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Matrix systemic reasoning in socio-technical systems applied to rail transportation

Razonamiento sistémico matricial en sistemas sociotécnicos aplicado al transporte ferroviario

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Keywords

TRANSPORT- SAFETY-ACCIDENT INVESTIGATION MODEL - RAILWAY - SYSTEMIC ANALYSIS - COMPLEX SYSTEMS.

Palabras clave

TRANSPORTE-SEGURIDAD OPERACIONAL-MODELO DE INVESTIGACIÓN DE ACCIDENTES-FERROVIARIO-ANÁLISIS SISTÉMICO-SISTEMAS COMPLEJOS.

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Abstract

Methodological proposal for analyzing transport systems based on the concepts of the systemic approach to accident investigation developed through the creation of possible coupling matrices.

This article addresses the following questions: How can we arrange the elements of a complex system in a simple, organized, repetitive and general way? How can we visualize the interactions to see the emergent properties? Is there only one way to search for or handle these properties?

Resumen

Propuesta metodológica para el análisis de sistemas de transporte basada en los conceptos del enfoque sistémico de investigación de accidentes, desarrollada mediante la creación de matrices de acoplamientos posibles.

A lo largo de este artículo se trabaja sobre los siguientes interrogantes: ¿cómo podemos hacer para ordenar los elementos de un sistema complejo de forma simple, metódica, repetitiva y general? ¿Cómo podemos visualizar las interacciones para ver las propiedades emergentes? ¿Existe una sola forma de buscar o manejar esas propiedades?

Introduction

To develop the central idea of this paper, let me start with Albert Einstein's phrase, published in The Saturday Evening Post in 1929: "Imagination is more important than knowledge. Knowledge is limited and imagination encircles the world."

So, what was the idea born from imagination and in what context did it become known? Its origin dates back to the introductory courses given by Alejandro Covello at the Transportation Safety Board (Junta de Seguridad en el Transporte, JST), with the support of the National Director Eng. Diego Di Siervi, and Eng. Germán Goñi, investigator of the National Department of Rail Occurrences of the JST (DNISF, Spanish acronym). On such occasion, the notions of systemic analysis and normal accidents in sociotechnical systems intersected with the concern that the country was going through in the context of the COVID-19 pandemic. So, in the process of searching for information on a systemic analysis of the Argentine economic and political crisis, we came across the investigation "Systemic analysis of the coronavirus pandemic. "A normal accident" by Covello and Muro (2020), in which the authors break down the sociotechnical systemwhere the pandemic develops into its different components and then analyze them in a new way.

Reading this material triggered a series of questions; how can we order the elements of a complex system in a simple, methodical, repetitive and general way? How can we visualize the interactions to determine the emergent properties? Is there only one way to search or handle those properties? These questions remained in the realm of ideas until confronted with the regulations, methods and risk-matrices of the DNISF Studies area, used to arrange information elements in intersections of rows and columns. Therefore, to try to answer the initial questions, and based on a wealth of knowledge in electronics and programming, we begin to reason in terms of systemic analysis through a matrix organization. And this is how we arrived to the system-matrix reasoning (SMR) that is described throughout this paper.

Possible coupling matrices

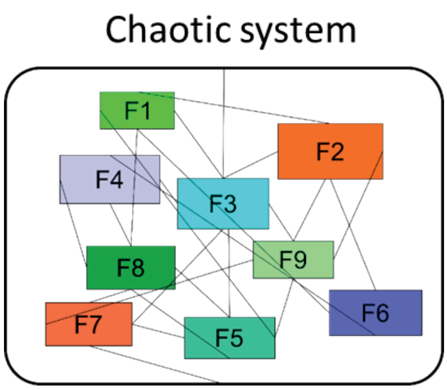
To develop the concept of the possible couplings matrices (PCM), we start from the idea of sociotechnical system (STS) coming from the general theory of systems (GTS).

Sociotechnical systems can be defined as a set of interacting elements. Interaction means that the "p" elements are in "R" relationships. The behavior of a p element in R is different from its behavior in another R' relation. If the behaviors in R and R' do not differ, there is no interaction, and the elements behave independently with respect to the R and R' relations (Ludwig von Bertalanffy, 1976).

