ADAPTIVE BEHAVIOR IN COMPLEX HEALTHCARE INTERVENTIONS: ASSESSMENT USING COMPUTER SIMULATION

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ABSTRACT
Projects of case management of older persons were implemented in Belgium. This type of long-term healthcare interventions presents many aspects of complexity including human interactions and contextual effects. Computer simulation enables to mix advantages of classic qualitative and quantitative analyses to assess why differences in the implementation of these projects led to failure or success. A simulation model of case management was designed using a Rule-Based Methodology. Based on the research material, variables and rules definitions were elicited into a simple conceptual frame. The simulation was then confronted to field experts. The rigorous formulation clarified the description of the interventions. Parametric analyses were performed with the experts. Problems and adaptation processes were reported. Eventually, a number of recommendations were addressed. The simulation model presented should be seen primarily as a tool for thinking and learning. The computer simulation can help to unfold causal mechanisms of complex interventions.

Keywords: Computer Simulation, Participatory Research, Complex Healthcare Intervention, Case Management

1. INTRODUCTION

1.1. Complexity in Healthcare Interventions

Interventions aimed at improving chronic and long-term healthcare present many aspects of complexity. Their action mechanisms are often characterized by feedback loops, delays and non-linearity (Plsek and Wilson 2001). These effects cannot be modeled properly by linear quantitative tools, leading to inconclusive results when assessed with classical effectiveness studies such as quantitative randomized experimental designs (Eldridge et al. 2005). For this reason, qualitative studies are usually preferred, to take advantage of their explorative power.

Quantitative and qualitative methodologies are often presented in opposition to each other. However, both approaches present different advantages and rely on empirical data of different natures. On the one hand, quantitative studies establish relationships within a limited set of variables, following a mathematical normative approach. On the other hand, qualitative studies build on perceptions and interpretations to find a contextual meaning and propose a causation mechanism (Greenhalgh and Russel 2010). The contrast between these perspectives makes a formalization combining both approaches difficult to construct.

In addition, long-term interventions are characterized by non-linearity and non-determinism. This implies that the collected data represent only one specific instance of reality in one particular context. Hence, a proper data collection would ideally involve data on a very long term, with an exhaustive set of variables. The cost and feasibility of such studies make them hard to set up. Besides, the mere fact that such data are highly context-sensitive makes them hard to handle in a generalization process.

1.2. Computer Simulation: a Possible Answer?

Computer simulation has been argued to be one possible solution to overcome the complex aspects of healthcare studies (Auchincloss and Diez Roux 2008; Diez Roux and Auchincloss 2009). While already being used in the modeling of infectious disease (Epstein 2009), computer simulation has not yet been exploited to its full potential in health system research. However, further advances in this field may be encouraged by simulation applications from other fields.

Firstly, simulation research in the field of project management might bring useful insights for the evaluation of complex interventions in health care. Indeed, the simulation of projects modeling heterogeneous workers within teams and organizations has helped managers to take step forwards in decision-making processes (Peculis, Rogers and Campbell 2007; Araùzo, Pajares and Lopez-Paredes 2010).

Secondly, the simulation strategy has also offered many opportunities in organizational and public policy modeling. The analysis of multiple scenarios enables to build more robust solution by considering policy decisions as an adaptive response that evolves over time (Lempert 2002).

Finally, simulation as a tool of participatory research might also shed light on health system research applications. Indeed, the opinions of field experts can prove to be an important and valuable source of information when data are scarce and submitted to the constraints mentioned earlier. These opinions can be gathered, confronted and aggregated using a simulation model. This results in the building of a formalized and generalized knowledge. Interesting applications in the fields of ecology have been designed using role-playing games and companion modeling methodology (Bousquet et al. 2007; Barreteau and Le Page 2011).

