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MODELLING PROJECT COMPLEXITY

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1 INTRODUCTION

As the underlying cause of many risks, complexity is identified as a crucial issue within the field of project management. However, there is still a controversial debate about what complexity really is. Several factors seem to be drivers of project complexity, but little is known about them. Complexity is itself complex and many authors emphasize that attention should be paid to define clearly the kind of complexity being managed. We believe that project performance is closely related to project complexity management. Consequently, once clearly defined, project complexity should be accurately measured in order to drive more efficiently project complexity management. It should also be kept in mind throughout the reading of this paper that complexity can have both a negative influence on project performance and a positive influence on project outcomes (since properties emerging from complexity can create new opportunities). As a consequence, project complexity management should not consist in reducing or avoiding it but in maintaining it in a good range.
In this paper, we first focus on three different aspects of complexity: definitions of complexity and project complexity, existing models of project complexity, and existing measures of complexity and project complexity. We then argue that it can be modelled through an interactions model between the different elements constituting the project system. We do believe that by defining those objects, their attributes and their interrelations through systemics, we are able to model project complexity. A first model was tested in partnership with PSA Peugeot Citroën and proved to be helpful. This paper also aims at refining this model into a new model named ALOE and finally gives perspectives on how it will be further developed to enable its users to define a project complexity measure and link it more efficiently with project performance, so that they can finally lessen the number and impact of the risks and problems emerging from complexity.

2 BACKGROUND

2.1 Project complexity and project performance

Project management is in essence complex, and different aspects of complexity have to be dealt with: on one hand, projects are complex entities, and on the other hand, the management activity is also complex. Focusing first on the management aspect, it must be kept in mind that management is composed of decisions and activities made by people, those decisions being made at a given instant to reach an objective in the future. Once made, a decision changes the states of the elements it impacts and thus the state of the project itself, targeting a final state for the project (composed of the objectives of the project). The difference between the targeted state and the reached state basically accounts for the project performance. It should also be kept in mind that every management decision is relative to a context which is the known present situation (resulting from the past decisions) and that the aim of this decision is to reach the future objective, which is more or less correctly defined and more or less stable. This overall decisions chaining determines the trajectories of the evolution of the project system and thus determines the final reached state (which determines the overall project performance). This complexity of the management activity is not the only complexity that has to be dealt with when talking about project management complexity: one has also to focus on the project system complexity.

Before focusing on the project system complexity, we give some information on the link between project management performance and the project models that are used to manage the project.
Indeed, we argue that project management performance is related to the project model complexity, stating that the project model should reach a lower level of complexity (so that there is enough interaction and enough emergence to have good opportunities) without reaching a upper level of complexity (so that unnecessary complexity resulting in high risks is avoided) in order to create more value by a good interactions and interfaces management: project management performance, functions of project model complexity, is strongly likely to have an optimum, as shown by *Figure 1*.

