2	2
1990	Mont Blanc (France/Italy)		2		2
1990	Raldai (Norway)		1		1
1993	Serra Ripoli (Italy)			4	4
1994	Huguenot (S. Africa)		28	1	29
1995	Plander (Austria)			3	3
1996	Isla de las Mujeres Italy	20		5	25
1997	St. Gotthard (Switzerland)		1		1
1999	Mont Blanc (France/Italy)			39	39
1999	Tauern (Austria)			12	12

Adapted of Geo-control

Once a fire breaks out in a tunnel, occupants face a confined and hazardous environment and need to evacuate before reaching untenable conditions. Failure to evacuate in the event of a fire will cause serious injuries and fatalities due to toxic smoke and high temperatures, as many past fire accidents have taught us. Driven by the need for fire safety in tunnels [5].

Tunnels are highly important structures that facilitate road transportation over long distances. However, the fires in the Mont Blanc (between France and Italy) and Tauern (Austria) tunnels in 1999, the Gotthard (Switzerland) tunnel in 2001, and the Fréjus (between France and Italy) tunnel in 2005 demonstrated the dramatic consequences that tunnel accidents can have in terms of human life and property damage [6].

Fig.: 1 Remains of a fire truck recovered from the Mont Blanc tunnel

Note: (Jessica, 2024) The truck that caused the tragedy, when it was removed from the tunnel

Despite the fact that the fire detection systems acted differently, promptly and non-promptly, neither of the two fire detection systems installed in both tunnels was able to warn of the start of a fire in time. According to reports from the Geocontrol magazine, the lack of respiratory apparatus (4 SCBA and 6 firefighters) and their lack of autonomy, combined with the lack of pressurization of the fire shelter, caused the death of the fire chief shortly after his rescue[7].

Fire in a confined space develops in limited spaces and is conditioned by the availability of air for its progression. It requires non-gaseous phase fuel, air, and a heat source to initiate "pyrolysis" and generate combustible vapors. Its evolution depends on complex and multiple factors in this type of confined structures [8].

The objective of the research is to determine how G.E.L.D. influences the optimization of emergency response in confined spaces such as tunnels and basements. Seeking to measure its influence on operations and response times, implementing improvement proposals adapted to the country's needs. Proper emergency management will be essential to maximize the benefit of the available technical means. The combination of G.E.L.D. and Lean Manufacturing tools will allow for exploring, rescuing people, and extinguishing fires safely, minimizing working times and optimizing processes.

Considering the history of fires in confined spaces such as the one that occurred in the basement of the Larcomar shopping center in 2016, which left 4 people dead and 13 missing, with the intervention of 24 fire units and 120 firefighters, highlighting the current deficiencies. According to García-Ramos, the singularities of the fire risk in tunnels are as follows: Combustible materials, Confinement, Physical evacuation conditions and emergency management [9].

The research question formulated is: How does G.E.L.D. influence the optimization of disaster response in confined spaces in the C.G.B.V.P? In response, the improvement proposals presented in this research as a result of the analysis of the current situation in Peru will be described. The General Volunteer Fire Corps of Peru (C.G.B.V.P) is the only organization responsible for firefighting nationwide. Currently, within the multiple specialties that it has developed to cover the needs of the first response to emergencies, we have different courses in the Technical training program, but they are not focused on tunnel fires, which prevents us from having information on how to face this type of dangerous emergencies.

Table 2. Technical training courses taught by the CGBVP

TECHNICAL TRAINING PROGRAM OFFICE	
COURSES	CODE
SEARCH AND RESCUE IN STRUCTURES ON FIRE	BREI
HYDRAULICS APPLIED IN FIRE FIGHTING	HCI
LOTS OF ROPES FOR RESCUE	LCR
RESCUE IN CONFINED SPACES	REC
VEHICLE RESCUE	RV
FOREST FIGHTER	BF
HAZARDOUS MATERIALS / WEAPONS OF MASS DESTRUCTION / LEVEL OF OPERATIONS	MAPTEL ADM OPERATIONS
HAZARDOUS MATERIALS / WEAPONS OF MASS DESTRUCTION / TECHNICAL LEVEL	MAPTEL ADM TECHNICAL
RAPID INTERVENTION TEAMS	RIT
RESCUE IN DITCHES	REZ
SEARCH AND RESCUE IN COLLAPSED STRUCTURES	BREC
INCIDENT SECURITY OFFICER	OSI
FIRE OPERATIONS	OCI
ROPE RESCUE	RCC
GREAT RESCUE SEARCH	BRAGG

The Long Duration Exploration Group is a specialty developed in Paris, France in 2012 whose mission is to intervene in difficult environments (tunnels, underground parks, subways and RERs, etc.) and rescue rescuers [10]. They currently participate in multiple tunnel and basement fires with great success. Unlike other firefighters, they work differently. Using personal protective equipment designed for penetration, breathing apparatus with an autonomy of more than 1 hour, guide lines with tactile patterns, self-winding guide lines, diversion equipment, beacons, intrinsically safe communication radios with signal repeaters included, together with prior training, work methodologies, and specific function assignment, they can explore, detect, and extinguish fires more quickly in such difficult environments. This allows for the successful rescue of victims.

