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Developing a Resilience Framework for Railway Companies

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In a dynamic environment like a transportation company, accidents are commonplace. For this reason, it is essential to have a qualitative and quantitative model of Resilience to manage possible problems. Therefore, resilience engineering is significant and increasingly used in complex systems. This paper studies Resilience Engineering, its applications, and how it is essential to define and measure a System Management for Resilience. In this regard, a qualitative Resilience Framework is proposed and applied to a rail company to react to adverse and sudden events. Furthermore, it is crucial to measure a company's level of Resilience. The FAHP and TOPSIS models were used and suitably reworked to create an appropriate resilience index.

Keywords: Resilience Engineering, Resilience Index, Resilience Framework.

1. Introduction

Transportation companies play a critically important role in mobility in cities, regions, and countries. Following what has been reported in studies conducted on the development of rail transportation (Ilona J., 2010), the number of people who use public transportation daily to reach workplaces and universities or use it for simple leisure trips has reached considerable numbers over time. This has resulted in the need to intensify rail networks and increase the number of daily scheduled trips and the services offered to travel users on board and at stations. At the same time, it has proven cost-effective and efficient to increase the use of the rail network for freight transportation (Grimaldi, 2021). Nowadays, a considerable proportion of the food on our tables or the items we commonly see in warehouses has been transported by rail. However, as is only natural, to increase the number and complexity of transportation, it has been necessary for companies operating in the railway sector to have increased the quality and quantity of their human and material resources. In fact, with the appropriate improvements, it is possible to solve the problems that arise daily and threaten rail services. Therefore, each company must cope with the ability to promptly resolve all problems that descend from mechanical failures due to trainsets or infrastructure or human error. For these reasons, it has proven to be fundamental to know the concept of Resilience and to understand how to modify the organization of individual companies to increase the ability to solve unexpected problems (T.O. Grøtan, 2016). In addition, Resilience indicates the ability to adapt to uncertain environments, respond promptly to hazards, and recover after they have occurred (Sutcliffe e Vogus, 2003-2012). In railways, this translates into a well-organized workforce with specialized emergency response teams with equipment available to diagnose networks and trainsets and repair infrastructure vehicles.

The innovation of this article consists of creating a general quantitative index of the Resilience of a railway company, which has not yet been identified in these terms. This work is organized as follows: in section 2, Resilience Engineering, where the meaning of this capability is explained and how it is understood in the field. Section 3, Proposition Framework, explains the need to reorganize the company to maximize Resilience. In section 4, Determining the Resilience of a rail transportation company, where the need for a quantitative index is explained, and the use of FAHP is shown. In section 5, Quantification Index is summarized on how information on resilience indicators should be collected. Section 6, Resilience Level with an Improved TOPSIS, explains all the topsis analysis steps. In section 7 Propositions and, finally, in section 8 Conclusions.

2. Resilience Engineering

Organizational Resilience was initially considered a reactive ability of companies to adapt to the changing conditions of the external environment. However, Mayer (1982) defined Resilience as the result of the adaptive Capacity with which companies try to face a sudden or unexpected external change so as to determine the incompatibility of the strategic and managerial approaches usually used by companies with external contingencies.

Therefore this interpretation takes into account the existence of a self-regenerative capacity of the organizations, which can carry out a metamorphosis of their own structures or organizational processes to increase their ability to survive in the long term (Nemeth et al. 1997); it neglects the ability of companies to act proactively to anticipate external change (Hollnagel, Westrum, & Leveson, 2007).

This concept was explained by Kaplan, who stated that: an individual's ability to adapt can be explained by protective factors, present at every systematic level, which can balance the effect of risk factors (Kaplan,1999).

Resilience Engineering has been proposed as a reference for research aimed at improving the ability of a company's organizational system to plan work and respond to these pressures (Luthar et al., 2000).

