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Functional analysis, a resilience improvement tool applied to a waste management system – application to the "household waste management chain"

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Abstract. A waste management system plays a leading role in the capacity of an area to restart after flooding, as their impact on post-crisis management can be very considerable. Improving resilience, i.e. enabling it to maintain or recover acceptable operating levels after flooding is primordial. To achieve this, we must understand how the system works for bringing any potential dysfunctions to light and taking preventive measures. Functional analysis has been used for understanding the complexity of this type of system. The purpose of this article is to show the interest behind this type of method and the limits in its use for improving resilience of waste management system as well as other urban technical systems[1], by means of theoretical modelling and its application on a study site.

1 Introduction

Improving the resilience of urban areas against flooding is one of the main principles for flood prevention[2]. In fact, towns and cities are areas that are particularly vulnerable when faced with this type of catastrophe[3]. Damage to them may weaken the way in which the area globally operates and even put a country's economy in peril. However, strategies based solely on diminishing damage related to flooding are no longer sufficient. It is now essential for towns and cities to be capable of guaranteeing continuity and adapting themselves to modifications in the surrounding environment, i.e. for them to be resilient. To do this, they rely on a self-organisation capacity, that is to say a capacity to permanently adjust their behaviour depending on interactions both inside the town or city concerned and with the outside environment (Pumain et al., 1989). Waste management systems, i.e. all the activities for collecting and processing waste, play a central role in this self-organisation capacity. During flooding, water degrades everything it touches, thereby producing very important quantities of waste. Blocked infrastructures, attacks on health and environment, psychological impacts, and deterioration in the area's image are the impacts made by poor management of this new waste. Therefore, adapting waste management systems and anticipating flooding contributes to improving urban area resilience (Beraud et al., 2011a).

A resilient waste management system must be capable of remaining in operation at acceptable levels during and after the crisis. The word "acceptable" is understood to mean that the missions for which the system was created can be maintained. To achieve this, the system must be capable of reacting and adapting itself to variations in infrastructure availability, but, above all, to variations in the amount of waste produced (Beraud et al., 2011b). To assess the resilience of a waste management system, we have to understand how the

[1]In a systemic vision of the city, urban technical systems combine all the user service systems that are essential for the city to operate (electricity, water supplies, transport, sewerage, etc.). These systems are generally organised in the form of networks (Coutard, 2010; CERTU, 2005).

[2]In May 2010, The United Nations Organisation launched a worldwide campaign for helping cities to reinforce their resilience against the effects of natural catastrophes.

[3]The characteristics of a flood (water height, duration, speed, muddiness) are liable to vary significantly from one area and/or period to another. However, here we shall use the terms "flood" and "flooding" generically for qualifying all the events belonging to this type of fortuitous event. For application to a study field, we will specify the characteristics of the event in question.

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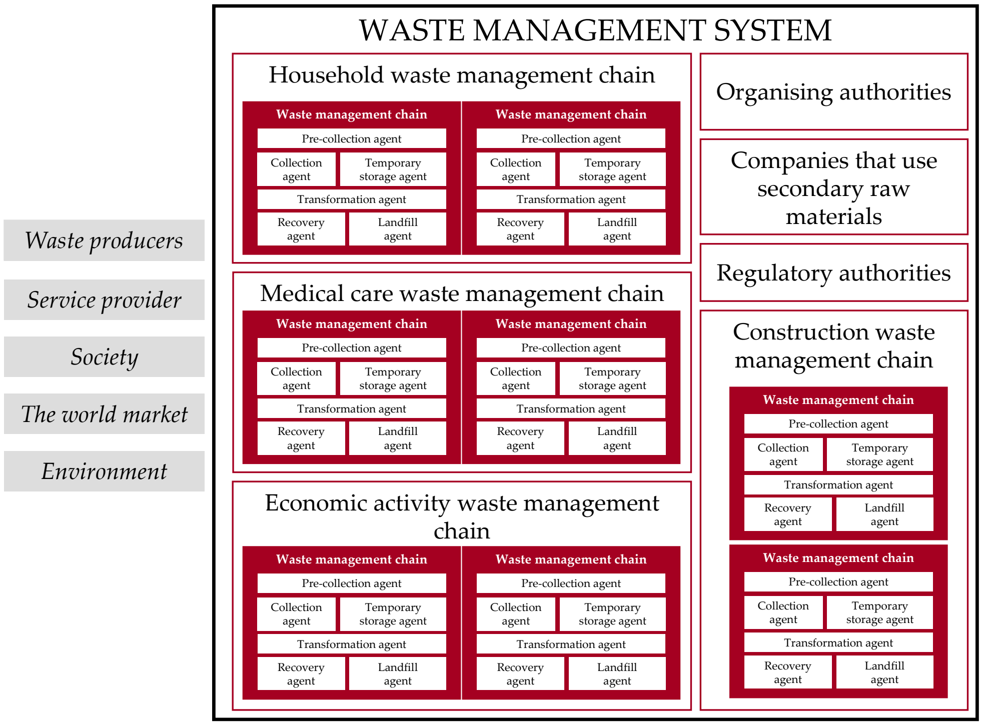

Fig. 1. Organisation of a waste management system.

system works. Indeed, understanding this will then enable us to define the system's dysfunctions and, in this way, improve its resilience to flooding. Now, studying the way this type of system operates is not easy (due to the number of different parties concerned and their levels of involvement and to the different scales and sizes of area). A functional analysis concept has been chosen in order to understand this complexity. After the method has been presented, it will be applied to a theorical waste management system, then to an existing waste management system at Ivry-sur-Seine. The results of this work will be presented in part three of this document.