Inspired by Lean Manufacturing tools, it is possible to adapt work methodologies to the CGBVP, since having a justification for the need for existing underground spaces in our country would currently provide great support to the detected need. Tunnel fires are processes that develop rapidly. Practice shows that in general, the time available for evacuation ranges from a minimum of 5-6 minutes to a maximum of 10-12 minutes, depending on the characteristics of each tunnel and the fire. Therefore, it is not possible to wait for the intervention of rescue teams to start the evacuation, since except in the case that the tunnel has its own intervention service, the response times of these teams will be longer than the indicated margin [11].

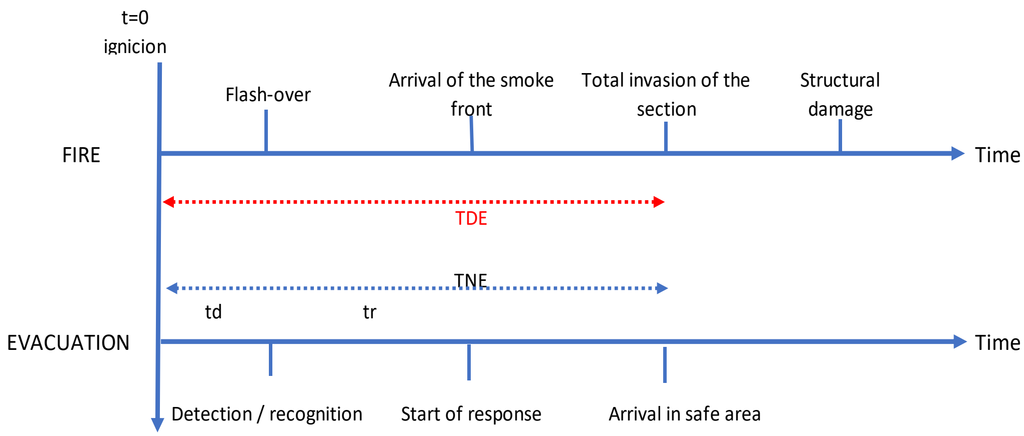

Fig. 2: Time involved in an evacuation.

By using these new tools in our country, we can anticipate obtaining better results that will allow us to have more encouraging forecasts in terms of rescued victims.

The experience gained from years of fighting urban fires teaches us that we cannot prevent a disaster from occurring if there is a possibility that it may materialize due to the inherent characteristics of the activity being carried out on site. The way we fight fires has changed along with technological advances, but undeniably, the human hand will still be needed to carry out rescue and lifesaving work at times when life or death depends on it. That action will make the difference between living and dying.

2. Methodology:

A systematic review methodology was employed for this research. Scientific documents pertaining to the keywords were analyzed, and inclusion and exclusion criteria were meticulously considered. A systematic review explicitly utilizes systematic methods to gather and synthesize the findings of individual studies that address a clearly formulated question [12].

The keywords utilized for the search of scientific articles and research for this endeavor were: Tunnel fires, Tunnel fire prevention and control, Fire safety in tunnels, Fire protection in tunnels, Tunnel fire studies, Tunnel fire experimental studies. Articles presenting results older than 25 years were discarded. ResearchGate, Scielo, IOP Science, Gregorian Scientst, Science Direct, and articles from universities in Latin America and Europe were considered as the foundation for this research. Systematic reviews enable us to stay abreast of diverse topics of interest without expending excessive time; however, this type of study is not invariably associated with a level of evidence, guaranteed validity or veracity, methodological quality, and reliability or reproducibility of results [13].

Inclusion Criteria:

The following criteria will be considered in the selection of research papers from the repositories of universities in Latin America and Europe:

Language: Publications in French, English, and Spanish will be considered.

Research Focus: Studies on the optimization of disaster response in confined spaces will be prioritized.

Disaster Response Optimization: Studies that discuss disasters in confined spaces that lack optimized disaster response measures will be taken into account.

Publication Sources: Publications from academic institutions, universities, journal articles, books, technical conferences, and books will be considered.

Exclusion Criteria- The following information was excluded during the systematic review:

Theses and monographs: Information in theses and monographs was excluded. Publications before 1998: Publications made before 1998 were excluded, including those that do not contribute to this research.

Publications from unrecognized databases: Publications from unrecognized databases were excluded.

Publications that do not contribute to the research objective: Publications that do not contribute to the objective of this research were excluded.

Research that can derive the most benefit from the proposed topic will be selected. This research will analyze and describe the importance of an immediate response to an incident in confined spaces. Subsequently, through the process of inclusion and exclusion of articles in Tables 3 and 4, we have 23 reference articles for the development of the research, taking into account the search engines and databases in recent years.

Table 3. Articulé Search Statistics

Fountain	Artícles from 1999 al 2007	Artícles from 2007 al 2022	Total
Science Direct	6	1	7
Taylor & Francis	0	1	1
HAL Science	2	1	3
IOP Science	0	1	1
Georgian Scientist	0	1	1
Springer link	0	2	2
ResearchGate	0	11	11
Scielo	0	1	1
IcePublishing	3	0	3
Construction engineering magazine	2	0	2