In 2014 Francis and Bekera tried to identify the capabilities common to the various areas, identifying three main ones, as shown in Fig-1:

- Absorptive Capacity
- Adaptive Capacity
- Restorative Capacity

The first one measures the degree to which a system can absorb the impact of perturbations, minimizing the consequences. This feature depends on the configurations and operating procedures of the system.

Adaptive Capacity is the ability of a system to make some changes to adapt its operation before or during the occurrence of anomalies.

Restorative Capacity is the ability of a system to quickly return to normal or even improve system reliability after an adverse event occurs.

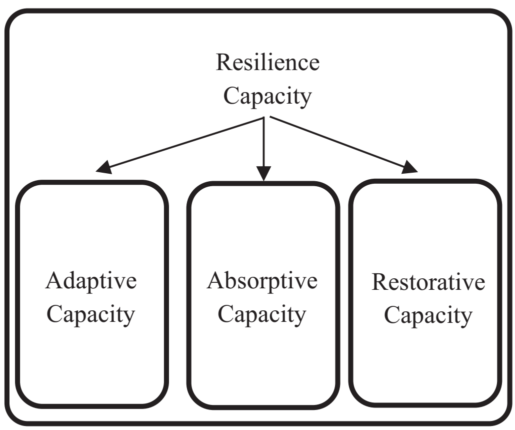

Fig.1-Resilience Tank

For example, consider any company's ICT (Information and Communication Technology) environment. The ISO standards we take as reference are ISO 9001 on quality, ISO 27001 on information security and ISO 22301 on business continuity. All three standards are certifiable, so they are subject to verification by a third-party body that certifies their compliance.

The quality standard is included as the main container of the company management system. It is standard with the most history and has reached such a level of maturity that it has now encompassed all product sectors in the market, involving companies of all sizes. This standard generally underscores the leadership's ability to focus on customer satisfaction in delivering products/services with a given quality standard. In addition, we represent engineering Resilience through a hierarchical model, as shown in Fig-2.

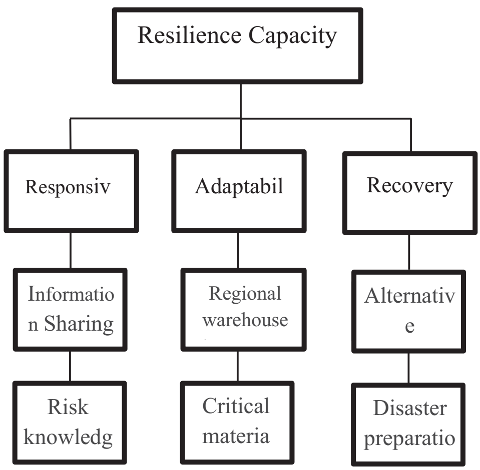

Fig.2-Hierarchical model

Fig.2-Classification Index

This chart shows the three levels of Resilience that will be useful for quantizing it. Indicators can analyze the company's tendency to respond resiliently at different times by predicting incidents and will make the company's current Resilience quantifiable.

In a resilient context, it is also important to keep in mind what concerns the area of security, especially in a highly industrialised era such as Industry 4.0.

With a scientific analysis (Di Nardo, M 2021), a resilient view of the company can be obtained by taking into account the improvement of workers' health and the benefits derived from it.

In the rail sector, however, there is a gap in the literature regarding the concept of Resilience; for companies that provide services and work closely with travelers, whether tourists or business people, it is necessary to have an organization and a framework that is able to determine what and in what order to do in the event of an accident.

3. Proposition Framework

The application of these concepts is widely reflected in the prevention/resolution of problems related to railway accidents.

Although the train is one of the safest means, as indeed the plane, the consequences of rare accidents are very often dramatic. For this reason, it is the common will of railway undertakings and infrastructure managers to contain the risk as much as possible and reduce an already very low probability of occurrence.

Over the years, the evolution of technology has contributed significantly to railway safety and will continue to improve the trend towards zero accidents, the primary objective of all actors involved. The "Developing a resilience framework for railway companies" is one of the action segments for increasing railway resilience.