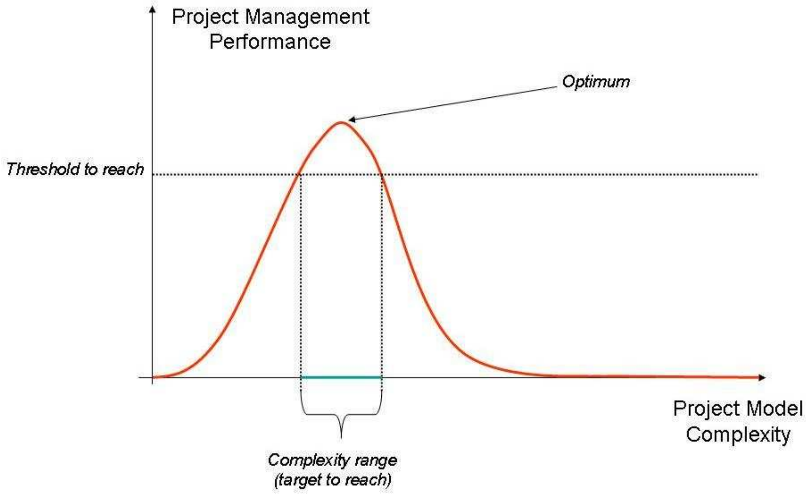

Figure 1. Project management performance, functions of project model complexity

This can be easily understood through a simple example, the one of the level of detail of the work breakdown structure. If the work breakdown structure is not extensive enough, the project may have been weakly decomposed and work packages not properly defined: as a consequence, work packages might be in fact decomposed in sub-tasks that have not been defined by the project manager and the self-organization resulting from this absence of detail is likely to affect badly project performance. On the contrary, if the work breakdown structure is too extensive, the decomposition may be too complex to be effectively used as interactions and interrelations between work packages may be too numerous to be properly managed. There is likely to be therefore a range of extensiveness for the work breakdown structure that would be proper for a successful project management. In this case, a complexity measure and a complexity scale of the project model that is the work breakdown structure (projection of the project on a tasks axis) could help project managers to assess the potential effectiveness and efficiency of their work breakdown structure. That is why many researchers tried to build different kinds of complexity measures to assess the potential effectiveness and efficiency of different models of projects. In order to understand those different aspects of the problem, the three next paragraphs focus on definitions of project complexity, existing models of project complexity and existing measures of project complexity.

2.2 Definitions of project complexity

There is actually no consensus about what complexity is. Calinescu and al. [1] argue that “the reasons for the lack of a universal modelling framework of manufacturing complexity include the variety, dynamism, and uncertainty of the sources of complexity and on the relationships between them”. The difficulty in defining complexity is mainly reduced through the definition of key drivers of complexity. But defining those key drivers is not a simple thing to do, in the field of project management as well as in other domains. Indeed, those drivers depend on the environment and context of the project. Sinha and al. [2] insist on the fact that “when modelling the complexity of the design process it is first essential to determine the context” (work context, time context, motivational context and social context). They also underline that there is once again a lack of consensus on project complexity drivers and that little is known about the interrelations between those drivers. Project complexity is therefore difficult to define as a whole in generality.

That is why several authors try to express project complexity as composed of different kinds of complexity, so that they can define more easily the aspects and drivers of those kinds of project complexity. For instance, David Baccarini [3] explores project complexity as the association of organisational complexity (number of hierarchical levels, the degree of interaction between the project organisational elements, etc…) and technological complexity (number and diversity of inputs/outputs, number of interdependencies between tasks, etc…), defining those two kinds of complexity through the concepts of differentiation and interdependency. Such a distinction enables project managers to manage complexity more efficiently since they can to some extent simplify their complexity management approach by distinguishing the kind of complexity being managed.

However, Edmonds [4] tries to define complexity in general as the "property of a model which makes it difficult to formulate its overall behaviour in a given language, even when given reasonably complete information about its atomic components and their inter-relations". This definition, which is quite appropriate to encompass all the aspects of project complexity, emphasises that complexity is generally relative to the way the project system is modelled. This definition indeed underlines that an absolute *a priori* definition of the complexity of a system cannot be given though complexity may be a property of it: the complexity of a system is generally characterised through a model of this system. Consequently, measuring project complexity requires that one is able to define a general measure of this characteristic that would be independent of the project model, otherwise the so-called project complexity measure is in fact a project model complexity measure.

However, project complexity has to be managed even if there is no definitive definition of project complexity. Williams [5] insists on the fact that "what are needed, then, are new ways of looking at modern, complex projects, new models and technique for analysing them, new methods for managing them". In order to manage project complexity, a project manager must be able to understand and deal with the underlying phenomena of project complexity and project dynamics although it is impossible to have precise and complete information on a project at a given moment (which makes decision-making never easy and always uncertain). For all practical purposes, a good project manager first identifies a general *a priori* framework for the project (that for instance enables him to estimate the project risks within this framework) but he is aware that unpredictable phenomena (for instance unpredicted risks) are very likely to appear. To anticipate them, complexity should be *a priori* measured and modelled so that complexity management is facilitated. Important steps in a project complexity management plan should be for example: *a priori* complexity measure and model definition, identification of irreducible project complexity (closely linked to the emergence of new properties and to unpredictable consequences and phenomena) and manageable project complexity (closely linked to predictable consequences and phenomena), definition of a manageable project complexity management plan, practical project management and project complexity management, capitalisation of this complexity management experience. Irreducible and reducible complexity should be correctly identified thanks to a good complexity measure and model definition, the project manager's experience, the project management maturity of the firm, etc… As a consequence, this paper reviews in the forthcoming paragraph the literature on project complexity models.