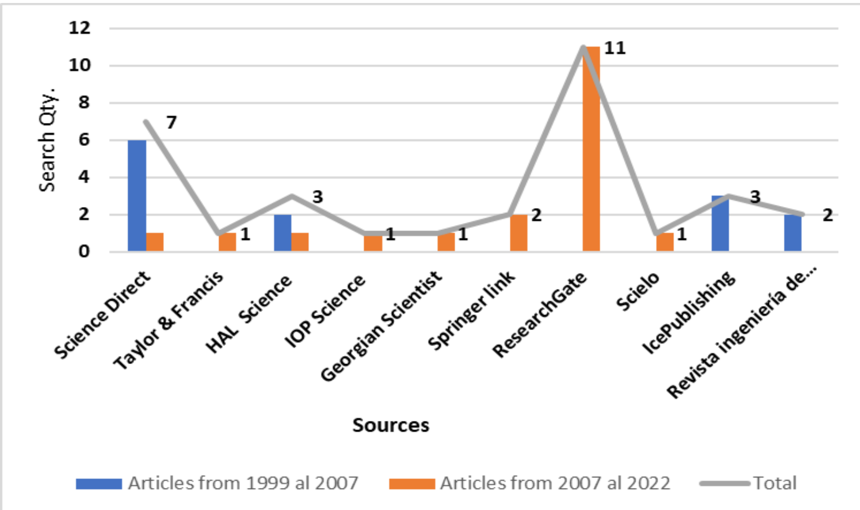

Fig. 3: Information search statistics

In the realm of search engines, employing appropriate keywords serves as an expeditious method for accessing desired information. When space permits, outlining the central concepts can be beneficial. However, in instances where space is limited, keywords prove to be invaluable tools [14]. The following table eticulously organizes the keywords utilized for the retrieval of scientific articles alongside their corresponding search engines. Notably, the search included terms in English, French, and Spanish.

Table 4. Article Search Keywords

Search engines	Keywords
Science Direct	Fire; Protection; tunnels; Eureka; Risk; Traffic flow; Fire-induced spalling; concrete; Tunnel lining
Scielo	Ventilation; Ventilation System; Ventilation controlled fire; tunnel ventilation
Taylor & Francis	Incendio; Tuneles

Ice Publishing	Tunnels; Fire
HAL Science	Tunnel; Incendie; Mont Blanc Essais Ventilation
IOP Science	Tunnels; Fire; Accidents
Construction engineering magazine	Highway tunnels; exploitation security; risk analysis
Georgian Scientist	Ventilation; Ventilation System; Ventilation controlled fire; tunnel ventilation
Springer link	Underground transportation system; Rail Tunnels; Road tunnels; Underground stations; Fire; Human
Research Gate	Tunnel Fire Safety; Evacuation; Case study; Full scale experiments; Huaman bahevior; Double fires

3] Results: Present the findings of the research paper in this section.

The starting point for improvement is to recognize the need. This comes from the recognition of a problem. If no problem is recognized, the need for improvement will also go unrecognized. [15] In a fire, we generally have different wastes such as: waiting, unnecessary processes, and rework. Since firefighters face fires in open-air structures, they are accustomed to handling a single firefighting methodology, along with personal protective equipment for firefighting approach, an autonomous respiratory protection equipment with a total time of 22.5 minutes at 80 liters per minute, guided by the Manual of the C.G.B.V.P Basic Firefighter Training Course [16].

Flashlights for common use in very limited quantities and common communication radios, the same radios that a private security service would use, are other limitations when it comes to firefighting. Upon arriving at a fire in response to the emergency call, the firefighters go to extinguish the fire.

While the conditions of fires generally remain consistent in terms of structure size and fuel load, basement fires present distinct challenges that share similarities with tunnel fires. These challenges were evident during the Larco Mar fire in 2017, where many firefighters lacked the appropriate personal protective equipment (PPE) to safely enter the burning structure [17]. This was particularly concerning given the presence of combustible materials, such as concrete, where maximum temperatures can reach between 800°C and 1000°C [17]. In contrast, NFPA 1971: Standard on Protective Clothing and Ensembles for Structural Fire Fighting and Proximity Fire Fighting [18].

Specifies a maximum heat resistance of only 260°C for firefighter protective gear. Basement fires pose unique hazards compared to conventional fires: Elevated Temperatures: Basement fires typically involve significantly higher temperatures than conventional fires. Direct Heat Exposure: Firefighters in basement fires face more direct exposure to high temperatures from both flames and gases. Smoke Concentration: Smoke tends to accumulate in confined spaces, hindering visibility and disorienting firefighters. Radio Signal Loss: The absence of signal repeaters within basements can lead to a loss of radio communication, disrupting coordination and hindering search and rescue operations. Lack of Action Plan: In the absence of a clear plan of action, rescue teams may be deployed without adequate resources, including equipment, training, and a defined strategy. This can lead to operational inefficiencies and wasted resources.