This study proposes a methodological contribution (represented in Fig-3), hypothesizing resilience requirements and preventive and ex-post validation procedures that, in overcoming the emergency approach, favour Resilience in the railway sector in case of derailment and evacuation of the area safely. This framework shows how resilience indicators stand for requirements or capabilities that the railway company presents in similar situations.

- Command: Create an parameter a hierarchical and coordination reference pool to contact to coordinate the various emergency management actions.
- Assessment: evaluation of what happened and its evolution and sizing to correctly activate the resources necessary for management.
- Recovery triage and from the place of the event: securing the area and the operators who

must intervene in the area of action to rescue personnel and users and recover any victims; evacuation of the area.

- Safe transport: identification of modes of transport to safe places for survivors and organization of movement to the destination locations
- Information sharing: both internal (management of rail traffic, delays, etc.) and external (with reference to both the relationship with the media and the possibility of communicating with relatives of the people involved in the accident)

Psychological support for the subjects involved, including staff with a possible assignment to other tasks, appointing trusted lawyers for them collaboration with the authorities to allow investigations to be carried out as quickly as possible for the speediest evacuation of the wagons involved in the accident and the restoration of the section of line affected by the derailment.

consider that there are resilience indicators that can be traced back to the three capacities: Absorptive, Adaptive, and Restorative. When properly used, these resilience indicators return a clear and quantitative indication of the company's level of Resilience: Our goal is to formulate a Resilience Index. In order to formulate a Resilience Index a profound study has been developed. Supply chain experts have developed indices based on the Multi-Attribute Decision Making method (MADM) (Pournader, M 2016) (Pei, J 2019); however, these are not versatile enough. An alternative is to use the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) method coupled with the Fuzzy Analytic Hierarchy Process (FAHP), which is the evolution of the AHP method with a fuzzy environment (Ji D, 2006), which was also developed for the supply chain but is also appropriate for our purposes. With the FAHP method, we want to identify the weight of the indicators we use to calculate the resilience index.
We define the variables i and j:

- j (j=1,.n) enterprise resilience indicator

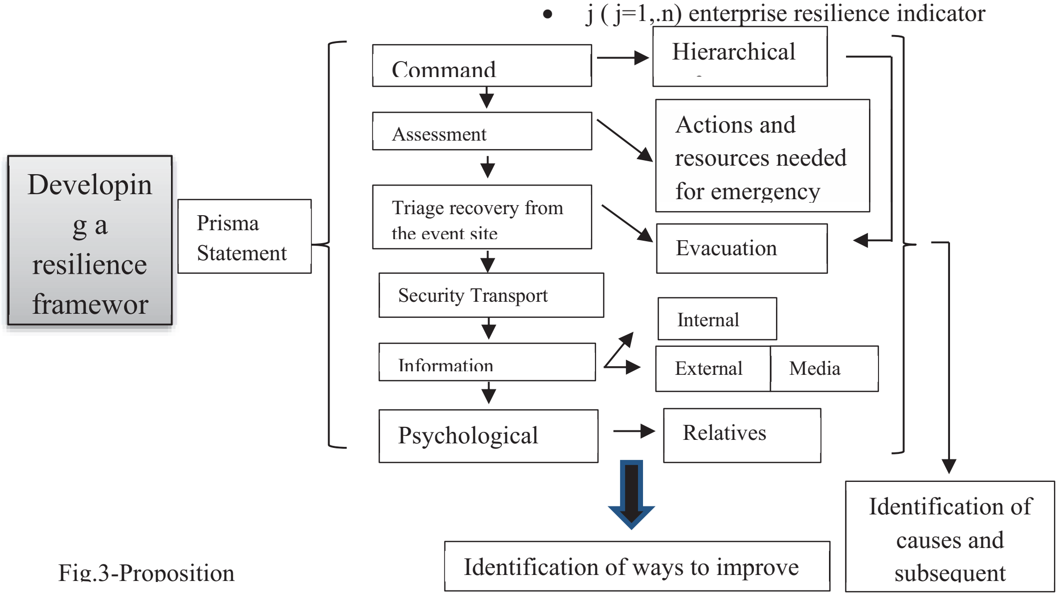

Fig.3-Proposition

4. Determining the Resilience of a Rail Transportation Company

Resilience is the ability of the company to resolve incidents and restore the services offered in the shortest possible time.