The mutual interaction of the different elements that make up a system gives rise to emergent properties that may or may not be desired, and which are the result of the set of relationships between parties. These properties are based on simple behaviors. The properties generate a whole that is greater than the sum of the individual properties of the elements that make up the system.

For the system-matrix reasoing (SMR), the p elements are the component factors F1, F2, Fn-1 and Fn, and the R relations are the mutual couplings. If these do not have any order, restriction or barrier, we can say that the emergent property of the system would be chaos, as shown in Figure 1

Image 1. Chaotic system representation.



Source: own elaboration.

In order to develop the matrix of the system-matrix reasoning (SMR) it is intended, first, to visualize and analyze the different constituent factors of the system and their interactions. Following this logic, the system can be analyzed from a state of chaos of the interactions in order to achieve certain properties for a desired state of order, or else, the system can be analyzed from the current state of order, to visualize a state of chaos of the interactions, that allows to foresee properties that were previously undetermined.

To this purpose, a list of general constituent factors of the system (GF) is defined first. In the case of a transportation system, for example, vehicular, structural, organizational, regulatory factors, etc. are stipulated, all of which provide information about the system itself. Table 1 develops a generic list of constituent factors.

Table 1. List 1 of constituent factors

Constituent Factors	Factor 1	Fac-tor 2	Factor 3	Factor 4

Source: own elaboration.

Then, List 1 is transposed with List 2 of factors and they are mutually correlated, creating a Possible Couplings Matrix or PCM, as seen in Table 3.

Table 2. List 2 of factors, transposed with those from list 1

Constituent Factors
Factor 1
Factor 2
Factor 3
Factor 4

Source: own elaboration.

Table 3. Generic PCM of constituent factors

PCM	Factor 1	Factor 2	Factor 3	Factor 4
Factor 1	Element 11	Element 12	Element 13	Element 14
Factor 2	Element 21	Element 22	Element 23	Element 24
Factor 3	Element 31	Element 32	Element 33	Element 34
Factor 4	Element 41	Element 42	Element 43	Element 44

Source: own elaboration.

The numbers of the row and column they intersect identify the PCM information elements. For example, Element 12 intercepts Factors 1 and 2. Later on, they are defined as possible couplings and are identified with the letter "A". The cells in Table 3 that are shaded in gray are the values that make up a diagonal in the PCM, and that are later defined as "System identities".

The general factors of the system, in turn, are subdivided into the individual factors involved in the event. These factors are factually identified in the field survey.

Each element of the PCM can create a new matrix of correlations, with new possibilities, as if it were a fractal2 that repeats itself on different scales. This reasoning will reproduce the method for the different combinations, from the general to the particular. It should be clarified that the confluence of factors coupled with connections and interactions between them prevail over the search for cause-effect relationships.

In order to better visualize the application of PCM, we develop an example with a generic model, with general contributing factors, and then we will see how it is applied to a more specific example.

"It should be clarified that the confluence of factors coupled with connections and interactions between them prevail over the search for cause-effect relationships"

Factors defined for a first analysis

The defined constituent factors are determined abstractions in order to visualize the interactions within the transportation system, inspired by the RES170/2018 of the Ministry of Transport[2].

In order to carry out the analysis of an accident, the systemic model involves a series of steps (Hollnagel, 2009). The first refers to identifying the essential functions of the system. To do this, it must be determined what constitutes the system and its components. The second instance foresees determining the potential for variability of the context and of the main functions (human, technological and organizational). The third step refers to defining the dependencies between (correct and incorrect) functions and, finally, deciding the countermeasures (policies, defenses, monitoring, procedures, communication, etc.) (González, 2016).

Table 4 shows the general constituent factors with their functions, capacities and characteristics. Then, through the exemplification of an event, we will observe the particular variables.

1. A fractal is a geometric object in which the same pattern is repeated at different scales and with different orientation.
2. If the reader finds that a factor is part of a larger subsystem, he/she must consider that it is here used to apply the concepts in a more general way.