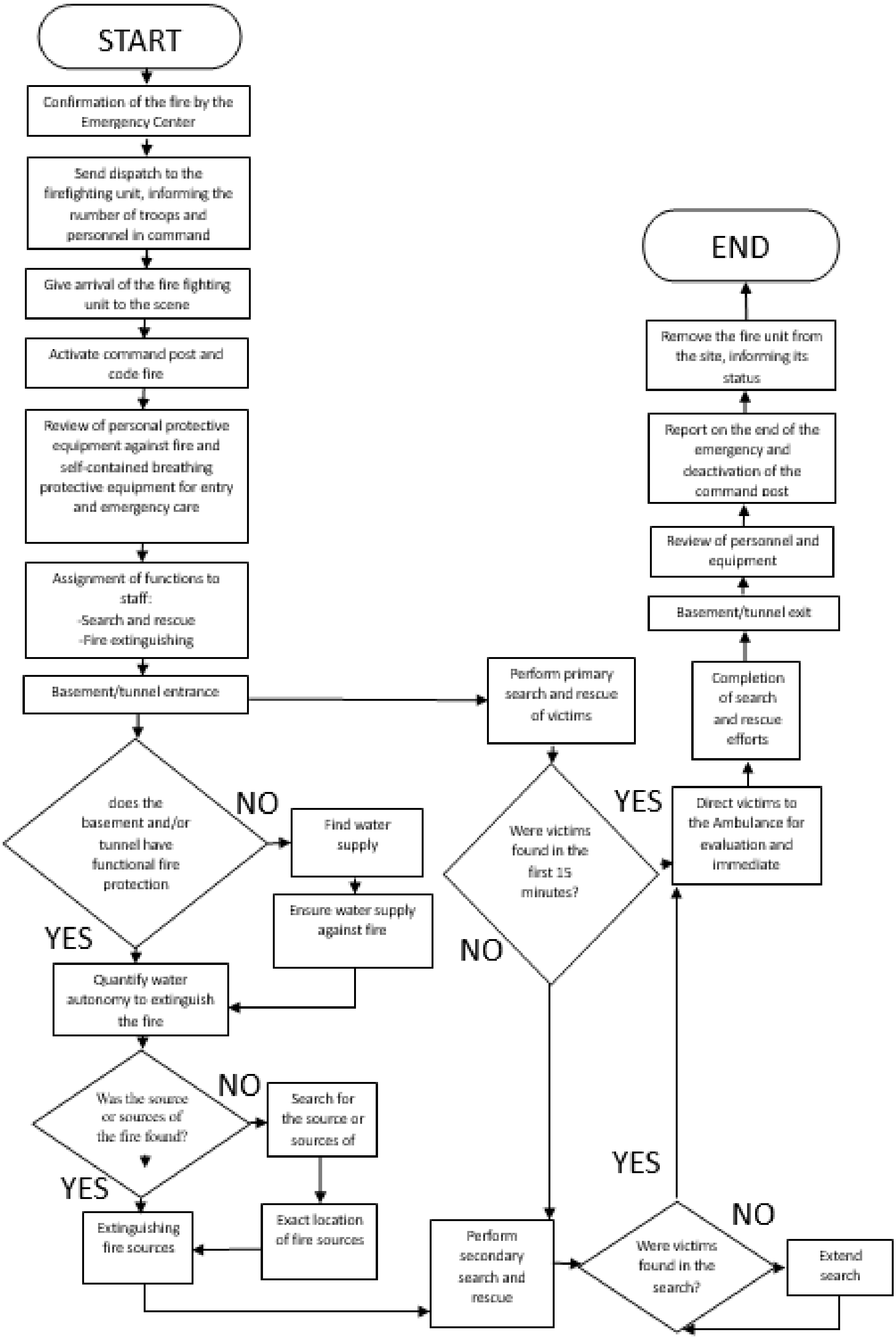

Fig. 4: Fire response flow in confined space

Table 5. Operational waste

Operational waste	
You wait	* EPRA recharge time * Rest of staff due to fatigue *Explorations with a long duration, but few results due to orientation problems.
Internal processes	* Exposure of firefighters to dangerous environments *Fatigue of exploration equipment due to thermal stress
Reprocessing	* Search and rescue operations in already explored sites

Based on the identified issues, we will implement the following Lean tools: Kanban, Poka Yoke, and Andon.

Resource management on-site is handled using a whiteboard. On this board, we create visual representations of the area—a sort of mental map—based on the spoken testimony of each firefighter who explored the affected environment. This environment typically involves smoke and poor visibility due to lack of illumination. The challenge arises because work time is directly tied to the amount of air available for exploration. In other words, when the air supply runs out, the search must cease, and the firefighter needs to exit to replace their air tank. Once the empty tank of the EPRA (Self-Contained Breathing Apparatus) is swapped with a full tank, they can re-enter and continue their work. To address the autonomy issue, we made a switch from the SCBA (Self-Contained Breathing Apparatus) to a closed-circuit breathing apparatus. This change allows firefighters to continue exploration without the need for frequent stops.

RESPIRATORY PROTECTIVE EQUIPMENT		
PHOTO		
BRAND	Dräger	SCOTT
MODEL	PSS® BG 4 plus	AIR-PAK 75I
TYPE	Closed circuit breathing apparatus	Self-contained breathing apparatus (SCBA)
T.T DURATION 80l/MIN	240.0 min	22.5 min
TE	180.0 min	15.0 min
TR	60.0 min	7.5 min
TT:Total time		
TE: Effective time		
TR: Reservation time		