2.3 Existing models of project complexity

In this paragraph, we give several models that have been elaborated by different researchers in order to model project complexity. As shown on *Figure 2,* our literature review underlined two different approaches to deal with project complexity. The first one focuses on the project system structure: by modelling it, researchers intend to assess project complexity thanks to a better understanding of the project structure model complexity. The second one consists in a twisted approach by focusing on some issues of project management (such as the project scheduling problem) and considering the complexity of those issues as an assessment of project complexity. As we intend to understand the fundamental phenomena of project complexity, we focus on the first approach of project complexity assessing and modelling from now on.

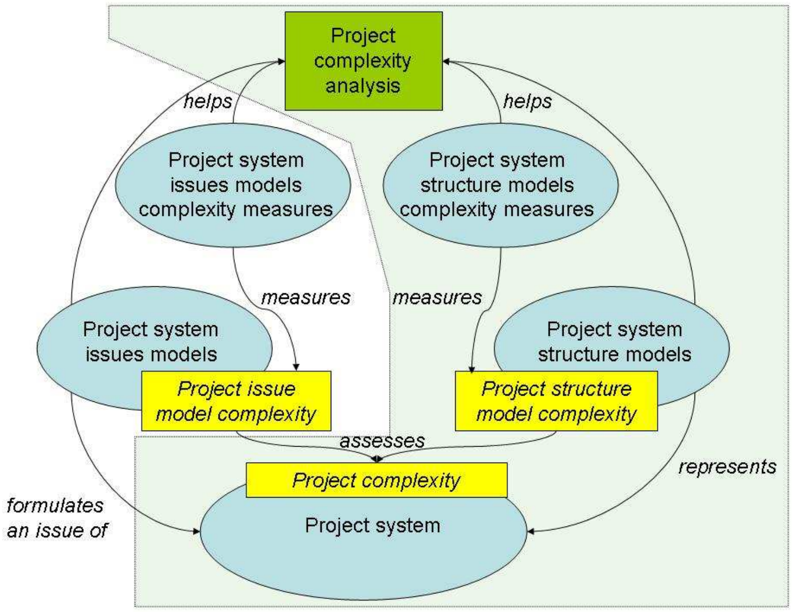

Figure 2. Project complexity modeling through project structure or project issues

Laurikkala and al. [6] aim at describing how the complexity of large industrial projects models can be reduced. To reach this objective, they design a modelling tool for industrial use. They compute their model in a distributed and networked information system named Simo that proved to be helpful as it was notably very visual and easy to use. It mainly consists of business, resource and product modelling. This information system aims at modelling the project through all its lifecycle and testing some scenarios such as "alternative and new ways to operate". The greatest breakthrough of this model is that it permits to vary the level detail in modelling: it therefore enables a project manager "to concentrate on the most critical issues of the project […] whereas less important information can be modelled roughly or left out altogether". Laurikkala and al. argue that modelling at different levels enables one to reduce complexity for all practical purposes since unnecessary guesswork can be considerably reduced. However, the model aims at reducing complexity and giving the possibility to reduce the level of detail when one wants to do it, but there seems to be no complexity scale definition and above all no willingness to reach a complexity range target for the model that could be the optimal one for the project.

As for them, Earl and al. [7] define a complexity model that makes a distinction between time-dependent and time-independent (static structure of processes) complexity. They aim at modelling the complexity of design processes thanks to the interactions among multiple product developments. They insist on the fact that "this interaction cannot be avoided through decomposition and dependency reduction since it provides the mechanism through which knowledge and experience are used". These interactions must indeed be modelled since these interactions management is likely to be the greatest source of value creation during the project. The model is defined thanks to the modelling of connectivities thanks to multidimensional networks. Even though the model is based upon multiple product development projects, it can easily be extended to a single product development project. They then define the difference between the original complexity of the model (time-independent) and the dynamic complexity of the model when values of the models are likely to change and therefore create flows between elements of the model. They finally argue that the information measures of complexity can help setting an ideal design complexity level.