All these computer simulations typically use an Agent-Based or, more generally, Rule-Based Modeling (RBM) approach, which can also be used to assess complex interventions. The RBM consists in the definition of a set of variables and their rules of interactions (Collopy and Armstrong 1992). These rules can be expressed using a logical language such as if-else statements, which is well suited to translate experts' opinions. Other quantitative data can also feed the model. Moreover, random effects can be introduced and parametric analyses performed.

1.3. The Case of a Complex Intervention

The National Institute of Health and Disability Insurance in Belgium (NIHDI) has financed 62 innovative projects in order to enable the elderly to remain in their own residences (Protocol 3). A consortium of universities was asked to perform a scientific evaluation of all projects, in order to identify the types of projects likely to provide the most effective support to the elderly and help them to remain at home in good conditions.

However, the types of interventions covered a large scope of care services (case management, night care at home, occupational therapy, psychological and psychosocial support). In addition, the projects were submitted to diverse levels of embeddedness in the local healthcare system. Hence a classic comparison process between the projects was not an option.

Preliminary analyses of seemingly identical case management interventions (N=19) seem to reveal that they have adopted different patterns of adaptation leading to success or failure in achieving their pre-set goals. This may be explained by the high number of different actors and interactions involved in such interventions. Indeed, case management involves interactions with patients, healthcare providers and case managers, in assessing needs, planning, coordinating, carrying out and evaluating care.

Typical assessment of this hypothesis would require comprehensive case studies to assess and test emergent practice theories (Polit and Beck 2008). However, computer simulation provides a rigorous language that can help to build a structured assessment. In addition, parametric analyses can be performed, and different scenarios can be implemented. The whole implementation of the model can generate valuable insights regarding this theory, which can then be transferred with a reduced ambiguity.

In this paper, we show that computer simulation can help to unfold causal mechanisms of a complex intervention (i.e. case management in home-dwelling frail elderly) through the conception and the test of a conceptual frame. Moreover, the building of this type of framework supported by both quantitative and qualitative inputs might represent a valuable and reliable output of studies in a complex context.

2. METHODOLOGY

2.1. Gathering of Data

Several sources of data were available to perform computer simulation for the assessment of case management action on elderly depression. Firstly, empirical data about the health status of the elderly person were available from the BelRAI database. BelRAI is the adapted version of a multidisciplinary comprehensive geriatric assessment tool for the elderly, and is part of the international InterRAI project. The projects managers were asked to fill out these data via an on-line health questionnaire regarding the elderly people included in their project. In the context of our study, the level of depression state was particularly used as an indicator of well-being (Depression Rating Scale (Burrows et al. 2000)).

Secondly, the initial project proposal description, was used as the first key step in conceptualizing the project.

Thirdly, a yearly questionnaire relating to the description and implementation of the project was used to assess the current evolution of the project. Finally, scientific researchers conducted specific case studies analyses for 4 out of 19 projects to develop an in-depth understanding of the implementation: what was the planned intervention? With what result? For what target population? By whom? With what means? Did the project achieve its goals? How and why? How did the project adapt to the specific challenges of the context throughout the implementation process?

2.2. Conceptual Frame

Based on the preliminary interpretation of the researchers, a conceptual frame of the typical description of a project was built following a Rule-Based Methodology. Three agents were defined succinctly with a corresponding set of variables.

- Case Manager (CM): Knowledge, Informal Knowledge and Organizational Skills.

- Caregiver (CG): Knowledge and Capacity.
- Older person (ELD): Needs and Demands.

The links between the agents (topology) are represented in Figure 1.