Fig. 5: Respiratory protective equipment

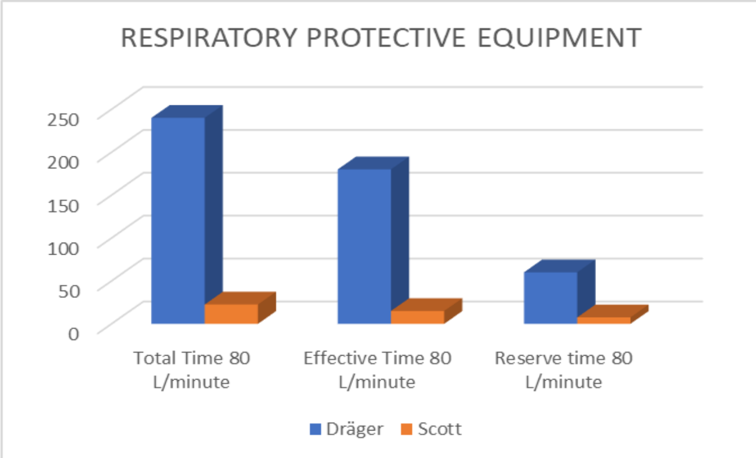

Fig. 6: Evolution of autonomy teams

Control Point System (Kanban)

Personnel management is crucial for the success or failure of an operation, as are the resources available to each team member. However, when we discuss a resource as limited and critical as breathable air during a fire, it demands strict attention. Command posts typically rely on whiteboards and markers to record various data. But when it comes to efficiently controlling the amount of air consumed in a hazardous atmosphere, this approach alone lacks the capability to provide accurate measurements or reference patterns for individual team members' air autonomy.

Fig. 7: Command post, operations center where the fire is planned to be put out 06/12/2017

To address the challenge of limited air supply during EPRA (Self-Contained Breathing Apparatus) operations, we implemented a Lean Kanban system. Kanban is a visual tool for managing workflow as it progresses through a process. Kanban visualizes both the process (the flow of work) and the actual work that goes through that process. The control point board allows not only to accurately place data such as names, work teams, and quantity of air. It also allows, through a stopwatch, to assign working time in order to monitor times assigned by function in relation to the amount of air available. Once the time is up, the stopwatch will beep to indicate that the time has expired. In this way, we have the assistance of devices for this purpose without assigning a person to do this counting.

Fig. 8: Self-contained breathing apparatus control table

Marking (Andon)

Upon entering an area with smoke, a neutral plane is formed. This imaginary line separates the smoke from the smoke-free area horizontally. Darkness poses a challenge along with the lack of orientation during exploration tasks, leading to the loss of firefighters. The risk of death increases because they have a limited air supply to breathe in the toxic atmosphere where they are operating. When a firefighter enters, they carry a hose connected to a pressurized water supply pumped from a fire truck located outside the area. According to the Search and Rescue in Burning Structures (BREI) manual from the CGBVP, it is recommended to locate a hose and orient oneself using landmarks when advancing without a clear sense of direction.

However, this resource is often ineffective due to the intense heat, which can lead to reduced concentration. [16] The Andon tool in Lean is a visual control system that alerts to issues and imperfections during production processes and quality control flows. It ensures that these issues are promptly addressed and corrected without significantly disrupting operations [17].

The underlying principle of this tool is chromatic language, which posits that each color evokes a different sensation. By using color as a form of communication, we transmit inherent feelings associated with each hue. [18] Through marking, a type of situational signaling using lights and devices, we indirectly communicate during exploration tasks. We will employ markers in four different colors for this purpose. [19]

Table 6. Types of beacons and functions

BEACONS				
PHOTO				
COLOR	Red	Blue	Green	Yellow
FUNCTION	They indicate danger areas: Skylights, stairs, electrical panels, open elevators.	They tag members of the GELD team making them visible	They indicate safe exits, safe places of refuge	Used to mark safe trails as exploration progresses

Among the advantages that we obtain by using beacons we have the following.

Indirect Communication: Beacons allow for the transmission of critical messages across different times and spaces.

Fig. 9: Lighted Beacon Illustration

Position Visibility:

In smoke-filled environments where visibility is limited to approximately 1 meter, firefighters often struggle with disorientation due to their inability to determine their location. Beacons address this challenge by providing a recognizable position within the area. Firefighters can easily identify themselves and their location, which can be mapped using the recognition system created by the GELD group.

Marking Explored Sites:

Beacons enable the clear demarcation of explored areas, preventing the duplication of efforts during exploration operations. This eliminates the risk of revisiting previously searched areas, ensuring a more efficient and streamlined exploration process.

Distinguishing Between Fixed Lights and Personnel:

During exploration, the lights from flashlights can easily be mistaken for stationary fixtures. Beacons provide a clear distinction between lighting fixtures and personnel, ensuring that team members remain visible throughout the operation. This is particularly important in case a GELD member requires rescue.

To evaluate the utility of beacons, a survey was conducted among 30 volunteer firefighters from the Centro de Lima fire station. The survey presented two sketches to the participants and asked them to assess the effectiveness of beacons in enhancing communication and visibility in smoke-filled environments.

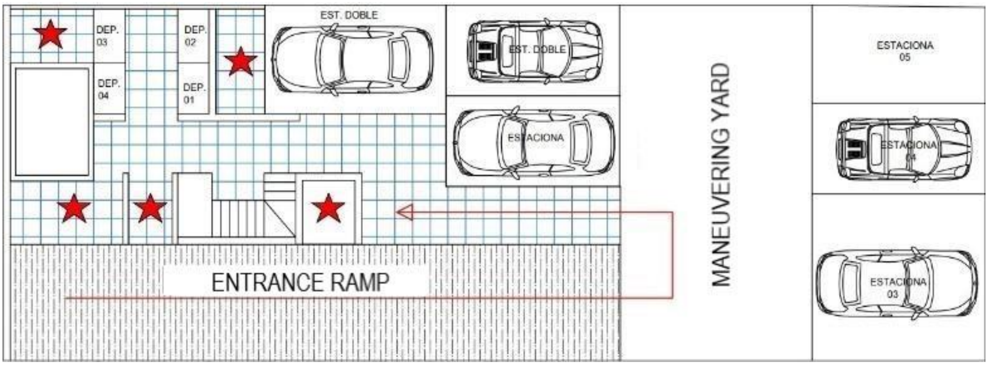

Fig. 10: Traditional information recording method

In one, the traditional method of recording search and rescue information was applied, and in the other, the GELD method was applied.