As for them, Eppinger and al. [8] or Carrascosa and al. [9] use design structure matrices to create task models for complex projects and processes. Eppinger and al. [8] compared some existing design representation techniques. They argue that using numerical design structure matrices contributes to a clear understanding of the complex interactions that can occur during design projects. Indeed, more than just a mathematical tool, matrices are a way to visualise the structure of the design activity by mapping (in a precise order) and quantifying the interrelations between tasks. Interactions, interdependencies (and notably critical dependencies) are thus explicit and one can easily see for instance at a glance which tasks can be performed in parallel. The numerical design structure matrix also helps to quantify both the level of information that is exchanged between tasks and the sensitivity of each task to uncertainty (incomplete information). The matrix format is also convenient to define complexity numerical measures and complexity ranges objectives or targets since calculations are likely to become easier. Carrascosa and al. [9] elaborate a model based on design structure matrices (with their property of capturing the interactions between tasks) that can assess the probability and level of completion of a project, given the project complexity. They model complexity by assessing the impact of a change on a task and thus assessing the propagation of this change thanks to the definition of task states and task states transitions. This framework characterises both "the uncertainty in the definition of the information and the impact of changes in the development process" and is consequently a tool to assess to some extent project complexity. Although these model bases on design structure matrices are powerful, they are only based on tasks that are only parts of the project system. Indeed, design structure matrices model project complexity thanks to tasks and their interrelations but some part of project complexity is therefore absent in this model.

2.4 Existing measures of project complexity

This paragraph aims at giving a brief review on the literature on complexity measures defined within the field of project management or that can be extended to the field of project management. Several authors tried to define complexity measures in order to explain project failures, to identify intricate situations, etc... Whatever the complexity measure is, one must be able to define a list of criteria that can be used to assess if it is good or not. Latva-Koivisto [10] proposes several criteria in his research report such as validity, reliability, computability, ease of implementation and intuitiveness.

Our methodology for the literature review on project complexity measures was the following. We first reviewed the literature to list existing complexity measures. We insist on the fact that, as explained on *Figure 2*, we intended to focus on project structural complexity even if some other complexity measures do exist (for example computational complexities such as the complexity of the project sequencing problem studied by Akileswaran and al. [11], etc…) The works of Edmonds [4], Latva-Koivisto [10] and Nassar and al. [12] were the main basis of this list (about fifty complexity measures globally listed). In his thesis, Edmonds [4] identified formulations and measures of complexity, working on a large scope of fields and applications. As for him, Latva-Koivisto [10] reviewed complexity measures to assess the structural complexity of business processes, arguing that the complexity of business processes could be assessed through the conversion of process charts (composed of activities, dependencies, information flows, material flows and control flows) to graphs [13], giving the example of the resource-constrained project scheduling problem. The interested reader should directly refer to these three references for more information on complexity measures and formulations. We then tried to refine the list thanks to the criteria cited hereinbefore. We finally selected four complexity measures that appear to be potentially appropriate in the field of project management.

- The coefficient of network complexity (CNC) defined by Kaimann [14] applies to both PERT neworks and precedence networks. In the case of PERT networks, the CNC is equal to the quotient of activities squared divided by events. The CNC, thanks to a very simple and intuitive definition is a good complexity measure to catch the structural complexity of systems that are modelled thanks to graphs. However, some counterexamples have shown that some graphs and networks were sharing the same CNC but were very different considering their easiness to be managed.
- The cyclomatic number defined by Temperley [15] gives the number of independent cycles in a graph. The equation calculation the cyclomatic number is equation (1) (S is the cyclomatic number, A is the number of arcs and N is the number of nodes).

  $$S = A - N + 1 \qquad (1)$$

- The traditional static entropic measurement of complexity by the Shannon information [4] based on the probability of receiving a message (see equation (2) where $p(n_i)$ is the probability of receiving a message n_i). The Shannon information is also a complexity measure since information and disorder are strongly related.

  $$Sha = -\Sigma \log_2 (p(n_i)) \qquad (2)$$

- Arguing that complexity measures such as CNC are imperfect since they take redundant arcs into account and therefore show that the system is more complex than it actually is, Nassar and al. [12] define a measure for project schedules in terms of the connectivity of the activities. This measure is expressed as a percentage that gives the degree of interrelationships between the activities in a schedule. Once again, attention should be paid to the fact that this measure depends on the level of detail of the schedules, that is to say the level of detail of the model. This complexity measure is the following equation (3) for an AON project network.

$$Cn = 100 \times (Log(a/(n-1))/Log[(n^2-1)/4(n-1)])\% \text{ if } n \text{ is odd}$$

$$Cn = 100 \times (Log(a/(n-1))/Log[n^2/4(n-1)])\% \text{ if } n \text{ is even} \quad (3)$$

In the following sections, we detail our research objectives, methodology and results and focus particularly on how we try to be exhaustive on the different aspects of project complexity.