2 Material and method

2.1 The waste management system: defining the study's objectives

A waste management system brings together all the activities concerning collecting and processing waste. It can be considered as being a complex system, i.e. as "*an object, which, in a given environment, endowed with given aims, exercises an activity and sees its structure develop as time goes by without it losing its one and only identity.*" (Le Moigne, 1977). It is composed of subsystems that correspond to the different waste management chains or channels. These chains combine all the activities needed for handling a single type of waste (household waste, economic activity waste, building and public works waste, medical care waste, etc.). They can also be broken down into sub-chains ("glass" chain, "residual household chain" chain, "WEEE" chain, etc. for household waste). On a second level of analysis, each "chain" subsystem is broken down into "waste management stage" subsystems (pre-collection[4], collection, storage, transformation, landfill, waste recovery; Fig. 1).

In the same way as other urban services (electricity, water supplies, storage, and transport), a waste management system is organised in the form of networks. They possess infrastructures (roads, incineration plants, storage centres, etc.), also called "support networks", comprised of a number of points or nodes and a network. These points correspond to distinct, differentiated entities that are support points for the network's activity (waste production sites, incineration plants, storage centres, etc.). They are the places where the parties involved (owner, entrepreneur, administrator, etc.) think out their actions, that is to say, the places where an individual or collective will to create relationships with another point or person involved is born (Dupuy, 1991). This infrastructure supports the material flows (waste, secondary raw material, etc.) and immaterial flows (information, regulations, etc.) required for providing the service (Blancher, 1998; Gleyze, 2005; Martinand, 2001). All the interactions between these different points creates a structure (or a "grid") that is specific to the system (Gleyze, 2005). Providing the required

[4]Pre-collecting covers all the operations for transporting waste from its point of production to the point where waste is taken in hand by the collection entity (Le Bozec, 1994).

service relies on a general organisation encompassing the infrastructure and the structure, called the "service network" (Blancher, 1998; Gleyze, 2005; Martinand, 2001). Together, all these different constituent elements form the waste management system.

For this reason, a waste management system is an extremely complex system that is composed of several subsystems that correspond to the different waste management chains and which are organised in the form of a network. To be able to study it in terms of reliability, a detailed study must be made of the dysfunctions in every "chain" subsystem.

2.2 Purpose and interest of functional analysis

Functional analysis has already been used in an exploratory way on socio-technical systems (Zihri, 2004; Maiolini, 1992; Barrère-Lutoff, 2000; Lhomme et al., 2010), and on other complex systems (Peyras, 2002; Serre, 2005), but never on a waste management system. This method of understanding of how the system operates is derived from reliability assessment methods. Reliability assessment is concerned by making an entity capable of meeting one or more functions required for it to operate correctly (Villemeur, 1988). To do this, the concept proposes methods for analysing potential failures in a system should an accident occur (Zwingelstein, 1996). The first step in all these methods is to become familiarised with operating modes under normal conditions (Noyes and Pérès, 2007). Functional analysis is an interesting tool in this respect, as it makes it possible to "*understand and make a synthetic description of the way in which the system under study operates: it defines its limits, its environment and its constitution and it searches for the functions*[5] *that the system provides*" (Peyras et al., 2006b). As such, it systematically and exhaustively establishes functional relations both inside and outside the system. This then enables a study to be made of the possibilities of any dysfunction and their consequences (AFNOR, 2004). After functional analysis, the FMEA (Failure Modes and Effects Analysis) method is generally used. This method is an interesting way to assess failure in a system. But, in this work, it has not been used because it was too unwieldy.

There are several models of functional analysis depending on the type of the system under study[6]. One of them, the APTE method (APplication aux Techniques d'Entreprise) is frequently used for analysing failure modes (Serre, 2005). It has the advantage of carrying out a structural analysis before doing the functional analysis, i.e. making a description of the system (constituent elements, environment, relationships) and calling on two tools: the functional block diagram and the functional analysis chart (Zwingelstein, 1996).

2.2.1 The tools

The functional block diagram is the principal tool in functional analysis. It is a representation of the system, the system's outside environments and the interactions that irrigate it. It enables functions to be identified by examining the flows that put the different constituent elements in relation with each other and with the environment (Peyras, 2002). This is done by means of a structural analysis that enables a detailed understanding of the system's general framework to be acquired. The functional analysis chart ensues from the functional block diagram. It presents the functions carried out by the system depending on the constituent elements concerned (Peyras, 2002). In this way, "*allocation of internal functions to the different elements (...) enables the "who does what" to be defined, and thereby a check to be made to ensure that all the functions required are provided. In the other direction, this is a relationship that enables any possible dysfunctions in these elements to be linked with behavioural disturbances (...) [in the system].*"(AFNOR, 2004).

2.2.2 Two levels of analysis

After describing the system studied and its boundary defined, functional analysis can begin.

External functional analysis

The first stage consists of understanding why the system exists. To do this, on the one hand we must bring out any relationships that exist between two elements outside the system and which pass through the system itself. These relationships are supports for the main functions that express the system's objective. They correspond to the relationships created by the organisation between certain of its constituent elements and the outside environment. On the other hand, interactions between the system's constituent elements and outside environments must also be determined. These interactions reveal constraint functions and these functions express the requirements of an outside element in relation to the system (Peyras, 2002).

Internal functional analysis

Secondly, the flow movements through or inside the system and its constituent elements must be determined. These flows define the functions that enable the system to attain its objective and in this way give a description of the system's internal operation (Peyras, 2002). The definition of these functions could be run at several granularities depending on the needs of the study. Indeed, each constituent elements of the system can operate as a subsystem of the system. It also can be

[5] Here the term "function" is defined in the sense of standard NF X50-150, i.e. the action of a product or one of its constituent elements expressed in terms of finality.