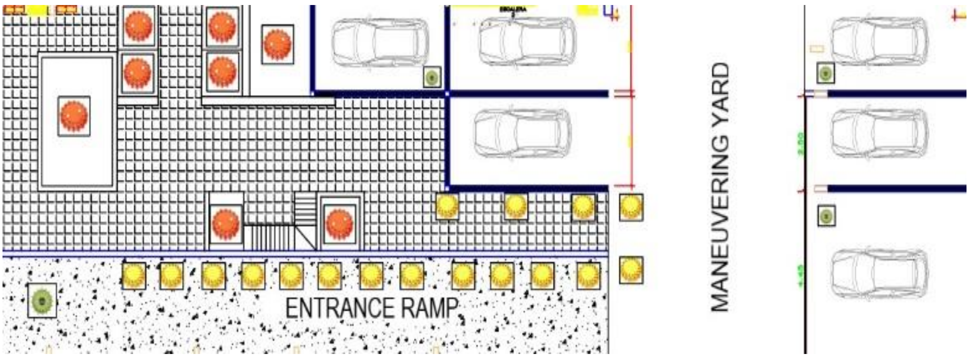

Fig. 11: GELD information recording method

As a result, more than 50% recognize that beaconing is a useful tool that provides benefits to reach important objectives in exploration efforts.

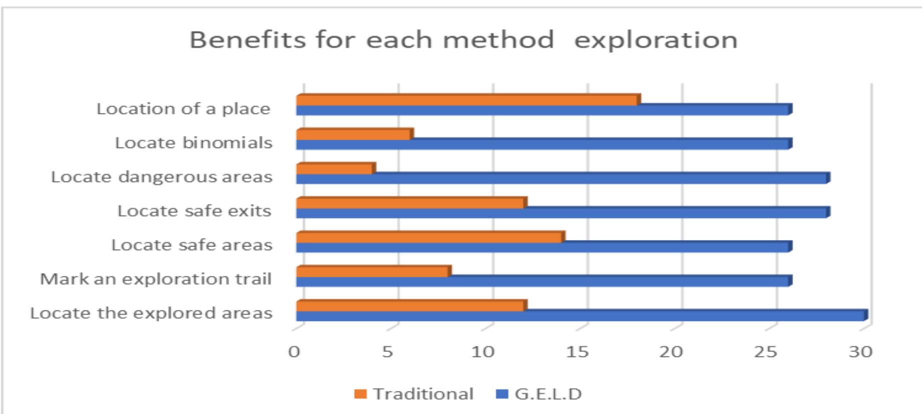

Fig. 12: Benefits for each method

Guide Line (Poka Yoke)

Nonverbal communication, also called body language, is the process of sending and receiving messages without using words, whether spoken or written [23]. Tactile communication is a form of non-verbal communication of great importance, the most primitive and is part of the essence for survival and relationships with our social and emotional environment. Inspired by the Braille System, which is a reading and writing system designed for blind people, based on the sense of touch [24], a communication system through touch is implemented for firefighters in high-smoke environments with Only 2 vital messages are the location of the fire and the exit.

Guidance method in exploration work.		
Type	**Fire hose**	**Línea guía**
PHOTO		
Material	Nitrile	Aramid
Reference pattern	1 c/30 meters	1 c/ 2 meters
Repetition of reference pattern in 60 meters	2	30
Cloth tour	15sec=30m	15 sec =30 meters
Speed	1.5 mts/sec	1.5 mts/sec
It takes in seconds to locate me from 0 meters	20	1.33

Fig. 13: Guidance method in exploration work

Below, we mention the advantage that this system has over the conventional use of fire hose as a guiding method in exploration work.

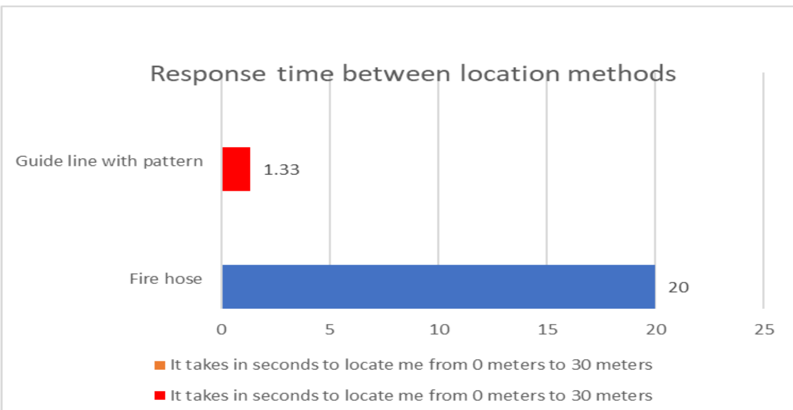

Fig.14: Response time meters/seconds from 0 to 30 meters between location methods

In the first analytical process diagram we can see that by using different binomials per exploration we will only travel 15 meters, because the search and rescue time is limited to the availability of air in the self-contained breathing protective equipment.