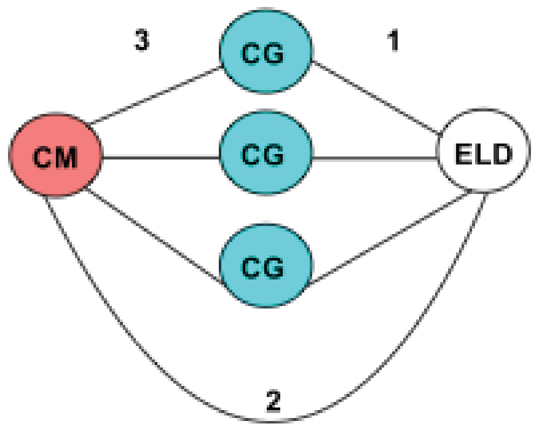

Figure 1: Conceptual Frame Representing the Interactions between Three Types of Agents: Case Manager (CM), Caregiver (CG), Older Person (ELD). The number of agents of each type can be varied.

Using these variables simple rules were designed integrating the qualitative material available, representing the opinions of stakeholders and researchers. Three parameters were used to determine 'reasonable' Demands, 'good' Organizational Skills and 'good' Informal Knowledge. The main rules were defined as follows.

1. The Needs of the ELD were set to increase constantly as a natural evolution.
2. Interaction CG-ELD (1): if the Needs of the ELD are met by the Capacity of the CG, these Needs decrease; else the Needs and Demands of the ELD increase. In addition, in the case where the Needs of the ELD are not met by the Capacity of the CG, then if the Demands of the ELD are reasonable, the CG increases his Capacity and his Knowledge (reflexive process); otherwise the CG decreases his Capacity.
3. Interaction CM-ELD (2): if the Informal Knowledge of the CM is good then he decreases the Demands of the ELD when they are not reasonable. When the Needs of the ELD are not met, the CM increases his Knowledge, Informal Knowledge and Organizational Skills (reflexive process).
4. Interaction CM-CG (3): if the CM have good Organizational Skills he can identify the ELDs for whom needs are not met, identify the associated CGs, and increase their Capacity and Knowledge.

The model was implemented in Netlogo, a free open source software providing a user-friendly graphical interface (source code and accompanying implementation details are available at the following link https://sourceforge.net/projects/cmsimulation/).

This preliminary implementation was designed and presented to four experts in elderly case management. The definition of their project, the problems encountered and the possible mechanisms of adaptation were translated in terms of the variables and rules used in the conceptual frame.

Different scenarios could be investigated using the number of each type of agent, the initial states of their variables and the good/reasonable parameters,. Different simulations were performed to construct the conceptual frame step by step beginning with the older persons only, and successively adding caregivers and a case manager. The group of experts and the researchers discussed each scenario.

3. RESULTS

3.1. Use of Empirical Data

As an initial step, raw Depressive Rating Scales data were retrieved from the BelRai. They were averaged over all projects and their evolution was succinctly investigated. Obviously finer analyses would be required to enhance the descriptive power of these data, possibly including confounding variables, and discussed for each project. However, the assessment of this single variable already revealed the inherent resulting blur when comparing across projects, and the difficulty of establishing a possible causation process from a before-after assessment.

In parallel, while designing the rules, poor quality in the data filled out in the questionnaire was observed. This revealed a problem in both the filling out of the questionnaires and the perception of the evaluation process by the stakeholders. Hence, these observations emphasize the problem of the reliability of the data in a complex context integrating human response under evaluation. To counter this issue of reliability, a triangulation of the data by means of case studies analyses in four projects enabled the clarification of questions and the purpose of the evaluation process.

Both these problems emphasize the need for other methodological approaches.

3.2. Ontological Step

The qualitative material was used to define in explicit details the variables used in the conceptual frame (see Table 1). While the definitions and language elaborated could not be exhaustive, this ontological step was considered as an essential common dictionary in the discussion with the experts. In addition, in terms of operationalization, it clarified the type of case management (e.g. according to the typology of Lee (Lee et al. 1998), such as brokerage model, integrated case management model, self-managed care, or a combination of them).

Table 1: Ontological Dictionary. Three Agents are defined: Case Managers (CM), Caregiver (CG), and the Older Person (ELD). Each Agent (1st column) is Associated with Corresponding Variables (2nd column) and their Details (3rd column).