3 RESEARCH METHODOLOGY

3.1 Objectives of this research work

This research work aims at modelling and assessing complexity in the field of project management. In order to model project complexity, the results should meet some requirements:

- the definition of a standardised referential that makes any kind of confusion vanish when talking about the elements of the project system.
- the construction of a model of the project system that permits an easier visualisation of project structural complexity;
- the possibility for the model to visualise more efficiently local interactions and interfaces in order to manage them best;
- the possibility for the model to assess the impact of a change or of an event considering the propagation phenomenon into the project system.

In order to be the basis for a project complexity measure to be as helpful as possible for complexity management, the model should be conceived without losing the sight of the criteria that a good complexity measure should meet.

3.2 Methodology

The herein mentioned steps have been successively followed in order to carry out our research:

- A literature review in the fields of complex systems sciences, complexity, project management, design management and systemics.
- A systemic analysis that enabled us to define a standardised referential for project structure definition.
- The definition of the project complexity model relative to the standardised framework formerly described.
- The computation of the model in a software prototype.
- A test phase in the context of several industrial projects.
- The refining of the project complexity model thanks to the results of the test phase, recent research work and systemics.
- The computation of this new model and the associated test phase.
- The definition of a project complexity measure thanks to the model that has been built.

At the time of the writing of this paper, the first six bullets have been performed. The next section aims at presenting the results of theses phases of our research work.

4 FINDINGS

4.1 The 3*7 model

A model of the project system has been developed [16]. This model, named 3*7 describes the project system as composed of elements of three different kinds: objects, attributes and links (See *Table 1*). Attributes are the characteristics and parameter that can describe the state of on object. Links are the possible relations between two objects within the project system.

*Table 1. The 3*7 framework*

*	**3** (categories : objects, attributes, links)		
7 (components in each category)	**O1** - Project	**A1** – QCD parameters	**L1** – Hierarchical link
	O2 Objective	**A2** - Advancement	**L2** –Contribution link
	O3 - Deliverable	**A3** – Internal decision	**L3** – Proximity link
	O4 - Activity	**A4** - Description	**L4** – Sequential link
	O5 - Actor	**A5** – Allocated resources	**L5** – Influence link
	O6 – Process	**A6** – Triggering event	**L6** – Resource link
	O7 – External decision	**A7** – Ratio Added Value / Risk	**L7** – Exchange link

This model, defined partially thanks to systemics [17], aims at modelling and managing project complexity as it enables people to define and describe clearly the elements of the project system and their relations. Where there was sometimes some confusion and lack of agreement on the definition of all the elements that were involved in a project, there is now a general framework and a standardised structure that creates consensus within the project team. The model permits to visualise project complexity by giving at a global level an overall clear vision of the structure of the project system.
But the most important breakthrough is that the model gives at a local level a better vision of all the interactions that exist in the environment of any object within the project system (*Figure 3*). Indeed, the 3*7 model makes available to any project team member all the information about the properties, attributes and environment of an element of the project system, whatever the nature of the element and the nature of the project are. As a consequence, thanks to this model, one can navigate from an element A of the project system to a connected element B (which means those there is a link between A and B), the properties, attributes and environment of which are also described thanks to the model. Therefore the consequences of a change or any decision on an element A can be understood more efficiently by having a clear vision on the impacts of this change or decision on the elements connected to A. The negative aspects of project complexity are thus reduced since one comprehends more the consequences of the evolution of an element of the project for its other elements.