While an ad hoc organizational model is the first requirement for structuring the company, we must

- i (i = 1,2,…,m) decision points;

With the FAHP method, we construct a consistency matrix to simplify the operation of assigning weights, which is crucial for obtaining more reliable results.

1-Define the resilience indicators to be used for index calculation

2-Construct the judgment matrix using the five-scale method (Wang X, 2019) by comparing the value ratio $a_{ij} = (i, j = 1,2, \ldots, n)$ for each pair of indicators using Fig-4.

If indicator i is as or more important than indicator j	the a_{ij} VALUE is:
=	0.5
>	0.6
>>	0.7
>>>	0.8
>>>	0.9
In the case of reciprocal $a_{ij} = 1 - a_{ij} = 0{,}5$	

Fig.4-Table Value-Ratio indicators

3-Define r_i as the sum of i rows of the A_{nxn} matrix and constitute the consistency matrix R_{nxn}

$$r_i = \sum_{j=1}^{n} a_{ij} (i = 1,2, \ldots, n) \qquad (1)$$

$$r_{ij} = \frac{r_i - r_j}{2(n-1)} + 0{,}5 \qquad (2)$$

4-Normalizing the consistency matrix R_{nxn}, we obtain the weight of each indicator W = (ω1,ω2,...,ωn) of each resilience indicator. W = $(\omega_1, \omega_2, \ldots, \omega_n)$

$$\omega_i = \frac{\sum_{j=1}^{n} r_{ij} - 1 + \frac{n}{2}}{n(n-1)} (i = 1,2, \ldots, n) \qquad (3)$$

5- Construct the characteristic matrix $W_{nxn}^{*}(w_{ij})$ of A_{nxn} to calculate the compatibility index:

$$w_{ij} = \frac{w_i}{w_i + w_j} \qquad (4)$$

$$I(A, W^*) = \frac{1}{n^2} \sum_{i=1}^{n} \sum_{j=1}^{n} \left| a_{ij} + w_{ij} - 1 \right| \qquad (5)$$

If $I(A, W^*) < 0{,}1$, it passes the consistency test.

5. Quantification Index

For the use of the FAHP-TOPSIS method, however, it is necessary to collect data on the values to be assigned to the individual indices, which must also be defined by qualitative analysis. The most effective way to achieve these values is, unfortunately, to be inside a railroad environment and have the help of the experts and insiders who deal with railroad resilience daily. Each index will be analyzed by the FAHP method to identify its weight coefficient. The indices are then divided according to the 3 components of Resilience, and each index must be associated with an appropriate value either locally or globally. The indicators listed are just an example; to quantify them all would require on-farm experimentation. The next step in the research is to conduct information acquisition directly in the field by asking rail industry insiders what aspects impact rail service most. This would first identify the resilience indicators and, more importantly, derive the needed weight. Examples of resilience indicators that we propose are the Available Fleet index, Wear index of each vehicle and infrastructure (including technical values such as wear number).

It should be noted that the normal operation of a railway company requires an assessment of the resilience of external services.

Telecommunications and power services are critical to this industry, and resilience analysis must consider which services may fail if infrastructure fails. In addition to identifying the causes of service interruption, the analysis must also identify when and how external services can be re-established. It is also important to determine whether these services are the responsibility of the railway company or not, and what actions can be taken in the event of a failure.

These considerations make clear that the system was complex and that the relationships between its components were not straightforward. The analysis of resilience determines the ability of a system to withstand, to adapt and to recover from unpredictable events. In order to improve the level of resilience, it is important to have an understanding of the characteristics and criticality of individual infrastructure assets. Di Nardo (2020), focused on the Railway Communication System, looking at its level of control and the time taken to recover. This system is essential for tracking rolling stock and for secondary applications such as quantifying rail wear.