[6] There are three main families of functional analysis: analyses based on value analysis techniques (Reliasep; FAST, Den, APTE, and other methods), analyses applied to information technology and software (SADT, ASA, and other methods), and analyses applied to organisations (MESIRE and APTE method; Zwingelstein, 1996).

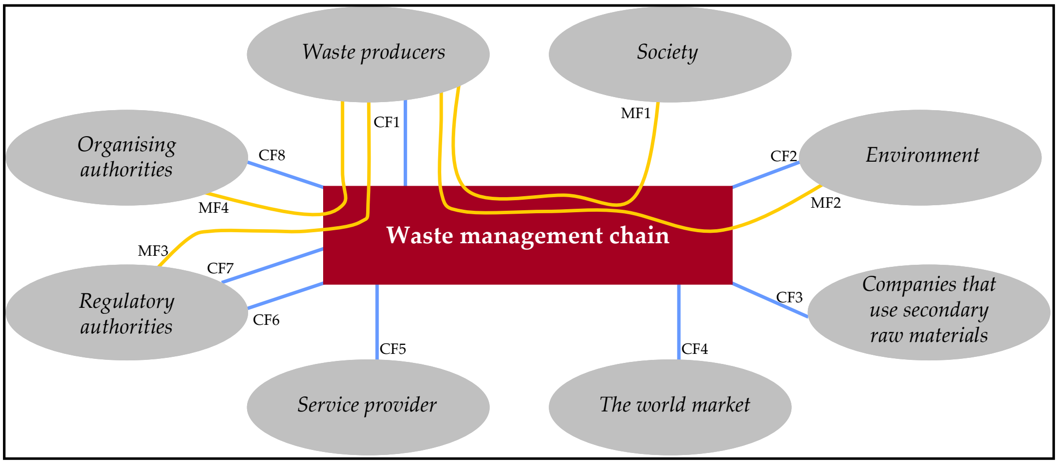

Fig. 2. External functional block diagram of a waste management system.

broken down into components. So different analyses could be run at small granularities or large granularities if required (Peyras et al., 2006a). It needs to find the appropriated scale of analyse according to the objectives' study.

Once the granularities defined, each level of the system must be described (structural analysis). Lastly, interactions between constituent elements or with outside environment must be determined. These interactions are the flow movement which define functions.

For these reasons, this method has been applied to a waste management system. The main results of this analysis are presented below.

3 The usefulness of functional analysis for improving a waste management system's resilience to flooding

3.1 Applying a functional analysis

To provide an example, the functional analysis concept has been applied to a subsystem of the waste management system: the "household waste management chain" subsystem. The procedure is the same for all the other subsystems.

3.1.1 External functional analysis

The main functions and constraints have been defined by studying the relationships existing between the subsystem and outside elements (waste producers, regulating authorities, the environment, etc.)[7] (Fig. 2). They have been brought together under three titles that correspond to the main missions in common to all waste management chains: managing waste in a way that suits the type of flow, limiting impacts on the environment and guaranteeing that waste management treatment is maintained (continuity of service, obligations in terms of sanitation and public safety; Beraud et al., 2011c). The way in which the "household waste management chain" subsystem operates internally must enable these main missions to be carried out.

3.1.2 Internal functional analysis

Granularities and structural analysis

The "household waste management chain" subsystem deals with household waste: residual household waste[8], glass, paper, etc. It could even be broken down into "chain" subsystems. However, with a concern for simplicity, it has been decided to limit the study to a "household waste management chain" level, and to consider that all household waste is processed in the same way.

The subsystem is broken down into six subsystems that correspond to the six stages in household waste management: pre-collection, collection, temporary storage, transformation, landfill and waste recovery. It is linked to elements from the outside environment through which and for which it exists: waste producers, society in general, the world market, regulatory authorities (State, EU, decentralised state services, etc.) organising authorities (regional councils, eco-organisms, etc.), companies that use secondary raw materials, service provider and the environment (Beraud et al., 2011c; Fig. 3). This organisation is based on an infrastructure that is specific to every sub-system, and which corresponds to the different stages of waste management, comprising a road

[7]For example: MF1: Meeting society's expectations in terms of sanitation, health and safety; MF2: limiting effects of waste on the environment; MF3: inciting producers to reduce the waste they generate by means of different standardisation and rule-making tools; CF4: taking account of world market evolutions for choosing the system process; CF6: meeting control organisation requirements; CF7: complying with regulations.

[8]Residual household waste represents all household waste from which the recoverable part has been removed.

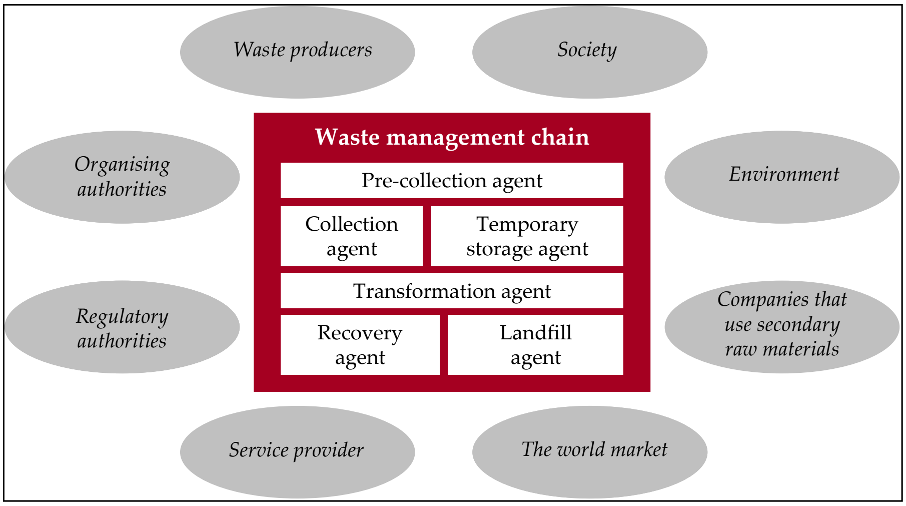

Fig. 3. Organisation of a subsystem of the waste management system, the "household waste management chain".

