A Logical Framework Approach to the Monitoring of an Emergency Evacuation Exercise for an Urban Transport System

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Abstract. Disaster Risk Reduction (DRR) is one of the main challenges at the global level. The main goals and targets to be achieved are set out in Agenda 2030 and the Sendai Framework. According to the international risk management cycle, different actions can be implemented before (mitigation and preparedness) and after (response, recovery) a disaster event. This work focuses on preparedness actions. The main objective of this paper is to propose a Logical Framework Approach (LFA) to monitor an emergency evacuation exercise in a transport system. LFA allows the analysts to distinguish the involved resources (input), the exogenous activities to perform the exercise, and the products in terms of capacity (output). The paper investigates the issue related to increased capability (outcome) of emergency managers and people to perform evacuation planned activities in a real context, and then for achieving exposure reduction (goal). With respect to a classical LFA approach, the paper introduces two classes of endogenous activities to measure the transformation: 1) from capacity (output) to capability (outcome), by specifying specific statistical tests; 2) from capability (outcome) to exposure knowledge (goal), by adopting Transport System Models (TSM). The paper contributes to enhancing transparency in the evacuation exercise process by integrating LFA and TSM. The main results of the proposed method's application are presented in relation to an example of a discussion-based activity (workshop). LFA clarifies the existing gaps between capacities and capabilities in relation to DRR. The experimentation results show how it is possible to measure all components of a structure's training and exercises aimed at increasing the preparedness level of a community. The paper is of interest to researchers who study science-policy gaps and to public and private decision-makers involved in the emergency planning process.

Keywords: Emergency Evacuation · Preparedness · Emergency Training and Exercises · Transport System Models · Sustainable Development Goals

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1 Introduction

In recent decades, the frequency of natural and man-made disasters has increased. According to the EM-DAT international disaster database, the disasters' impacts on people and goods are relevant. In 2024 alone, EM-DAT recorded 393 disasters that caused 16,753 deaths, affected over 167 million people [1].

The 2030 Agenda for Sustainable Development acknowledges the necessity of taking action to reduce the risk of disasters. Some Sustainable Development Goals (SDGs) include direct or indirect references to disaster risk reduction. Some particularly relevant SDGs are SDG 1 – *No Poverty*, SDG 11 – *Sustainable Cities and Communities, SDG 12 – Responsible Consumption and Production* and SDG 13 – *Climate Action* [2]. The Sendai Framework for Disaster Risk Reduction 2015–2030 is closely related to the 2030 Agenda and is the United Nations' main global instrument for disaster risk management [3]. The Sendai Framework promotes the adoption of a structured Disaster Risk Management (DRM) cycle, integrating prevention and preparedness before a disaster event, as well as response and recovery afterwards.

This work regards the prevention and preparedness phases of the DRM cycle. In particular, the focus is on evacuation planning aimed at reducing exposure risk components. The objective of an evacuation plan is to reduce the number of people present in the area affected by the effects of the disaster by improving mobility in emergency conditions [4]. However, literature underlines the gaps between the planned actions and their implementation in a real context [5]. In order to reduce these gaps, it is possible to adopt Training and Exercise (T&E) actions. The final aim is to increase the level of capabilities and knowledge of people and managers about planned procedures and their implementation [6–11]. However, mere participation in a T&E action does not ensure the effectiveness of the prevention and preparedness phases. It is necessary to define a clear connection between the evacuation planned procedures and their implementation in real-world systems during a disaster.

To overcome the literature gaps, the paper proposes a Logical Framework Approach (LFA) to monitor an evacuation exercise or training action about transport system planning.

After this introduction, the paper has three sections. Section 2 proposes the LFA framework, illustrating its main components. Section 3 presents an example of the application of the proposed framework. Section 4 closes the paper with a discussion and some final remarks.

2 The LFA Framework for Controlling Training and Exercise Action

2.1 Training and Exercise Actions

During the preparedness phase, T&E activities help to raise awareness among people and managers of the planned procedures. The main aim is to trial these procedures in a stress-free environment. Different international agencies have provided guidelines to help emergency decision-makers design and implement T&E actions [12].

Literature underlines the main characteristics of each T&E action and the potential contribution to:

- *capability*, which assesses the ability to intervene in real conditions to reduce exposure, measured by indicators related to the objective of risk reduction;
- *complexity* of planning and training, measured in terms of the quantity and type of actors involved in the specific activity.