Table 4. General Factor for N9 Model

General constituent factors	Function	Initial Characteristics
Vehicular	Transportation	Design, specifications, damage, recommended maintenance, etc.
Structural	Bear transportation	Design, status, construction measures, time and intervals; pending, levels, damages, etc.
Human organizational	Operate	Techniques and psychophysics. Management, politics, researcher, etc.
Load	Load to transport	Characteristics of the transported load. Damage, human users, passenger. etc.
Visibility	To identify or be identified	Obstacles, position, measures and materials, etc.
Noise and variability	Disturb and modify	Unwanted random movements. Noise pollution, visual pollution, etc.
Surveillance and registration	Monitor and record the activities	Security cameras, videos taken by passers-by. Communication media Related legal events. Statistics.
Rules and customs and usage	Rule and regulate	Current standards, regulations, good practice manuals. Customs and usage.
Environment	Provide natural conditions for functioning	Climatic, topographical, physical. Energy, etc.

Source: own elaboration.

N9 Model

Table 5 shows the possible couplings matrix (PCM) of the factors defined in Table 4. The example is called the N9 Model (N9 refers to the number of constituent factors used). Variables are susceptible to simplification, and some could be included within others. In this example, however, all nine variables will be used separately.

The PCM is the result of the transposition and crossing of each element of the list of general constituent factors. An analysis of each relationship is carried out starting with the identity links, which are those that relate the factor to itself. Then, the other connections are analyzed. General couplings are identified as A[i][j] where i are the rows and j are the columns of the matrix

Table 5. PCMs of the general factors (GF) of the system defined as N9 Model

N9 PCM	Vehicular	Structural	Human organizational	Load	Visibility	Noise	Surveillance and registration	Rule	Environment
Vehicular	A11	A12	A13	A14	A15	A16	A17	A18	A19
Structural	A21	A22	A23	A24	A25	A26	A27	A28	A29
Human organizational	A31	A32	A33	A34	A35	A36	A37	A38	A39
Load	A41	A42	A43	A44	A45	A46	A47	A48	A49
Visibility	A51	A52	A53	A54	A55	A56	A57	A58	A59
Noise	A61	A62	A63	A64	A65	A66	A67	A68	A69
Surveillance and registration	A71	A72	A73	A74	A75	A76	A77	A78	A79
Rule	A81	A82	A83	A84	A85	A86	A87	A88	A89
Environment	A91	A92	A93	A94	A95	A96	A97	A98	A99

Source: own elaboration.

The general constituent factors (GF) can be subdivided, in turn, into individual factors (IF). They refer to the factual elements of the system under analysis and will have their corresponding PCM.

To visualize the PCM of the individual factors, we will now see an example of a level crossing collision (LCC) between a locomotive carrying a fuel coach and a passenger bus. These characteristics or elements will be part of the vehicle identity.

Table 6. PCM of the vehicle identity

A11 Vehicular	Locomotive	Coach	Bus
Locomotive	A'11	A'12	A'13
Coach	A'21	A'22	A'23
Bus	A'31	A'32	A'33

Source: own elaboration.

In table 6, the A11 Vehicular identity interaction generates a new PCM with A' couplings between the factual elements participating (FEP) in the event. That new matrix will also have possible combinational identities and elements. Gray shows identities and red, the collisional couplings between the locomotive and micro identities. Green shows the coupling between the locomotive and coach identities. And white shows the possible couplings not taken into account.

Table 7. PCM of the Organizational Human identity

A33 Organizational human	Locomotive Driver	Driver Assistant	Bus Driver	Investigator
Locomotive Driver	A'11	A'12	A'13	A'16
Driver Assistant	A'21	A'22	A'23	A'26
Bus Driver	A'31	A'32	A'33	A'36
Investigator	A'61	A'62	A'63	A'66

Source: own elaboration.