In addition to reducing the chances of finding survivors as the explorations increase, we could consider the maximum total time for an evacuation to be 15 to 20 minutes [25]. If survivors are in a fire shelter with pressurized air, they will have a rescue time of 1 hour [26]. In the event that the fire lasts 4 hours, 32 firefighters will be required and even then they would not be able to cover more of the field where mentioned.

Analytical Diagram of the Process

Survival Odds		
(green)	High	15 minutes
(yellow)	Median	30 minutes
(orange)	Minimum	45 minutes
(red)	Low	60 minutes onwards

AREA :	Operations	METHOD: Traditional	
UNIT:	M3.01	Date :	28/19/2023
TASK:	Search and rescue	Analyst: Héctor Peralta C.	

Step No.	"Time (min.)"	"Distance (meters)"	○	□	⇨	▽	D	◎	DESCRIPTION OF THE STEP	Position
1	1.00	0.50		●					Confirmation of the fire by the Emergency Center	Central emergency telephone operator
2	1.00	1.50	●						Send dispatch to the fire fighting unit, informing the number of troops and troops in command	Firefighter in command
3	0.50	0.50		●					Give arrival of the fire fighting unit to the scene	Firefighter in command
4	0.50	0.50						●	Activate command post and code fire	Firefighter in command
5	5.00	5.00						●	Review of personal protective equipment against fire and self-contained breathing protective equipment for entry and emergency care	Firefighter in command
6	5.00	1.00						●	Assignment of duties to personnel:Search and rescue	Firefighter in command
7	5.00	1.00						●	Assignment of functions to personnel: Fire extinguishing	Firefighter in command
8	0.50	2.00			●				Entrance to the basement/tunnel 2 meters from the exit	Firefighter 1 and Firefighter 2
9	15.00	15.00						●	Carry out search and rescue of primary victims (travel 13 meters)	Firefighter 1 and Firefighter 2
10	0.50	15.00			●				Tunnel exit (15 meters)	Firefighter 1 and Firefighter 2
11	5.00	1.00						●	Changing empty air tanks for full tanks	Firefighter 1 and Firefighter 2
12	0.50	2.00			●				Entrance to the basement/tunnel 2 meters from the exit	Firefighter 3 and Firefighter 4
13	15.00	15.00						●	Perform search and rescue of secondary victims	Firefighter 3 and Firefighter 4
14	0.50	15.00			●				Tunnel exit (15 meters)	Firefighter 3 and Firefighter 4
15	5.00	1.00						●	Changing empty air tanks for full tanks	Firefighter 3 and Firefighter 4
16	0.50	2.00			●				Entrance to the basement/tunnel 2 meters from the exit	Firefighter 5 and Firefighter 6
17	15.00	15.00						●	Perform search and rescue of secondary victims	Firefighter 5 and Firefighter 6
18	0.50	15.00			●				Tunnel exit (15 meters)	Firefighter 5 and Firefighter 6
19	5.00	1.00						●	Changing empty air tanks for full tanks	Firefighter 5 and Firefighter 6
16	0.50	2.00			●				Entrance to the basement/tunnel 2 meters from the exit	Firefighter 7 and Firefighter 8
17	15.00	15.00						●	Perform search and rescue of secondary victims	Firefighter 7 and Firefighter 8
18	0.50	15.00			●				Tunnel exit (15 meters)	Firefighter 7 and Firefighter 8
19	5.00	1.00						●	Changing empty air tanks for full tanks	Firefighter 7 and Firefighter 8
TOTAL	102.00	142.00								

Fig. 15: DAP of search and rescue tasks according to traditional method

On the other hand, in the second analytical diagram of processes we can certify that if we use different binomials per exploration we will be able to travel 180 meters thanks to the use of closed-circuit, guide line and beaconing equipment.

Analytical Diagram of the Process

Survival Odds		
(green)	High	15 minutes
(yellow)	Median	30 minutes
(orange)	Minimum	45 minutes
(red)	Low	60 minutes onwards

AREA :	Operations	METHOD: Traditional	
UNIT:	M3.01	Date :	29/09/2023
TASK:	Search and rescue	Analyst: Héctor Peralta C.	