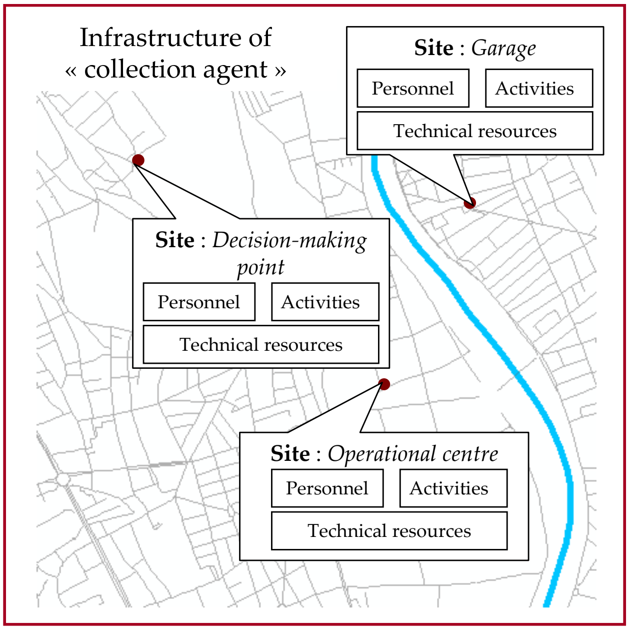

Fig. 4. Example of an infrastructure's organisation.

system, sites for producing, collecting, treating, eliminating and recovering waste and sites for organizing the activity (operational centres and decision-making points). Each of these sites possesses an organisation and resources that are specific to it and which enable it to carry out its mission (personnel, technical resources, management, etc.; Fig. 4).

3.1.3 Internal functional analysis

To define this means of operation, the role of each constituent element in the subsystem has been analysed by studying its relationships with the other elements and with the outside environment. As shown above, these relationships define the functions that enable the system to carry out the missions for which it was created. Each function is supported by a relationship that can be materialised by a flow or a link. On the level of the "household waste management chain" subsystem, eight types of relationship have been defined: waste flows, financial flows, information flows, the "pressure" link, the contractual link, the control link, material flows and nuisance flows. Each subsystem in the "household waste management chain" subsystem generates relationships with another subsystem. To illustrate this, the "transformation agent" subsystem establishes 12 relationships (seven information flows, two waste flows, one financial flow, one contractual link and one nuisance flow) corresponding to nine functions[9] (Fig. 5). In parallel, eighteen relationships with this same involved party are generated by the other constituent elements in the subsystem (five information flows, four constraint links, three waste flows, to financial flows, one contractual link, one control link, one material flow and one nuisance flow) corresponding to the eighteen functions[10] (Fig. 6). The fact that the "waste management chain" subsystem carries out sixty-three functions enables it to achieve the missions for which it was created.

On a finer scale, relationships are also established between the constituent elements in the subsystems of the "household

[9] For example: FI5: being in contact with partners in front of and behind waste management in order to manage evolutions in waste flows; FD6: Once it has been transformed, sending waste to its energy recovery facility; FC4: concluding service or supply contracts for carrying out the activity.

[10] For example: FI2/FI8/FI11/FI14: being in contact with partners in front of and behind waste management in order to manage evolutions in waste flows; FIC2: having regulations followed concerning waste storage; FD4/FD5: sending waste to its point of transformation.

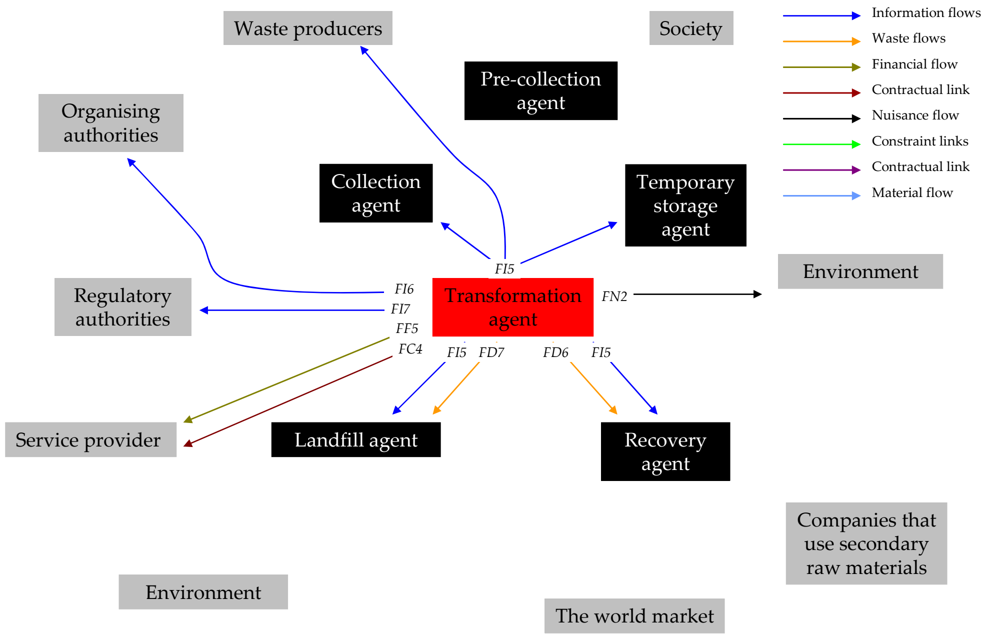

Fig. 5. The functional block diagram of relationships generated by a "transformation agent".

waste management chain" subsystem (for example, the "collection agent" subsystem). Four types of relationship have been defined: information flows, financial flows, material flows, and mixed flows (information and material; Fig. 7). Except for a few cases, these relationships are similar from one subsystem to another. Indeed, infrastructures are almost identical between the different agents. To operate, they generally mobilise the same type of resource and thereby generate similar functions[11].

