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Characterizing complexity in socio-technical systems: a case study of a SAMU Medical Regulation Center

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Abstract. Complexity theory has been adopted by a number of studies as a benchmark to investigate the performance of socio-technical systems, especially those that are characterized by relevant cognitive work. However, there is little guidance on how to assess, systematically, the extent to which a system is complex. The main objective of this study is to carry out a systematic analysis of a SAMU (Mobile Emergency Medical Service) Medical Regulation Center in Brazil, based on the core characteristics of complex systems presented by previous studies. The assessment was based on direct observations and nine interviews: three of them with regulator of emergencies medical doctor, three with radio operators and three with telephone attendants. The results indicated that, to a great extent, the core characteristics of complexity are magnified) due to basic shortcomings in the design of the work system. Thus, some recommendations are put forward with a view to reducing unnecessary complexity that hinders the performance of the socio-technical system.

Keywords: complex systems, emergency service, mobile emergency care

1. Introduction

The term complexity, in its widely differing definitions and applications, has been increasingly used in studies related to production systems, especially due to the predominantly cognitive characteristics that work activities have acquired in the last 20 to 30 years [11].

In fact, many studies define certain systems as complex ones. However, they do not provide evidence to justify such a claim. There are few studies that present a systematic analysis of the extent to which a socio-technical system is complex, and explain which characteristics of complexity are more or less present.

A sector, the performance of which can be understood and improved from the perspective of complexity is that of mobile pre-hospital care. This service includes any assistance given outside the hospital environment, which can range from a simple piece of medical advice or guidance to sending a basic or advanced support vehicle to the scene of the occurrence by means of a telephone request to a central switchboard. [6].

In Brazil, the main representative of this service is the Mobile Emergency Medical Service (SAMU in Portuguese). With a structured based on the French model, SAMU provides services through specialized teams, called bases, located at strategic points, which are managed by a command center called a Medical

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Regulation Center, which is responsible for receiving and processing urgent and emergency calls [1].

In this context, this paper aims to identify the characteristics of complexity present in the activities of a SAMU Medical Regulation Center in Porto Alegre (Brazil) and, on that basis, to identify opportunities for improving the performance of this system.

2. Characteristics of complex systems

Several authors propose characteristics that define complex systems [2, 3, 8, 9, 10], which can be used as a model for the systematic analysis of their presence in socio-technical systems [5]. The Table 1 presents a compilation of these characteristics.

3. Research method

3.1 Main characteristics of the SAMU Medical Regulation Center investigated

The scenario investigated in this research study consists of a SAMU Medical Regulation Center in the city of Porto Alegre (RS, Brazil). This center is active in regulating 35 ambulances, divided into 16 decentralised Bases, covering a total of approximately 2.5 million inhabitants in 30 towns. The Bases are

Table 1

Characteristics of complex systems

N.	Characteristics of complex systems	Source
1	Complex systems are open systems: the constant interaction with the environment makes it difficult to set the boundaries of the system	[3]
2	The interaction in complex systems is not linear: the sequences are not usually rigid; the interaction offers, in general, two or more options for decision-making; and small causes can have large consequences	[3, 9, 10]
3	The interaction in complex systems is potentially rich, since the elements influence and are influenced during the process	[3, 10]
4	Complex systems work far from the equilibrium: a steady flow of energy keeps the system running	[3]
5	Complex systems exhibit behavior which is between stable and unstable: the behavior of the elements changes as needed, without the systems being aware of these elements	[9]
6	Complex systems exhibit emergent phenomena: situations that arise because of the interaction and cannot be predicted	[8, 9]
7	Complex systems require standardized solutions, as well as new solutions: no situation deemed as simple or complex	[9]
8	Complex systems exhibit an indirect and distributed character of information	[3, 8, 9]
9	Complex systems exhibit the uncertainty factor in their interactions: there is not a route to the answer that is fully known, and reasons for this include that inputs are seen to raise questionable issues	[3, 2, 8, 9, 10]
10	Complex systems exhibit tight coupling: with constantly changing demands and resources; with time pressure on performing actions; and with effects that quickly propagate themselves throughout the system	[8, 10]
11	Complex systems have a history: which influences attitudes in the present	[2, 10]
12	Complex systems exhibit their elements but are unaware of the behavior of the system as a whole	[2]
13	Complex systems cannot be understood from a study of their parts	[3]

actioned by telephone from the Medical Regulation Center, and each base has a team of professionals and ambulances that cover a given number of municipalities. To meet demand, the Medical Regulation Center under study has 36 telephone attendants, 10 radio operators and 33 regulator of emergencies medical doctors (or medical regulator).