Step No.	"Time (min.)"	"Distance (meters)"	○	□	⇨	▽	D	◎	DESCRIPTION OF THE STEP	Position
1	1.00	0.50		●					Confirmation of the fire by the Emergency Center	Central emergency telephone operator
2	1.00	1.50	●						Send dispatch to the fire fighting unit, informing the number of troops and troops in command	Firefighter in command
3	0.50	0.50		●					Give arrival of the fire fighting unit to the scene	Firefighter in command
4	0.50	0.50						●	Activate command post and code fire	Firefighter in command
5	5.00	5.00						●	Review of personal protective equipment against fire and self-contained breathing protective equipment for entry and emergency care	Firefighter in command
6	5.00	1.00						●	Assignment of duties to personnel:Search and rescue	Firefighter in command
7	5.00	1.00						●	Assignment of functions to personnel: Fire extinguishing	Firefighter in command
8	0.33	2.00			●				Entrance to the basement/tunnel 2 meters from the exit	Firefighter 1 and Firefighter 2
9	60.00	180.00						●	Carry out search and rescue of primary victims (travel 13 meters)	Firefighter 1 and Firefighter 2
10	0.50	60.00			●				Tunnel exit (15 meters)	Firefighter 1 and Firefighter 2
11	2.00	1.00						●	Change of closed circuit equipment	Firefighter 1 and Firefighter 2
12	0.50	2.00			●				Entrance to the basement/tunnel 2 meters from the exit	Firefighter 3 and Firefighter 4
13	60.00	180.00						●	Carry out search and rescue of primary victims (travel 13 meters)	Firefighter 3 and Firefighter 4
14	0.50	60.00			●				Tunnel exit (15 meters)	Firefighter 3 and Firefighter 4
15	2.00	1.00						●	Change of closed circuit equipment	Firefighter 3 and Firefighter 4
TOTAL	143.83	496.00								

Fig. 16: DAP of search and rescue tasks according to GELD method

In terms of speed by binomials, although there is no difference in the entry stage, this changes when it reaches the exploration and exit stage as shown in the following table.

Table 7: Comparative table of speed by binomial

METHOD	INCOME	EXPLORATION	EXIT
GELD	1 METER EVERY 15 SEC	1 METER W/ 20 SEC	1.5 METER WITH 1 SEC
TRADITIONAL	1 METER EVERY 15 SEC	1 METER W/ 60 SEC	1 METER W/ 2 SEC

The autonomy of binomial exploration in the traditional method is far surpassed by the GELD method

Table 8: Comparative table of Autonomy by binomial

METHOD	INCOME	EXPLORATION	EXIT
GELD	2 METERS WITH 30 SEC.	180 METERS C/ 60 MIN.	60 METERS WITH 40 SEC.
TRADITIONAL	2 METERS WITH 30 SEC.	15 METERS C/ 15 MIN.	30 METERS WITH 60 SEC.

This increases the chances of finding victims because, having greater air availability, the greater the distance traveled by scanning.

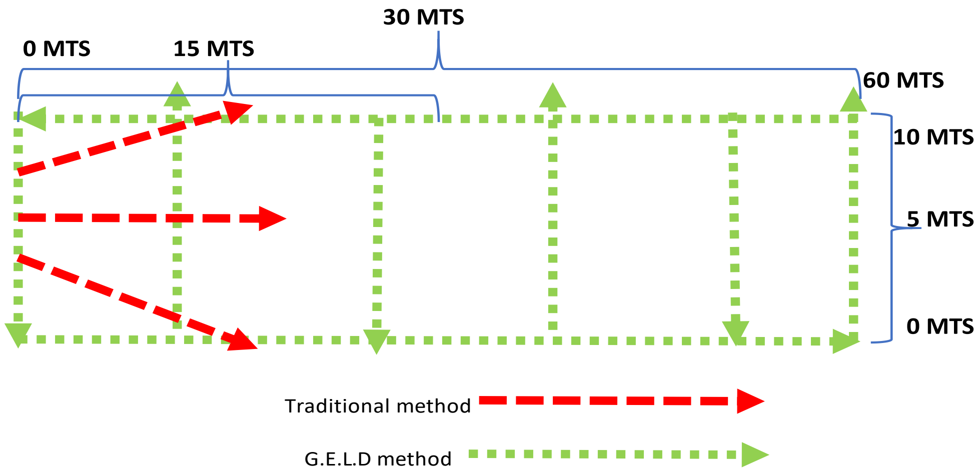

Fig. 16: Graph of distances covered according to exploration method

During this stage, it was studied how the GELD method can influence the optimization of incident response in confined spaces such as tunnels and basements. It was observed that the use of Lean tools offered by GELD produced significant differences in exploration distances, communication systems and location systems, benefiting long-duration explorations. Although NFPA standards are commonly used in the General Corps of Volunteer Firefighters of Peru, the use of tools and strategies used in European countries such as France is unknown. The lack of interest in seeking alternatives to existing methods is due to their perceived effectiveness, although their performance is not accurately measured, as well as misinformation about the dangers in confined spaces. A reengineering process is suggested in operations to improve effectiveness in emergency situations.

3. Conclusions

As conclusions to the research carried out, the influence of GELD on time optimization was verified through the following objectives achieved. The increase in air autonomy from 15 minutes to 60 minutes of effective time was demonstrated due to the replacement of the self-contained breathing protective equipment with the closed circuit equipment.Better resource management was evident using the checkpoint system board thanks to the fact that it allows the amount of air that each binomial has to be quantified through stopwatches, which is reflected in its exploration autonomy.

The impact produced on non-verbal communication through beacons was determined in order to transmit messages of vital importance for safe exploration in confined spaces, thus avoiding area recognition errors during the intervention. The fire hose was replaced by the guide line as a guiding method in exploration work, reducing times to locate from 0 to 30 meters from 20 seconds to 1.33 seconds. In addition to identifying where to go, to the fire or to the exit as required.

The use of Lean tools offered by GELD allowed the distances per scan to be increased from

15 meters to 180 meters per binomial. Thus determining that responding to emergencies in confined spaces using the GELD method increases the chances of achieving highly effective rescue of victims and location of fire source.

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