3.2 The usefulness of functional analysis for studying the waste management system's resilience

The waste management system's resilience has been defined above as being its capacity to react and adapt itself to variations in availability and in operation of its infrastructures, but, above all, to variations in the amount of waste produced. In an article, Barroca et al. (2012) define this as being the conjunction of three factors: territorial resilience, i.e. a propensity for the system to be mobilised on larger scales, correlative resilience, i.e. the capacity to reduce needs and to operate in degraded mode, and, lastly, functional resilience, which corresponds to the capacity to make a system operate reliably (Barroca et al., 2012).

[11]For example: FF.1: remunerating personnel; FF.2: purchasing and renewing equipment required for the activity; FI.3: handling evolutions in the quality and quantity of waste flows.

3.2.1 The capacity to operate in degraded mode

It would appear that a waste management system needs to be resilient in view of its impact on how urban systems operate and how they are kept in operation. Therefore, a technical urban system can be resilient if it succeeds in reducing the urban system's requirements and operating in a degraded mode in this way. Maintaining all functions in running order is not always necessary. Alternative solutions may be found. The system itself may be led to evolve with the catastrophe and to modify its missions. However, contrary to most technical urban systems where service dictates flow, in the case of the waste management system, flow dictates service. Production of waste takes place upstream from the service. Therefore, maintaining degraded operation means adapting itself to requirements, more than any other technical urban system. Now, for a waste management system, requirements cannot be reduced, because flooding generates extremely important quantities of waste. Therefore, it will probably be insufficient for the waste management system to diminish its requirements and reduce its activity in this way. It will need to adapt itself.

3.2.2 The capacity to maintain acceptable operating levels

Questioning the system's capacity to maintain an acceptable operating level compared with the functional solicitations made on it requires understanding the way it operates, and therefore calling on functional analysis.

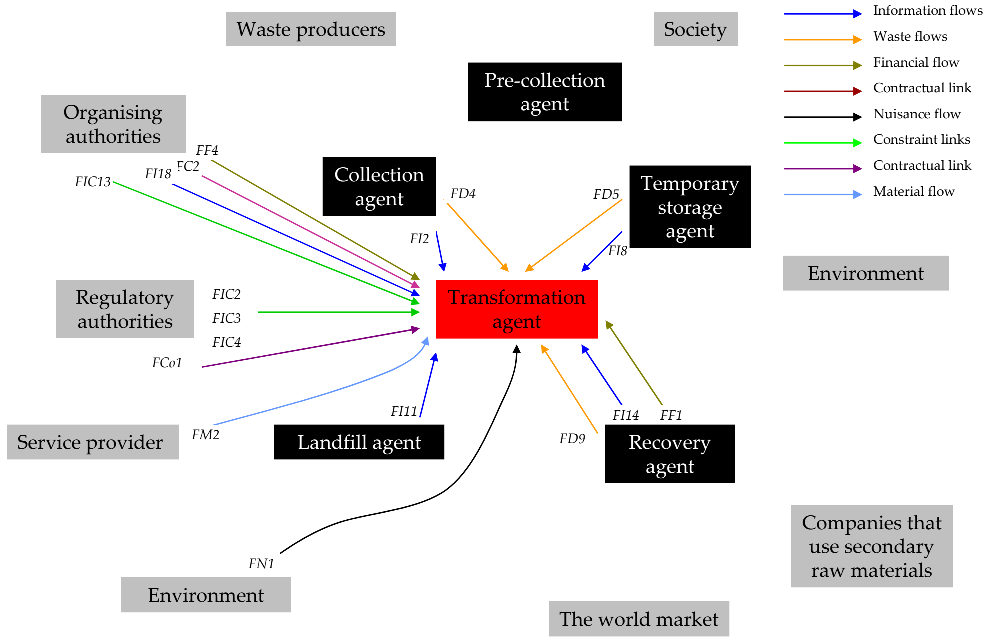

Fig. 6. The functional block diagram of relationships generated by other constituent elements toward a " transformation agent " subsystem.

Generically, in view of the results already presented, flooding may have consequences on all the constituent elements in the waste management system (Fig. 8): flooding of collection, processing or organisational infrastructures, unavailability of personnel or equipment, modifications to functions, even changes in main missions due to evolutions in infrastructure availability, or to the nature and quantity of the waste flow. Even if disturbances to the way the waste management network operates are, above all, clearly linked to any direct damage caused to the infrastructure due to flooding, or to its incapacity to adapt to the new flow of waste, they may have other origins. Indeed, it would appear that flooding can act directly on the system's organisation by modifying its main missions because of new requirements, new priorities or outside partners' changes in objectives. Consequently, all the functions can be disturbed by dysfunctions in the system.

Once these dysfunctions are highlighted, it is possible to determine if the system will be able to maintain acceptable operating levels. If not, it is necessary to study on his capacity to mobilise outside resources.

3.2.3 The capacity to mobilise outside resources: territorial resilience

A system is also resilient if it is able to adapt itself to perturbation. Therefore, waste management system's resilience can be assess by its capacity to mobilise others waste management infrastructures on a larger scale. This capacity allows system to deal with waste produced by flood.