According to international guidelines, T&E actions can be classified into the two following main classes, in relation to an increasing level of complexity and capability:

- *discussion-based activities* conducted in virtual or simulated settings, including seminars, table-top and other activities aimed at illustrating planning contents with a desk approach;
- *operations-based* activities carried out in real-world environments, comprehending exercises involving different classes of actors to reproduce emergency planning settings.

One of the main consolidated international approaches is the Homeland Security Exercise and Evaluation Programme (HSEEP) developed in the US FEMA agency after the disastrous events occurred at the beginning of the third millennium [13]. In the FEMA guidelines, an exercise is "an event or activity, conducted through discussion or action, to develop, evaluate or validate plans, policies, procedures and capabilities that jurisdictions/organizations can use to achieve planned objectives". According to the HSEEP, the discussion-based class includes seminars, workshops, tabletops and games; the operation-based class includes drill, functional exercises and full-scale exercises. In both classes, each activity involves an increasing level of complexity and produces a higher level of capability in the participants (Fig. 1).

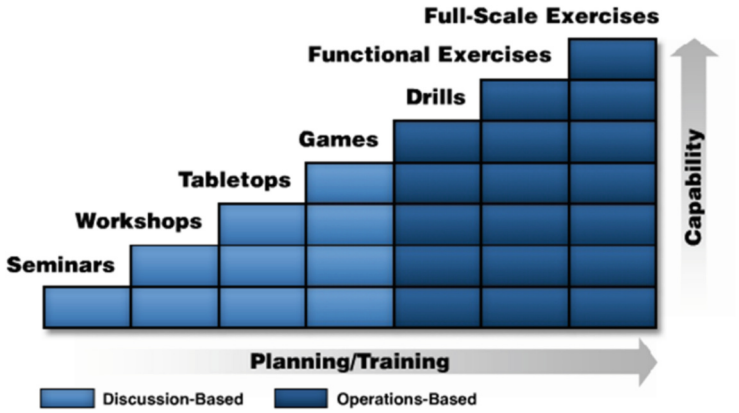

Fig. 1. Exercises classes (Source: [14])

Although the content and operations to be performed in each T&E action are well described and structured in international guidelines, the results of actions are often limited to certifying the ability of the actors involved to perform their assigned tasks. Unlike

material actions, where the product is tangible and measurable (e.g., the amount of temporary infrastructure to organize road signs), training and exercises produce intangible effects that are more complex to measure [15]. This involves the measurement of the awareness' level about evacuation procedures, the increase in skills and organizational capabilities of managers, as well as the changes in users' travel choices produced by a user information system.

2.2 Transport System Models and Transport Risk Analysis

Transport System Models (TSM) simulate the movement of people and goods to analyze, predict, and optimize the performance of transportation networks under ordinary and emergency conditions [16, 17]. This implies the study of transport, demand components and their interactions.

Transport Risk Analysis (TRA) involves evaluating potential hazards and operational uncertainties within transportation systems in order to assess their likelihood, vulnerability and exposure, thereby supporting decision-making processes in the event of an emergency [4, 18–20].

TSM and TRA can operate in an integrated digital platform to increase knowledge about potential effects produced by transport planning actions. The main actors involved should increase their knowledge of TSM and TRA to support their decision-making processes. This implies the necessity to define a framework for monitoring the acquisition of this knowledge.

2.3 The Proposed Framework

The Logical Framework Approach (LFA) was originally developed as a planning tool in a military context [21]. In recent decades, LFA has been adopted by the principal agencies for development as a "results-based" management approach [22]. In the context of the preparedness phase, LFA can be adopted to make the learning process more transparent, considering results connected to a T&E action [23–25].

LFA highlights the logic behind a generic activity in order to identify the components of an evacuation exercise and mutual relationships from the resources used to the specific and general objectives to be pursued.

The main components of LFA are here synthesised in the following subsections.

a. Input. Inputs include all the financial (e.g., amount of euros) and human (e.g., number of organisers) resources needed to conduct a T&E action. These resources must be sized according to the complexity of the specific **action**.