6. Resilience Level with an Improved TOPSIS

"The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision analysis method" (Chen P, 2021). It compares a set of results. After normalizing the results for each criterion and calculating the geometric distance for each alternative and the ideal alternative, he can determine the best score for each criterion. We use this method because it was developed with a view to high versatility in various areas (Harami-Marbini A, 2017). The result is a function of the values that have been attributed to the indicators. For this reason, it is advisable to choose the values to be assigned carefully, and it may prove useful to repeat the calculation several times, improving the accuracy of the indicators each time for more reliable results as seen in specific studies on improving TOPSIS (Yu X, 2020).

The steps to improve the TOPSIS method are as follows:

1-Determine the optimal and worst sets of index solutions based on the experience of experts in the field:

$$A = [y_1^+, y_2^+, \dots, y_j^+] \quad (6)$$

$$B = [y_1^-, y_2^-, \dots, y_j^-] \quad (7)$$

where $j = 1,2, \dots, n$.

2- Normalize the evaluation matrix $P_{mxn}(p_{ij})$ to obtain the feature matrix $N_{mxn}(n_{ij})$:

$$n_{ij} = \frac{P_{ij} - y_j^-}{y_j^+ - y_j^-} \quad (8)$$

where P_{ij} is the enterprise's index j value at time i.

3- Using the index weight matrix W_{mxn} obtained using the FAHP method, the weighted feature matrix $V_{mxn}(v_{ij})$ is calculated as follows:

$$P_{mxn} = N_{mxn} \; x \; W_{mxn} \quad (9)$$

4- Calculate the Euclidean distance between each index, positive and negative ideal solutions for decision time i:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - V_j^+\right)^2} \quad (10)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - V_j^-\right)^2} \quad (11)$$

for i = 1,2,…,m. The V_j^+ and V_j^- represent maximum and minimum values of each column of the matrix V_{mxn}.

5-Score the resilience level of the enterprise at decision time i and obtain its value:

$$c_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (12)$$

where $0 \leq c_i \leq 1$. The higher c_i is, the stronger the Resilience of the enterprise at the time i.

So strictly according to these quantitative methods coupled with our proposition framework, we can say that we have the issue of a company's Resilience under control even in the railroad context. To adapt the TOPSIS-based model to the railway environment, it is proposed to increase the number of processing for each additional information in the index and parameter database. This will provide a feedback on the possible improvement or deterioration of the resilience index.

7. Research propositions

From the analysis of the articles and keywords, it was found that there is no quantitative model for measuring the Resilience of a railway company.

Measuring could, in fact, allow a company to identify its global ranking in terms of Resilience relative to other companies, then establish an effective benchmark.

Such an index would certainly help companies to be more productive, in that, it constitutes an important response factor that would make the company able to adapt and contextually recover in the face of adverse events.

Achieving such a goal would enable a company to compete more in the market than others.

Conclusions

This article examined the Resilience of a railroad company by analyzing it from several aspects.

First, we analyzed the meaning of engineering Resilience, understood as the company's ability to absorb, adapt, and restorative. Starting from these aspects, an optimized organizational framework was developed in the management of unforeseen events or incidents, finding that the basis of good Resilience is based on the structure of the company's organization. However, we also need to measure that Capacity, and to do so we used a FAHP-TOPSIS model imported from the supply chain environment that, using industry indices, allows us to quantify a resilience index and measure its changes over time, keeping track of the evolution of the company's Resilience over time. The weakness of this article is the qualitative organizational model is too general, it would be appropriate to define one for each type of eventuality highlighting all the complications that each incident may hide. At the same time the lack of indicators of Resilience and quantification of them makes the TOPSIS model not very usable for all those new companies with little experience in the field, so it would be necessary to carry out field experimentation in order to outline at least global values that could become benchmarks for small-medium railway companies.

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