Functional analysis allows one to study the system's capacity to maintain acceptable operating levels. This is main stage of system resilience analysis. Therefore, using functional analysis for studying the way in which a waste management system operates appears to be interesting. Indeed, it enables work to be done on increasing the operational reliability, which is the system's main resilience factor. Let us try to apply this method to a concrete case, the waste management network of the urban district of Ivry-sur-Seine.

4 Assessment of the resilience of the "household waste management chain" subsystem of the urban district of Ivry-sur-Seine by means of a functional analysis

4.1 Concerning the relevance of working on the urban district of Ivry-sur-Seine

Ivry-sur-Seine is an urban district on the outskirts of Paris, which is significantly exposed to flooding by the River Seine. Its flood zone plays a central role in its development and its dynamics. In fact, the zone is the home of almost half the town's population and a major part of its economic activities. This situation should become increasingly important over the next few years as a significant urban renewal project (Ivry Confluences) plans for the arrival of 10 000 inhabitants and creating 20 000 jobs. Now, a major flood on this area would probably last for several weeks with water levels reaching a height of 2 m in certain areas[12]. Therefore, improving the area's resilience would appear to be primordial for the town's

[12] The reference flood for this area is the 1910 flood.

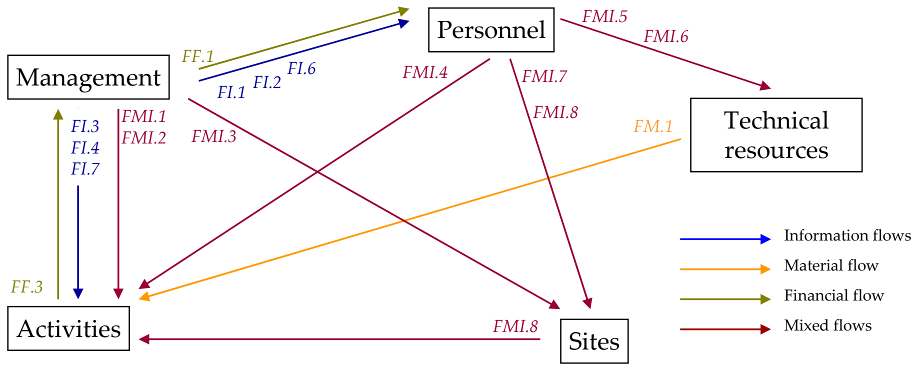

Fig. 7. The functional block diagram of a "collection agent".

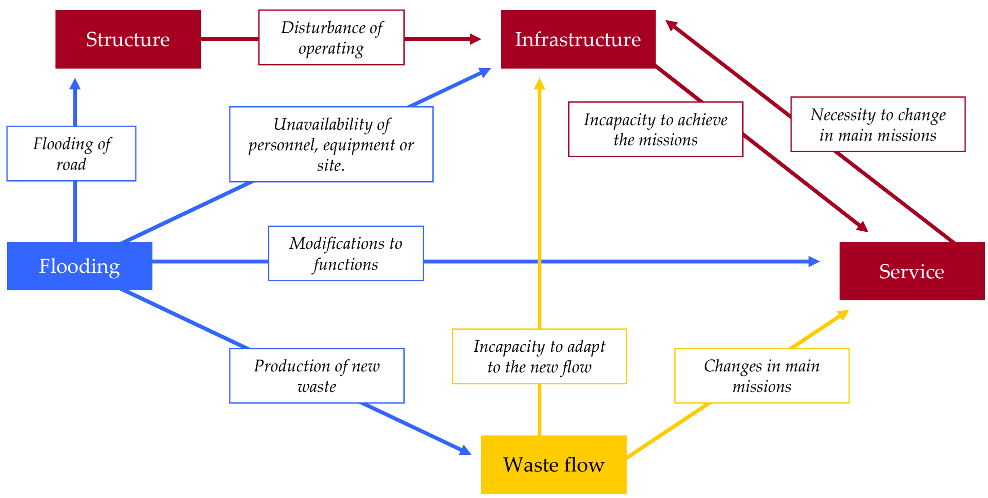

Fig. 8. Consequences of flooding on the waste management system.

long-term existence. In this context, making the waste management system resilient appears to be relevant. To do this, we need to measure what dysfunctions are liable to occur because of flooding. Like all other urban districts, Ivry-sur-Seine is responsible for managing the household waste produced by its inhabitants. As it is responsible for public health and safety in the context of local police responsibilities, it will also be in charge of cleaning the area after flooding. For these reasons, the method presented above has been applied to the "household waste management chain" subsystem. Interviews were held with local parties involved in waste management for obtaining the information required.

4.2 Analysis of the way in which the Ivry "household waste management chain" operates by means of the functional analysis

4.2.1 External functional analysis

The external functional analysis is similar to the one carried out above (Sect. 3.1.2). The main mission of the "household waste management chain" subsystem is (1) to handle waste in a way suited to the type of flow, (2) to limit impacts on environment and (3) to ensure that waste management processing can be continuously maintained.

4.2.2 Internal functional analysis

Structural analysis

In the town of Ivry-sur-Seine, the "household waste" chain is organised in eight flows (residual household waste, multi-materials, newspapers/magazines, glass, hazardous household waste, large objects and electrical/electronic equipment waste). The urban district is in charge of pre-collecting and collecting this type of waste. These two stages have been delegated to private companies, Plastic Omnium for pre-collection and OTUS for collection[13]. As far as processing responsibility is concerned, it has been transferred for all

[13]Even so, certain waste is collected by the urban district (time-work) in the context of road-cleaning: hazardous and large-sized household waste and electrical/electronic equipment waste.