The *na* input indicators can be grouped into the following vector:

$$\mathbf{i^a} = \left(i^a{}_1, i^a{}_2, \ldots, i^a{}_{na}\right) \tag{1}$$

b. Exogenous activities. With the available resources, it is possible to organize and implement the T&E action [26, 27]. The sub-activities and the corresponding allocation of available resources must be defined. For example, the distribution of staff*hours required to complete each sub-activity is established. A preliminary assessment must first be carried out to measure the participants' initial knowledge of the plan procedures.

The *nb* exogenous activities can be represented with a function vector that collects the possible organizational variables:

$$\boldsymbol{\gamma}^{\mathbf{b}} = \left(\gamma^{\mathrm{b}}{}_1, \gamma^{\mathrm{b}}{}_2, \ldots, \gamma^{\mathrm{b}}{}_{\mathrm{nb}}\right) \tag{2}$$

c. Output. The implementation of the T&E action produces immediate, concrete effects that can be objectively measured. This is the quantity of plan procedure content transferred to participants. The main outcome is participant capacity, which can be measured through a set of indicators, such as the actual number of managers who have completed all the planned sub-activities.

The *nc* output indicators can be represented in the following vector**:**

$$\boldsymbol{i}^{\mathbf{c}} = \left(\mathrm{i}^{\mathrm{c}}{}_1, \mathrm{i}^{\mathrm{c}}{}_2, \ldots, \mathrm{i}^{\mathrm{c}}{}_{\mathrm{nc}}\right) \tag{3}$$

d. Endogenous Activities 1: from outputs to outcomes. Capacity is a necessary but not sufficient condition for the expected effects of the activities to be achieved. It is necessary to assess the current level of knowledge and skills acquired by participants following the training and/or exercise activities. To this end, a test can be administered to participants to measure the capability acquired by each participant. Capability measures the actual level of learning of the concepts taught during the generic activity. A questionnaire with closed-end questions on the topics illustrated can be used [28, 29].

The *nd* endogenous activities can be represented with a vector of functions that collects the possible tests that can be carried out to verify the acquisition of the capabilities:

$$\gamma^{\mathrm{d}} = \left(\gamma^{\mathrm{d}}{}_1, \gamma^{\mathrm{d}}{}_2, \ldots, \gamma^{\mathrm{d}}{}_{\mathrm{nd}}\right) \tag{4}$$

e. Outcomes. Endogenous activities produce outcomes in terms of the achievement of capability by participants. Outcomes can be measured through a set of indicators. For example, this involves measuring the number of participants who answered the questionnaire correctly. Achieving capability strengthens participants' ability to respond appropriately in a real-world situation where an evacuation procedure must be activated.

However, acquiring capability alone does not guarantee risk reduction. It is necessary to quantify the improvement in the performance of the transport system under evacuation conditions following the acquisition of knowledge and skills.

The *ne* outcome indicators can be grouped in the following vector**:**

$$\mathrm{i}^{\mathrm{e}} = \left(\mathrm{i}^{\mathrm{e}}{}_1, \mathrm{i}^{\mathrm{e}}{}_2, \ldots, \mathrm{i}^{\mathrm{e}}{}_{\mathrm{ne}}\right) \tag{5}$$

f. Endogenous Activities 2: from outcomes to goals. These activities reflect the effects of acquiring capabilities. Possible tools for evaluating ex ante the reduction of exposure are the Transport System Models and their components for representing the transport supply [30, 31], the transport demand [32–34] and their interaction [35, 36]. TSMs can be used, for example, to simulate the functioning of a transport network in an urban context, including estimated times for users to reach the safe areas established by the plan.

The *nf* endogenous activities can be represented with a vectorial function that collects the functions of the TSM models with which to estimate the performance of the transport network in evacuation conditions:

$$\boldsymbol{\gamma}^{\mathbf{f}} = \left(\gamma^{\mathrm{f}}{}_1, \gamma^{\mathrm{f}}{}_2, \ldots, \gamma^{\mathrm{f}}{}_{\mathrm{nf}}\right) \tag{6}$$

g. Goals. Goals represent the final results intended to be achieved through T&E actions. The final objective can be measured, for example, in terms of reducing evacuation times and thus increasing the probability of saving lives. The best performances have already been calculated during the planning (or mitigation) phase and represent target values to be achieved with a series of T&E actions [6]. It is therefore necessary to estimate the effects produced by each training/exercise activity in terms of contribution to improvement or deviation of performance from the targets to be achieved.