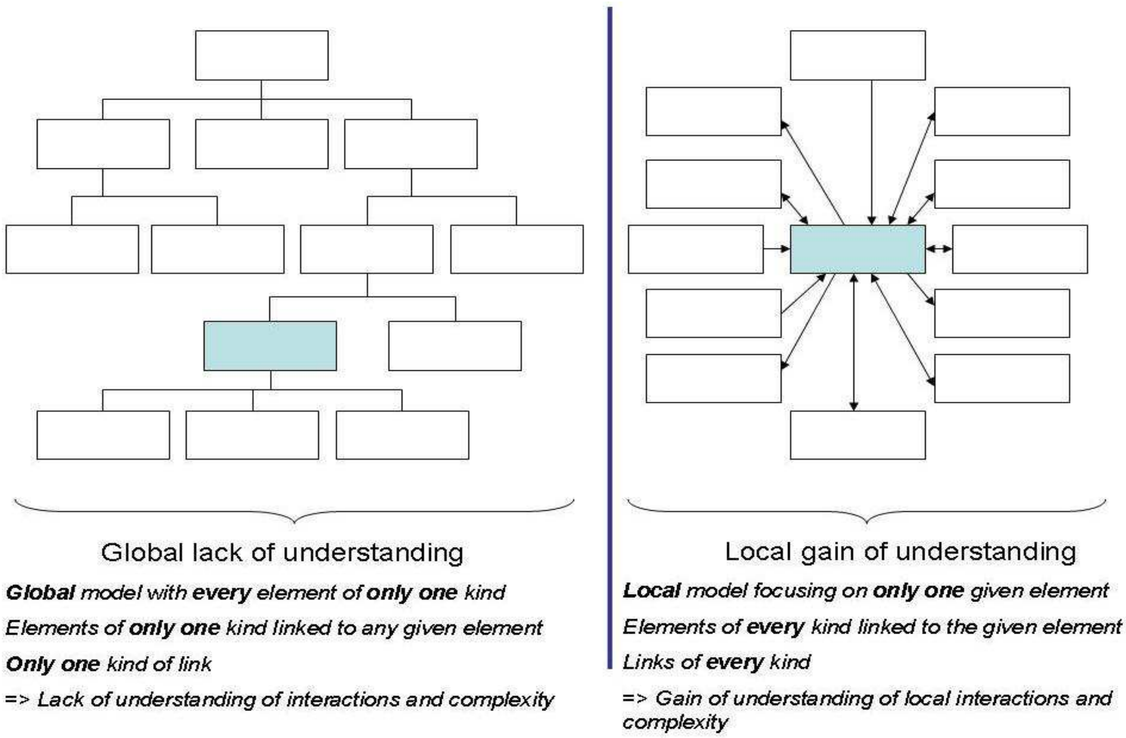

Figure 3. From a global lack of understanding to a local gain of understanding [16]

The model has been computed in a software prototype named ICARE performed and tested in partnership with PSA Peugeot Citroën on some automotive projects of their progress plan [16], [18]. This proved to be helpful and the industrial added value on the projects was notably to make visible some formerly non-formalised information thanks to the identification of the interactions between objects (and therefore of the interrelations between people). For all practical purposes, this permitted greater information sharing between project team members, especially between geographically farther team members: this model, as a practical representation of the relevance to exchange information, encourages the dissemination of it.
As a whole, the model appears to be a support for project complexity management since it improves interactions and interfaces management. However, we thought that some aspects of this model could be improved: for instance, the QCD parameters consisted of only one attribute; external decision and internal decision were not classified in the same category although the mechanisms are to some extent similar. And above all, the 3*7 model does not reflect the dynamics of the project as it permits to model the project at a given time under the conditions of this given time. We think that the project system complex evolution can be better modelled thanks to the improvement of the 3*7 model by refining the 3*7 standardised referential with in particular the introduction of a new category of elements: events.