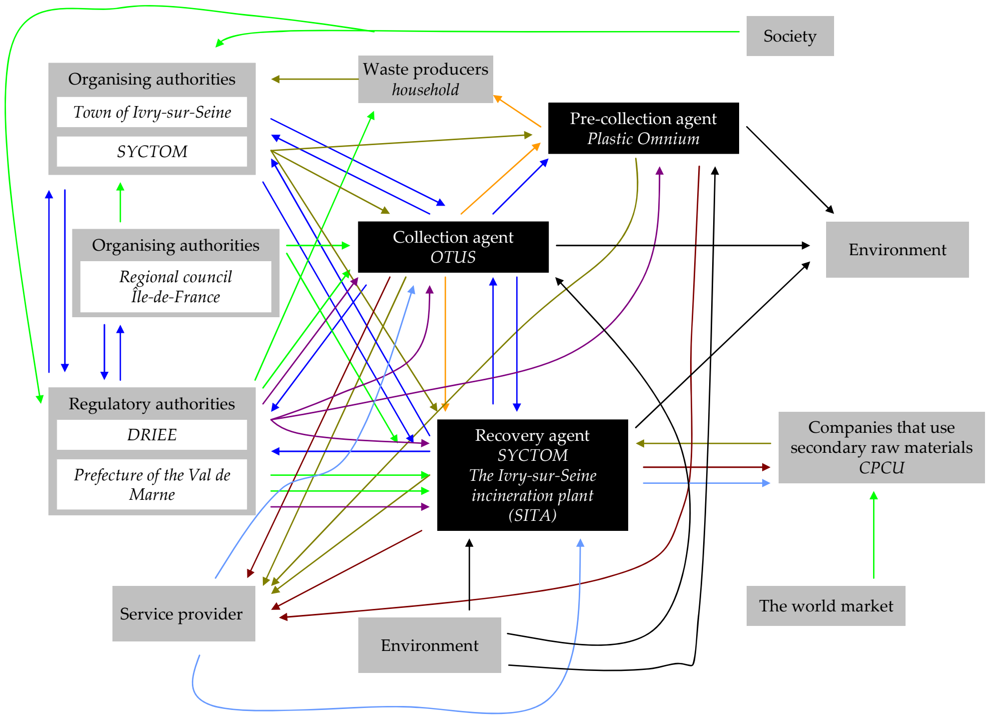

Fig. 9. The functional block diagram of the "residual household waste" chain.

waste flows (excluding glass[14]) to an inter-municipal syndicate, the syndicate for processing household waste in the Paris area (SYCTOM). Once waste has been collected, the SYCTOM deals with organising its processing and transformation for landfill or waste recovery. Waste is sent either to processing facilities belonging to the SYCTOM, but managed by a service provider, or to facilities belonging to outside companies with which the SYCTOM has contracts.

In order to analyse the way this network operates in more detail, all the chains comprising it must be modelled by means of a functional analysis. This stage has been carried out for each one of them. The article presents a number of results concerning the residual household waste chain (RHW). The chain is organised on the basis of three stages: pre-collection, collection and waste recovery. Once it has been collected, waste is transported directly by truck to the energy-upgrading site, without any intermediate storage. Residual household waste is incinerated in the Ivry-sur-Seine household waste incineration plant belonging to the SYCTOM and managed by SITA. This plant enables waste to be upgraded using the waste-to-energy concept. The steam produced feeds the urban heating network belonging to the "Compagnie parisienne de chauffage urbain" (CPCU).

[14]For glass, the urban district has signed a contract directly with St-Gobain, the company that acquires used glass.

Internal functional analysis

The internal functional analysis has enabled thirty-six functions supported by about fifty relationships to be brought to light (Fig. 9). This mode of operation relies on an infrastructure organised around the five management sites: the Ivry Town hall, SYCTOM's premises, the Plastic Omnium site, the OTUS operating unit and the Ivry-sur-Seine incineration plant. As described above, relationships are created between the different constituent elements (personnel, equipment, management, etc.) on each of these sites, and it is these relationships that enable the system to carry out its missions.

This model can be reproduced for all the "chain" subsystems in the "household waste management chain" subsystem.

4.3 Characterising the resilience of Ivry's waste management system: applied to the "household waste management chain" subsystem

After modelling has been done, questions can be put concerning Ivry-sur-Seine's "household waste management chain" resilience. This capacity will be put into question by means of the resilience factors brought to light in Sect. 3.2.

4.3.1 The capacity to function in degraded mode

In view of what has been said above (Sect. 3.2.1), the system's capacity to maintain an acceptable level of operation in degraded mode appears too insufficient. Indeed, it is true

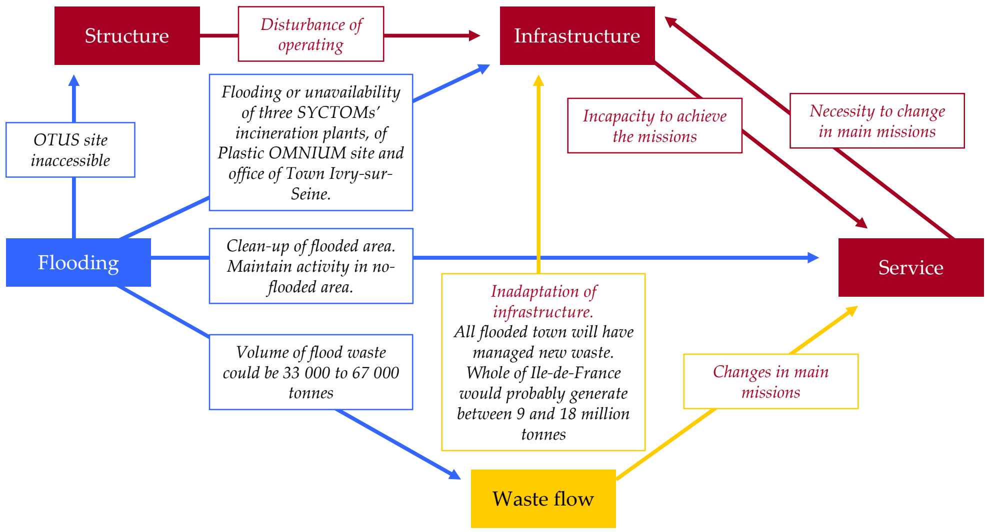

Fig. 10. Consequences of flooding on Ivry's waste management system.