The *ng* goals indicators can be represented in the following vector:

$$\mathbf{i}^{\mathbf{g}} = \left(\mathrm{i}^{\mathrm{g}}{}_1, \mathrm{i}^{\mathrm{g}}{}_2, \ldots, \mathrm{i}^{\mathrm{g}}{}_{\mathrm{ng}}\right) \tag{7}$$

The synthetic representation of the components is obtained through a Logical Framework Matrix (LFM). This is a matrix consisting of

- Seven rows, one for each component of the LFA;
- Four columns which, for each component, report the description, the indicators, the means of verification and the external factors, i.e. those outside the control of the overall process.

A synthetic representation of a proposed LFM is reported in Fig. 2.

LFA component	Indicators	Means of verification	External factors
a. Inputs	i^{a}	monitoring	
b. Exogenous activities	γ^{b}	validation	elements out of control
c. Outputs	i^{c}	monitoring	
d. Endogenous activities 1	γ^{d}	validation	
e. Outcomes	i^{e}	monitoring	
f. Endogenous activities 2	γ^{f}	validation	
g. Goals	i^{g}	monitoring	

If

Then

Fig. 2. Generic LFM matrix

3 An Example of Training Action

The case study is a numerical example designed to illustrate the variables and functions introduced to specify the LFA process and the related LFM presented in Sect. 2. The specific problem to be addressed is the evacuation of a portion of a city in the event of a flood. For this problem, during the mitigation phase, an evacuation plan was developed that defined the procedures and estimated the quantitative effects measured through a set of indicators. Among these, the evacuation times for the entire area are considered ($t_{ev,\,tot}$).

3.1 Activities Description

The designed action concerns the training of managers in the evacuation procedures being analyzed. Specifically, reference is made to a discussion-based workshop activity. It is assumed that a generic organization invests a certain amount of financial resources to organize and conduct training for a defined number of managers.

The managers will be required to participate in the training course (capacity) and acquire the knowledge and skills (capability) to simulate an evacuation of an urban area. The goal is to ensure that the managers are able to use the acquired capabilities to reproduce the planned conditions through T&E action and thus reduce exposure.

3.2 LFA and LFM

The components of the LFA are explained below.

Input indicators are:

i^a_1 amount of financial resources to organize and implement the training course = 40.000€;

i^a_2:potential number of managers to be trained = 20 managers;

The vector of input indicators of Expression (1) therefore assumes the following values

$\mathbf{i^a}$ = (40.000 €, 20 managers)

The function which represents the exogenous activities is the distribution of total hours available (htot = 400 h) intended for the organization (h1 = 150 h) and realization of the course (h2 = 250 h). The vector function represented in Eq. (2) is:

$$\gamma^b = h_{tot} = h_1 + h_2$$

Output indicators are:

i^c_1 mandatory threshold of hours assigned to participants to acquire the capacity of manager = 200 h;

i^c_2:actual number of managers who attended the course for a number of hours exceeding the threshold = 18 managers;

i^c_3:percentage of managers actually trained = 90%.

The vector of output indicators of Eq. (3) therefore assumes the following values:

$\mathbf{i^c}$ = (200 h, 18 managers, 90%)

The endogenous activity 1 is represented by a function that corresponds to a test composed of a vector of k = 20 multiple-choice questions q.

$$\gamma_1^{\mathrm{d}} : \mathrm{R}(\mathrm{q}) = \mathrm{R}(\mathrm{q}_1, \mathrm{q}_2, \ldots, \mathrm{q}_\mathrm{k})$$

Therefore, the vector function represented in Eq. (4) is:

$$\gamma^{\mathrm{d}} = R(q)$$

Outcome indicators are:

$\mathrm{i}^{\mathrm{e}}{}_1$ minimum threshold in terms of percentage of correct answers to be provided to demonstrate having acquired the capability:

$\mathrm{i}^{\mathrm{e}}{}_1 = \eta_\mathrm{j} = (\mathrm{c_j} / \mathrm{k}) \geq 80\%$

for example, if a participant j answers 17 questions correctly

$\eta^{\mathrm{e}}{}_j = \mathrm{c_j} / \mathrm{k} = 17/20 = 85\%$

$\mathrm{i}^{\mathrm{e}}{}_2$ number of participants who exceeded the threshold $\mathrm{i}_2^{\mathrm{e}}$, and who have therefore acquired the capability, for example equal to 16 participants.