In table 7, the A33 Human organizational identity interaction generates a new PCM with A' couplings between the factual elements participating in the event. In this case, the new matrix will have the identities of locomotive driver, driver assistant, bus driver and investigator. The identities could be more, but they were simplified due to a matter of length of the paper. In gray, the identities of the new PCM are observed, in green, the matches between driver and assistant and the matches between the investigator and all possible interviewees; and in white, the couplings not considered, such as the A'13 between driver and bus driver.

Identity Couplings

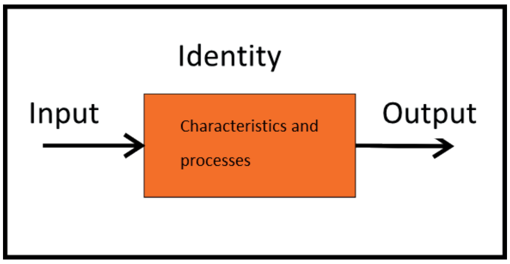
If we look at the PCM of tables 5, 6 and 7, we will see that the shaded elements mutually couple the factors. These are the elements where i is equal to j. In other words, when you look over the PCM, the row matches the column. These elements are defined as identities of the general factors (GF) PCM in Table 5 and as identities of individual factors (IF) in the PCM of Tables 6 and 7.

The characteristics of identities

To define identities, we rely on concepts from general systems theory. In this sense, the system itself is considered a "black box"; and its relationships with the environment and with other systems are represented in the block and flow diagrams.

Systems are described in terms of inputs and outputs. In our system-matrix reasoning (SMR), identities are defined based on their documentary characteristics and by the characteristics of the interactions that they may have at the input or output of the process. Documentary features can be photos, texts, and related files.

Image 2. Identity definition



Source: own elaboration.

The possible couplings

The possible couplings (PC) are those elements of the PCM that are not the general identities (GI) nor the individual identities (II). For example:

In Table 5:
1. Couplings A13 and A31 relate the Organizational Human and the Vehicular GI.
2. A71 and A17 relate the Vehicular and Monitor and registration GI.

In Table 6:
1. A'13 and A'31 relate Locomotive and Bus II.

2. Couplings A'12 and A'21 relate Locomotive and Coach II.

The PCs (possible couplings) arise from the combination of all the identities defined in the system model. In the N9 Model example, the nine general identities create [(NIG2)-NIG] or seventy-two possible combinations, and these in turn create individual identities with the same number of combinations, depending on the number of individual factors defined. Here, the need to develop a computerized tool to be able to go through all the combinations is observed.

MSR and PCM applications

This section introduces these applications. They are not analyzed exhaustively but are intended to show some principles and results obtained, since it is a large study still in developing process.

To put in practice the system-matrix reasoning (SMR) and the possible coupling matrix (PCM), a software in C# language4 was developed, where a local MySQL database (DB) is used to store the possible coupling matrices created as information is collected and the system under analysis is loaded, so they can then be processed and analyzed from different approaches.

First, the method was defined. Then, the lines of computer code were written to store the collected information and the tables of identity characteristics in a local database in the form of PCM. Images, texts, related files, etc. can also be stored in the database.

Application according to the desired emergent property

According to different interpretations of the possible links and interactions between the different identities of the PCMs, we could place ourselves in different systemic approaches.

The systemic model considers accidents as an emergent phenomenon. They are also "normal" or "natural" in that they are something to be expected. This is related to Perrow's (1984) concept of normal accidents, applicable to simple and complex systems (Hollnagel, 2009).

Then, we will focus on the failure prevention approach (Marchitto, 2011), where the desired emergent property will be "reliability."

We can detect some emerging defined in RES170/2018 of the Ministry of Transport through the MSR in the PCM couplings. For example, the "active failure" can be identified and recorded in the possible coupling of the example given in table 6 A11-A'13 between locomotive and bus, or A11 - A'31 between bus and locomotive which are marked in yellow in table 8.

Table 8. Emerging identified in PCM A11 Vehicular as active failure

Active failure	Locomotive	Bus
Locomotive	Identity	A'13: Crash
Bus	A'13: Crash	Identity

Source: own elaboration.

We can assign the "barriers or defenses" to the couplings identified as active failures. Table 9 shows an example with the assignment of an automatic barrier and the whistle signal.