The typical sequence of service in the unit investigated is the following:

a) the service is started by the telephone attendants, in the Medical Regulation Center;

b) the analysis of the call is made by the egulator of emergencies medical doctor, who makes direct contact with the user by telephone, and who infers the seriousness of the situation from data such as vital signs, breathing, consciousness, the presence of injuries. Based on this information, he decides either to send or not to send help and on what kind of help to send;

c) the radio operator, furnished with information transferred by the medical regulator – a statement of the seriousness of the case, the address at which the urgency has arisen and the type of help required – , contacts the closest ambulance (located in a base) within the territory covered, via radio or telephone, and requests an ambulance to go to the address;

d) as it has the relevant information, the ambulance goes there and the victim receives pre-hospital care.

The interaction between base and the Medical Regulation Center is maintained through the radio operator and medical regulator in order to determine where the patient should be taken to. Finally, the ambulance is advised what hospital to go to, and the patient is transferred to the appropriate location.

As can be seen, the entire SAMU process is guided through the Medical Regulation Center. There is a constant relationship between it and the ambulances in order to offer the quickest care possible to ensure the reduction of sequels and the survival of the victim.

3.2 Procedures for collecting and analysing data

To meet the goal proposed by this study, the procedures used were those recommended by Cognitive Task Analysis (CTA) [4].

As to the collection of data, nine interviews were conducted, of which three were with telephone attendants, three with regulator of emergencies medical doctor and three with radio operators. The approach used in the interviews was based on the Critical Decision Method, one of the techniques used for Cognitive Task Analysis, with a focus on challenging situations. This method consists of four steps: identifying an event considered challenging by the interviewee; the drawing up of a timeline about this event by the interviewee and interviewer; deepening the event chosen with a view to clearing up possible doubts; and finally, an "and if" step, which consists of questioning possible decisions and attitudes different from those used in resolving the event [4].

However, due to the characteristics of the work in the Medical Regulation Center, the Critical Decision Method was adapted in this study. In fact, the respondents could not identify a specific event which would serve as the basis for the interview, due to the large number of events that occur in a single day, the length of which is in the order of minutes. Thus, in this study, the CDM involved the following steps: a report of various events; analysing in greater depth some events considered noteworthy by the interviewees; the "if" step.

What was also used was the technique of non-participant observation, in which researchers monitored two work shifts in the Medical Regulation Center, on different days. The data resulting from these observations were recorded by means of notes and, later, used to supplement the analysis, together with the interviews conducted.

The analysis of the data collected was conducted by using the content analysis technique [7]. After transcribing the interviews (which were recorded), the researchers read them, thereby seeking to identify the characteristics of complexity and these are presented in Table 1.

4. Results

4.1. Characteristics of complexity in the SAMU Medical Regulation Center investigated

Of the thirteen characteristics selected in the literature to represent a complex system, all were identified in the Medical Regulation Center under study (Table 2).

Complex systems are considered as open systems (Characteristic 1) given the constant interaction with the environment, a fact that is clearly present in the Medical Regulation Center. The work begins, based on an external demand, made by one or more members of the general public, and public and health institutions. Meeting this demand also depends on the relationship with other sectors such as the base and other health facilities. The extract given below, taken from the interviews, exemplifies some of these interactions and demonstrates the interaction of the system analyzed with the external environment.

> .. whenever there is an accident in Cachoeirinha, an ICU, a doctor on site and such like are needed. Afterwards, the rescue service, or fire fighters are called in. First of all, the security guard has to go there; someone is needed who will contain the scene, and to ask onlookers to leave. For the police, one vehicle is not enough; they send the firefighters who are also police officers, they exert authority on the spot. So they see to it there will be one more security guide on the scene, so that we work better ... *"Radio Operator1*

The system represented by the Medical Regulation Center basically comprises the telephone attendants, the radio operator and the regulator of emergencies medical doctor, as the human elements, and computers, software, telephones and radios, as the main technological devices. Other elements of the system correspond to external elements, which are in constant interaction. Thus, it can be considered that the number of elements that constitute the complex system under analysis is not very numerous. However, the interactions produced by the system are characteristics of complex systems, with intense interactions, sometimes non-linear ones, between the elements (Characteristic 2).