The vector of outcome indicators of Eq. (5), relating to the generic participant j, therefore assumes the following values:

$\mathbf{i^e} = (80\%, 16$ managers)

The function representing the endogenous activity 2 allows the 16 managers who have acquired the capability to estimate the evacuation times for the assigned study area. The function used by the generic participant, the only component of the vector introduced with the Eq. (6) is equal to:

γ_j^{f}: cost function for estimating evacuation times adopted by the generic participant

A possible cost function for estimating evacuation link travel time is the BPR.

These activities can be supported by emerging Information and Communication Technologies (e-ICT) that provide digital tools (e.g. web maps or simulations visualization tools) that enhance the representation of a virtual environment [37].

Goals indicators are:

$\mathrm{i}^{\mathrm{g}}{}_1$ minimum threshold in terms of percentage of evacuation time calculated by the generic participant j (tev,j) compared to that calculated by plan

$$\eta^{\mathrm{g}}{}_1 = \mathrm{tev/tev, tot} = 75\%$$

$\mathrm{i}^{\mathrm{g}}{}_2$:percentage of managers who correctly calculated evacuation times exceeding the threshold η^{g}; for example, if only 15 have calculated evacuation times which, compared to the times calculated by the plan, exceed the threshold η^{g}

$$\eta^{\mathrm{g}}{}_2 = 15/16 = 93.7\%$$

The vector of the goal indicators of the Eq. (7), relative to the generic participant j, therefore assumes the following values:

$\mathbf{i^g} = (75\%, 93.7\%)$

Figure *3* describes the LFM matrix sintetysing all the LFA components and logical connections. The matrix reports the obtained results obtained from the exercise.

LFA component	Indicators	Means of verification	External factors
a. Inputs	i_a = (40.000 €, 20 manager)	Budget	
b. Exogenous activities	$\gamma^b = h_{tot} = h_1 + h_2$	Project	elements out of control
c. Outputs	i^c = (200 hours,18 manager, 90%)	Course register	
d. Endogenous activities 1	$\gamma^d = R(\mathbf{q})$	Test register	
e. Outcomes	i^e = (80%, 16 manager)	Test register	
f. Endogenous activities 2	γ^f_j	TSM validation	
g. Goals	i^e = (75%, 93.7%)	TSM application	

If

Then

Fig. 3. Generic LFM matrix

4 Discussion and Conclusive Remarks

Disaster risk reduction is a global priority. Major international agencies are promoting various actions related to the DRM cycle. All stakeholders recognize the important role of T&E actions in increasing preparedness. Guidelines are available to guide the development of these actions. However, the focus is primarily on capacity building among stakeholders, especially managers. It is necessary to broaden the audience of participants in the actions by involving citizens. Furthermore, it is necessary to ensure that the trained personnel acquire capabilities in terms of knowledge and skills. In the case of evacuation plans aimed at reducing the exposure component of risk, it is necessary to ensure that those involved are aware of the best practices to implement to ensure high levels of efficiency and effectiveness of evacuation procedures. However, capacity and capability are necessary but not sufficient conditions for reducing exposure and therefore risk. It is necessary to evaluate how the acquired capabilities can contribute to reducing exposure by narrowing the gap between planned and actual conditions.

The LFA is a potential tool for increasing transparency in the evaluation and monitoring of training and evacuation activities. Explaining the individual components of the LFA and summarizing them through the LFM increases transparency and highlights any gaps between planning activities and their actual implementation in real-world situations.

The example presented, albeit in a simplified way, has shown how to apply the proposed framework and present the results obtained from the organization and implementation of a generic training action.

The paper has some limitations. The first limit regards the kind of evacuation exercise, restricted to a workshop. The second limitation concerns the definition of indicators and functions. The analytical formulations presented need further improvement. A further limitation concerns the contribution of ICT to improving the monitoring of exercises and training activities as well as the construction of TSMs.

Further research developments regard the extension of the experimentation, for instance a full-scale exercise. More in general, it is possible to develop methods and models to control more complex discussion-based and operation-based exercises.

The results of this paper and the further development of the research are of interest to public and private decision-makers involved in emergency planning processes. The proposed methodology can be adopted for measuring disaster risk reduction and the achievement of sustainability goals.

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