4.2 The evolution towards the ALOE model

Recent research works have indeed motivated us to improve the 3*7 model by the elaboration of an updated model, named ALOE (Attributes, Links, Objects, Events). In this paragraph, we discuss the changes we made between the 3*7 model and the ALOE model and how these changes impact project complexity modelling.
First, the most significant change is the creation of a new category: events. Events can be either willed (in which case they are internal or external decisions) or unwilled (in which case they are internal or external risks). Events can have both positive aspects and a negative influence not only on objects of the system by changing their attributes or by the creation/destruction of new/past objects, but also on links (and their corresponding operators). Events can be characterised by their probability and date of apparition (probability for a risk to occur, probability for a decision to be made, date of a decision, etc…) and their impacts are defined thanks to operators. Note that for instance, once made, the date of decision is known for sure and its probability becomes equal to 1.
When computing this model, we must leave the opportunity for the user of the model to add new events in the system (events that spontaneously appear as a consequence of emergence). This possibility has two major objectives. First, when a new event emerges, the user can add it in the model and directly have a better understanding of the impact of this emergence for the whole project system. Furthermore, in order to anticipate the emergence of unpredictable events, one can use the model to simulate the possible apparition of events of a kind (described by some families of operators) during the project. As events are a new category, the elements “internal decision”, “external decision”, “risk” and “triggering event” are no longer part of the categories attributes, links or objects in the ALOE model.
The proximity link does not exist anymore in the ALOE model: as the proximity between two objects is a property mainly leading to the reuse of some experience and is therefore a property that makes an object influence another one, we thought that the proximity link was very similar to the influence link: that is why we only kept the last one in the ALOE model.
Similarly, the resource link defined in the 3*7 model was defined to link to objects if they were sharing resources. We argue that this link is in fact very similar to the exchange link (defined in the 3*7 model as information exchange, that is to say immaterial exchange) since sharing resources is equivalent to exchanging resources at different times (resource exchange, that is to say material exchange): that is why we only kept the exchange link in the ALOE model (exchange can be both immaterial or material).
Finally, other changes have been made in the objects category to be even clearer in the structure of the model (an actor is considered as a resource, a new object “other project within the firm” appears to tackle multi-project complexity, etc…).
The final structure of the ALOE model is given herein in *Table 2*. This structure is all the more interesting that is it remains stable during the evolution of the project whatever the phase of the project is.

Table 2. The ALOE framework

Attributes	**Links**	**Objects**	**Events**
Quality	Hierarchical Link	Objective	Internal decision
Cost	Contribution Link	Deliverable	External decision
(Duration, Start Date)	Sequential Link	Activity	Internal risk
Advancement	Influence Link	Resource	External risk
Description	Exchange Link	Other project within the firm	
Allocated resources			
Added value			

5 CONCLUSIONS AND PERSPECTIVES

Complexity has undoubtedly to be managed in order to reach a great level of project performance. Managing complexity does not mean avoiding it or reducing it at all costs: on the contrary, a good project manager should be able to manage complexity, keeping at every time a project between an upper and a lower level of complexity. To help project managers reach this complexity range, efficient complexity models and measures have to be elaborated. Thanks to our literature review, systemic analysis and successive stages of refining, we have been able to define a standardised referential that brings consensus by clearing the definition of the structure of any project. Moreover, this general framework helped us to define a model that is helpful for complexity management as it enlightens all the interfaces and interactions that exist between every object of the project. By clearing the situation and a local level and thus giving a better vision of the propagation of a change by navigating through the model at local levels, one can comprehend more how project complexity influences project evolution and thus project performance. One should indeed be able to reach objectives more efficiently as he can both assess the impact of a change or of any decision and simulate different scenarios of evolution (with or without emergence of unpredictable events).

Some work is still to be done on the ALOE model. By defining more accurately the attributes of the objects and the operators of the links and the events, by computing the model and testing it on several projects, we aim at refining the ALOE model and assessing the propagation of a change cause by an event within the system. As a consequence, we aim at assessing more efficiently the evolution of the project system and the impact of changes (static impact at a given time, semi-dynamic impact through the use of discrete events). After this test phase and the use of its results, we believe that the ALOE model is likely to be the conceptual basis of a tool for project managers so that they can visualise and therefore manage more efficiently their project complexity (notably in terms of interactions and propagation). Finally, we do believe that the ALOE model can also be a basis to define a complexity measure by adapting some complexity measures we dealt with in paragraph 2.2. since it meets the criteria that are necessary to define a complexity measure. Developing this complexity measure (and the associated complexity scale and range target) in parallel with the final development of the ALOE model is our last perspective, so that the project complexity management tool we aim at developing meets our requirements.

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