Table 2

Characteristics of complexity in the investigated SAMU Medical Regulation Center investigated

Characteristics	Evidence of the characteristic in the context under analysis
1	the beginning of any activity starts when a phone call is received from an element external to the system, which will trigger a series of events pertaining to the internal elements and which will lead to the outcome of the process.
2	in most situations the outcome options are the same: to send or not to send help; to find a health facility that will attend to the victim. However, the route to arriving at the result is not always the same.
3	decisions by the medical regulator to give priority to one rather than another case, or to send or not to send an ambulance influences the behavior of the other internal and external elements of the system
4	there is instability with regard to the workflow, which at times is high, with overloading for the professionals who are on the shift, but at times the demand drops, yet there is always a flow of work which keeps the system active.
5	The variable demand in the workflow (peak times of providing a service, a greater number of accidents; serious flooding) causes elements of the system to change their behaviour, as needed, so as to meet demand in the best possible way
6	new situations arise from the interactions between the elements, such as a refusal to provide a service by the internal elements (medical regulator) or external elements (health institutions)
7	the use of conventional responses to certain activities is not always possible, mainly due to the presence of unexpected situations from these types of activities, such as the refusal of a given element to meet a specific request
8	based on information coming from another location, usually by people not trained to analyse the situation correctly, the professionals have to decide on the actions to be taken
9	the factor of uncertainty is also present in these interactions, especially because the information which has been entered on the system and triggered the whole a process, may be questionable, especially those coming from the general public
10	the time component is regarded as fundamental to the activities: the quicker the outcome of situations, the greater chance there is to save the life of the patient
11	events that occurred in the past influence the system as a whole, given that they show situations that professionals know about and known options for resolving the problem
12	professionals' understanding is limited even of their activities, and take up a larger proportion of the activities of the other professional, and even more so of the activities of the external elements, who constantly engage in interaction
13	the constant interplay between the elements for the outcome of the activities demonstrates that the understanding of parties to this system are unable to comprehend an understanding of the whole

Still with reference to Characteristic 2, in the system represented by the Medical Regulation Center, the outcome for most situations tends to summed up by a few options: sending or not sending the ambulance; using or not using a health facility for the patient helped. However, the manner of reaching these results is not always the same. There are times when the service is set off by the telephone attendants, who passes on to the medical regulator and from there it goes to the radio operator, with the decisions made known. At other times, this sequence is changed, such that the medical regulator intervenes in another way with the external environment, or the radio operator takes a more active part with the telephone attendants to decide on the service.

Thus, there is not a rigid sequence or one that can always be followed to the outcome of the activity. This allows flexibility for the adaptations needed for the work context, given the different situations imposed by the variability of the external environment, an element that greatly influences this system.

It is seen that characteristics of complexity exhibit relations between each other. The interactions made in the Medical Regulation Center may be considered potentially rich on account of the influence that one element exerts on another so that activities are carried out (Characteristic 3). The decision taken by one professional can modify the strategy to be used by another professional, which very often gives rise to unexpected situations, which were not foreseen in the system. This is another aspect of complex systems present in the Medical Regulation Center, namely the springing up of emergent phenomena (Characteristic 6). New situations arise all the time, mainly related to the interaction with the external environment. Once again, it is clear that the use of only a standard solution is not always possible as there may well be a need to seek new strategies for solving any given problem (Characteristic 7).

The constant flow of energy needed to keep the system running (Characteristic 4) is also related to the characteristic of the behavior of the elements modifying themselves as needed (Characteristic 5). Instability with regard to the workflow is seen in the Medical Regulation Center. Workflow is sometimes high, when the professionals who are on the shift are overloaded, but sometimes the workflow drops yet there is always a flow of work to keep the system active. This particularity sees to it that the elements of the system change their behavior as needed to meet demand in the best way possible.

Since pieces of information are given indirectly and distributed throughout the system, (Characteristic 8), they influence the presence of uncertainty between interactions (Characteristic 9), which, in this case, is related primarily to questionable information used throughout the process. Every activity starts with a piece information originating from elsewhere, a piece of information that professionals should be able to interpret and decisions made on what actions to take. The indirect and distributed nature of information is a characteristic that brings with it potential difficulty to the Medical Regulation Center, especially regarding information from the general public. The following excerpt, taken from an interview illustrates the relationship between the characteristics cited.

> "... here you have to use your imagination. Here, the doctor (of the base) is the one making the request; he´s the one who lets you know what is happening at the scene, and they very often lie so that they send an ambulance because SAMU's end-goal is to rescue people from life-threatening conditions, they are grave cases and not just about consultation or transport. They say they are short of breath, have pains in the chest ... they know that if they say that we'll send an ambulance; otherwise we´d have to go and look and check if what they say it is, really is that ..." *medical regulator 3*

The type of service rendered by the Medical Regulation Center shows that the component of time is fundamental, so there is strong coupling in the system (Characteristic 10). The faster the outcome of existing situations is, the greater the chance of saving the patient's life. There is constant pressure to act quickly, in addition to the work demand being dynamic, with peaks in providing service, sometimes ones that are much as expected (some specific times of day) or unexpected ones (as in the event of an accident with a higher than normal number of victims).