Table 9. Example of defense assigned to the emerging A11-A'13 and A11-A'31

Defense	Locomotive	Bus
Locomotive	Identity	A'13: Whistle signal
Bus	A'31: Install automatic barrier	Identity

Source: own elaboration.

Up to here, we present two synthetic and simple examples of how the MSR and PCM can contain the prevention approach. This idea will be expanded and refined as the investigation progresses. The incorporation of the barrier will modify the A22 structural identity of table 4 previously defined, which in the example did not take into account an automatic barrier. The whistle use will modify the previously defined A88 Rule identity, which did not take the whistle use into account. These modifications at the level of general factors (GF) and individual factors (IF) will modify the possible couplings (PC) and will create new identities and, therefore, will modify the properties of the system.

When the desired emergent property is "control," rather than "reliability," we move into the control theory approach. We will give a simple example to identify a control structure through the MSR and relate

3. C# is a modern, object-based, type-safe programming language. C# enables developers to build many types of secure and robust applications that run on .NET.

it to a control structure based on STAMP5 from the Massachusetts Institute of Technology (MIT).

Tables 10 and 11. Simplified matrix of A13 and A31 couplings

A13 Vehicular - Organizational Human	Locomotive Driver
Locomotive	A'11

A31 Organizational human - Vehicularr	Locomotive
Locomotive Driver	A'11

Source: own elaboration.

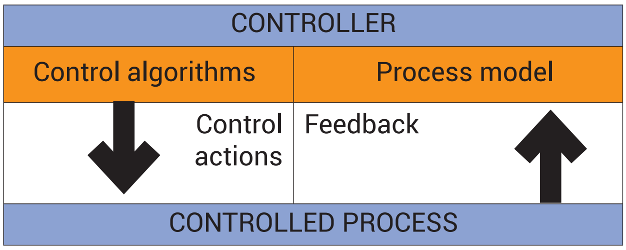
Table 12. Control structure contained in the simplified PCM

Driver		
A13 - A'11		A31 - A'11
Locomotive		

Source: own elaboration.

Table 12 shows a control structure between driver and locomotive comparable to that of Image 3.

Image 3. STAMP-based control structure



Source: own elaboration.

As demonstrated so far, the MSR can also be used from the control theory approach, identifying structures in PCMs, which will be developed in future investigations, along with other emerging properties that are identified with the system-matrix reasoning (SMR).

CONCLUSIONS

It is partially concluded that the MSR methodology allows the identification of several approaches in a single general possible coupling matrix (PCM) and in their individual PCMs, from which different emergent properties can be obtained. With the correct definition of the identities, accidents due to component failures can be analyzed, and with the analysis of possible couplings, accidents due to component interaction can be analyzed. To advance in its development, it is necessary to continue with the partial writing of the software presented in this article, which will allow, in turn, to automate the database and different parts of the procedure to make it more intelligible.

References

Covello, A. y Muro, M. (2020), Análisis sistémico de la pandemia del coronavirus. Un accidente normal. eBook, EPUB.

González, N. (2016). El error humano en el análisis de accidentes ferroviarios. Revista de Ciencias Sociales. Vol. IV, (158), 149-165.

Hollnagel, E. (2009). Barreras y prevención de accidentes. Modus Laborandis.

Ludwig von Bertalanffy (1976). Teoría general de los sistemas. Fondo de Cultura Económica.

Marchitto, M. (2011). El error humano y la gestión de seguridad: la perspectiva sistémica en las obras de James Reason. Laboreal. Vol. VII (2), 1-12.

Perrow, C. (1984). Normal Accidents: Living With High Risk Technologies. (Revised edition, 1999). Princeton, NJ: Princeton University Press.

Resolution 170 (2018). Por medio de la cual se aprueba la primera directiva nacional de seguridad operacional ferroviaria. April 3rd, 2018. B.O. No. 33842

4. The Systems Theoretic Accident Model and Process (STAMP) is a theoretical accident and process model that draws on control systems theory to try to find out as much as possible about the factors involved in a hazard, and to provide clear guidance as to to the control structure that leads to danger.