to say that the volumes of waste produced during past catastrophes are generally the equivalent of 1.5 to 15 yr of normal waste collection (Brown et al., 2011; Robin des Bois, 2007, 2010). By making a low assessment, as seen in New Orleans and Dresden (between 1.5 and three years' collection), the volume of waste produced by the River Seine flooding the urban district of Ivry-sur-Seine could be approximately 33 000 to 67 000 t[15]. In view of these volumes, it is highly probable that the system cannot maintain acceptable operating levels.

4.3.2 The capacity to maintain acceptable operating levels

Putting this capacity into question means listing all the dysfunctions that are liable to be encountered (Fig. 10). For this, constituent elements of the system or of the environment exposed to flooding were listed based on functional analysis.

This analysis shows the high number of waste management infrastructures exposed to flooding. Even if they are not all directly flooded, this will be the case for their accesses, which will make it difficult for their missions to be carried out successfully in flood and post-flood periods. Indeed, unavailability of some system constituents complicates achievement of system functions identified during functional analysis.

Nevertheless, the capacity to adapt cannot be put into question solely on the scale of Ivry and its area. The local waste management system is a part of a much larger system, which must be incorporated into the resilience analysis.

[15] Annual production of household waste in the urban district of Ivry is 22 283 t (2009). Annual production of household waste for the whole Île-de-France area is about 6 mio t (2005).

4.3.3 The capacity to mobilise outside resources: territorial resilience

In the present case, if the Ivry area was the only one to be affected, it is highly probable that waste management system infrastructures that cover a much larger area than just Ivry could face up to this production. However, the whole of the Ile-de-France area would be affected by the River Seine flooding, which would probably generate between 9 and 18 mio t of new waste[15]. Therefore, the capacity of the waste management system to absorb this additional production as well as its "normal" production would appear to be doubtful. How can the thousands of refrigerators, vehicles or mattresses, the tonnes of polluted sludge that this type of flooding is liable create in just a few days be handled, when several months, or even several years, are needed to reach these quantities under normal conditions?

Under the present circumstances, there appears to be a large number of dysfunctions. Now, infrastructures' reaction and adaptation capacity is essential for the system to be able to continue carrying out its missions. High infrastructure unavailability levels will give Ivry's waste management system very little resilience.

5 Discussions on results

The method used and the results obtained reveal a certain number of limits that need to be discussed. Firstly, the functional analysis was applied to the waste management system theoretically, without carrying out a complementary field study. In fact, the decision was taken to make the system's operational model reproducible for all the different chains (household waste, building waste, hazardous waste, etc.) irrespective of the study area. This reflection gives rise to a number of different points of view, as organisation is different depending on the chains and areas under consideration (parties involved, regulations, processes, etc.). However, the important thing was not to be exhaustive in terms of operations, but to have a generic model that is sufficiently accurate to serve as a basis for functional analyses applied to specific cases. Theoretical modelling is an indispensable tool; however, it is also important to take territorial and contextual factors into account. Depending on the areas, the parties involved have roles and responsibilities that are liable to vary. Therefore, modelling must be seen as a guideline that enables functional analyses to be applied to waste management system. Moreover, the results obtained on the analysis of dysfunctions ensue from empirical, theoretical reflections based on experience feedbacks and interviews. They show an interesting potential, but which is only validated by a single case study at present. Therefore, the method needs to be tested further on different cases in order to identify its limits.

6 Conclusion

A resilient waste management system is a system capable of remaining in operation over time, and therefore of reacting and adapting itself to dysfunctions caused by flooding. Its mode of operation must be clearly understood in order to make it resilient. Now, due to its organisation in the form of different chains, a waste management system is extremely complex to model. For this reason, the functional analysis concept was chosen to alleviate this difficulty, as it is capable of making the way complex systems operate understandable. It succeeds in this task by making a virtually systematic inventory of all the functions required for these systems to carry out their main missions. After making this inventory, the system's sensitive points – those that are liable to generate dysfunctions – can be identified. For this, it is necessary to identify constituent elements of the system or of the environment that exposed to flooding. If these components are exposed to flooding, some functions will not be achieve. In conclusion, functional analyses appear to be an interesting tool for clarifying the way in which complex socio-technical systems such as waste management system operate, and they make it possible for work to be done on improving their resilience.

Applying this method to the Ivry-sur-Seine area has enabled the system's sensitive points to be highlighted on the area in question, then to estimate its resilience in this way. Indeed, we showed that (1) the "household waste management chain" has to face extensive production of waste flood, but (2) it is not able to maintain acceptable operating levels because its infrastructures are exposed to flooding, and (3) its capacities to mobilise outside resources are uncertain. Therefore, we concluded the "household waste management chain" is not resilient to flooding.

This work also stresses the importance of reflecting on a system's resilience on different levels. Even if the collection agent's area of action is the urban district, the processing agent's area is regional. Therefore, reaction and adaptation capacities are extremely variable. Now, it is by thorough knowledge of the way the system operates that this characteristic can be brought to light. Consequently, these observations clearly show the need to have detailed knowledge of a system in order to work on its resilience and functional analyses contribute to this.

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