The idea that complex systems exhibit their elements without being aware of the behavior of the system as a whole (Characteristic 12) is evidenced in the activities of the Medical Regulation Center. It is noted that the professionals' understanding is limited even as to their activities, as they take up a larger proportion for the activities of other professionals, and furthermore of the activities of external elements. There is less evidence on this issue when the activities are performed by professionals who have spent longer in this type of work, and thus the factor of experience emerges. Thus, events that occurred in the past influence the system as a whole (Characteristic 11), given that they offer professionals well-known situations, and familiar options for resolving the problem.

And, finally, the aspect that represents the new paradigm of the science of complexity science, the entirety of which cannot be understood from a study of its parts (Characteristic 13), contrary to the reductionist view frequently used, can also be applied to understanding the dynamics of the activities in the Medical Regulation Center under analysis. The interdependence present in the activities performed, between the elements of the system and of these with the external environment, demonstrates that the understanding of only one part cannot match the understanding of the entire system. Therefore, analysis must be conducted in conjunction with a focus on the interactions and not on the elements in themselves, thus making the analysis of the systems, which are considered complex, more accurate, such as the sector under study.

What is noteworthy in the context analyzed is further evidence of some characteristics (1, 2, 6, 7, 8, 9, 10), as a result of the type of activity performed in the system under analysis. However, it is worth emphasizing that a complex system also exhibits, at certain times, the characteristics of simple systems, and this transition from simple and complex permeates the system during its flow of activities. In this study of SAMU, certain activities may exhibit the characteristics of simple systems, such as the regulator of emergencies medical doctor giving advice to the patient by phone, which followed the service standard when contact is between the telephone attendants and the medical regulator, and used a known sequence until the outcome of the process, the interaction of many elements not being needed and leading to the final result being reached under less time pressure.

4.2 Some examples of how unnecessary complexity could be reduced in the SAMU Medical Regulation Center

The analysis undertaken indicates that the actions aimed at improving the system should emphasize the control of the interfaces between the (internal and external) elements of the system. The characteristics of complexity evidenced are inherent in the system, especially with regard to the indirect nature of the information, the presence of uncertainty in decision making, and the dependence on the external environment.

However, it is possible as well as desirable to reduce this complexity so as to make the system more efficient and safe. For example, the use of antiquated technological devices, in poor condition and in insufficient quantities, such as computers, phones and software, hinder the flow of information between system elements. As the activity carried out there totally depends on the communication between the elements, these deficiencies increase the possibility nonlinear interactions occurring (characteristic 2), as well as increasing the issue of uncertainty between interactions (characteristic 9).

The lack of adequate training for professionals in the Medical Regulation Center also amplifies another characteristic of complexity, since better qualified professionals tend to know about their activity and the overall dynamics of the work environment, and become less ignorant of the behavior of the system as a whole (characteristic 12).

An important and difficult point to be controlled is the high number of hoax calls, which demonstrates the immaturity of the society towards the service offered. This factor amplifies the interference of the external environment (Characteristic 1). Modifying this environment, so that the complexity of the activities carried out in the Medical Regulation Center is reduced, is an ambitious goal because it involves people, health institutions, and policy issues. However, it can be considered that an action initiated in one of these sectors tends to trigger measures in the others. For example, greater policy attention to health institutions, by providing more resources for care leads to a greater capacity to receive patients sent by SAMU, thus providing a better relationship between these two spheres of public health. Similarly, public health with greater resources and by providing better service to the population brings in its wake greater support for running campaigns with society on the correct use of available resources. Finally, one improvement action tends to lead to another, thus promoting a continuous improvement of service.

While actions at the level of the external environment are awaited, attempts to change the configurations of the internal environment become necessary, an attitude that is possible and necessary, given the difficulties that currently exist. Therefore, the Medical Regulation Center system should be well structured so that it is able to absorb the different demands from the external environment and therefore cope with the variability imposed by this constant interaction.

5. Final Considerations

As demonstrated throughout the paper, the main characteristics related to complex systems reported in the literature are present in the system represented by the Medical Regulation Center.

However, these features can be mitigated, both through actions to make basic improvements to the internal environment (e.g., faster computers and more suitable software) and through actions to increase the flexibility of the responses to the external environment, or even actions to manipulate it, such as public awareness campaigns as to the proper use of public resources, particularly those of the health sector.

The perspective of complexity prompted the investigation of interactions and not the elements of the system as entities isolated from a context. As a result of this study, opportunities for future studies were identified, such as: (a) drawing up protocols for assessing the compatibility between the characteristics of complexity of a system and the design characteristics of certain elements of the socio-technical system (e.g., how to assess whether the system for managing procedures is compatible with the complexity of the system); (b) drawing up protocols that enable, more systematically than in this study, the assessment of the extent to which each characteristic of complexity is inevitable in a given system.

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