CM	Knowledge	**Evaluation of the ELD's needs:** Use of diagnostic tools to measure physiological state; evaluate the capacity of the older person
	Informal Knowledge	**Consider the specific demands of the ELD:** Analyse and consider the sociodemographic context; take into account the resources and will of the older person; establish a good acquaintance with the older person
	Organizational Skills	**Organization of a fine-tuned envelop of care:** Enable an access to differentiated care and services; setup efficient and durable partnership; coordinate and work at minimal cost
CG	Capacity	**Deliver care/services required by the CM:** Deliver quickly efficient care and service; be accessible
	Knowledge	**Knowledge of the physiological state and capacity of the ELD:** Fill out and use adequately ELD information; share information and collaborate with other CGs
ELD	Needs	**State of "health/frailty":** Regarding physiological, functional, psychological, socially, relational aspects
	Demands	**Life habits and preferences:** Influence the capacity to comply to the proposed care/service; ex: organization of daily life, cultural aspects, incomes, general ability

3.3. Confrontation to the Experts

First, the conceptual frame was presented to the experts in elderly case management, together with the ontology of the variables. Quite naturally, the simplistic and possibly controversial definitions of the variables were subject to discussion, refining the concepts behind the terms. For example, the experts would have exchanged the terms 'Demands' and 'Needs' or would have renamed the informal demands as 'Preferences'. In the subsequent discussion, the terminology was then specified in 'Formal Needs' and 'Informal Demands'. Despite the possible lack of political correctness of the terms, the experts could accept and handle the meaning of the variables.

Next, the experts were invited to define their own projects within the conceptual frame, in terms of the established variables. The experts were able to discuss, compare their projects, and position themselves within the schema with surprising differences in terms of topologies (links between actors), with different roles, profiles and missions of the case manager. For example, one expert positioned himself higher ('on the left') of the CM. Another described the agent ELD as being a group of elderly people. Another spontaneously declared that "this exercise allows a definition of factors and characteristics which look similar through projects, but that are actually totally different".

Then, the rules of interactions were presented and discussed. The written and spoken formulations appeared quite difficult to understand. However, running the simulation and visualizing the rules dynamics into graph (Figure 2) enabled a better comprehension.

Finally, the step-by-step reconstruction of the conceptual frame and playing with the parameters trained them to interpret simulations, similar to the one in figure 2, as follows. While the Needs of the ELDs increase, the Knowledge, Informal Knowledge and Organizational Skills of the CM increase as well. When Organizational Skills and Informal Knowledge become good, the CM is able to increase the Capacity of the CGs and to decrease the Demands of the ELDs. This results in a stabilization of the Needs of the ELDs.

The discussion of these simulations enlightened by insights of both experts and researchers led to the definition of problems, and the way the project adapted to them, according to the context in which the case management was delivered. Eventually, a number of recommendations for the implementation of case-management projects could be addressed.

3.4. Formal Needs and Informal Demands

Through all simulations, experts pointed out that making the distinction between formal needs (assessment and coordination) and informal demands (understanding and interpretation) was one big challenge for an effective case management. This justified a posteriori the two kinds of knowledge of the case manager.

In addition, the experts noted that a state of equilibrium in the different variables was reached after a certain time. While this is in fact a numerical property of the simulation, the experts interpreted this as the time of adaptation required for the case manager to increase their informal knowledge about the elderly individuals and their caregivers, which appears to be a reality of the field.

Further, while the question of the time of adaptation was raised, it came up as a recommendation that it is better to reduce the length of the monitoring in favor of the frequency of visits for both caregiver and case manager. While this intuitively enables to monitor for potential random accidents, it also contributes better to the understanding of the informal demands of the older person.

Moreover, recourse to persons previously acquainted with the older person (nurses, GPs, informal caregivers) or structures may help in a phase of needs assessment by better understanding the informal demands. While further management skills will still be required, this step may help to decrease the period of adaptation when attempting to organize or implement case management interventions.

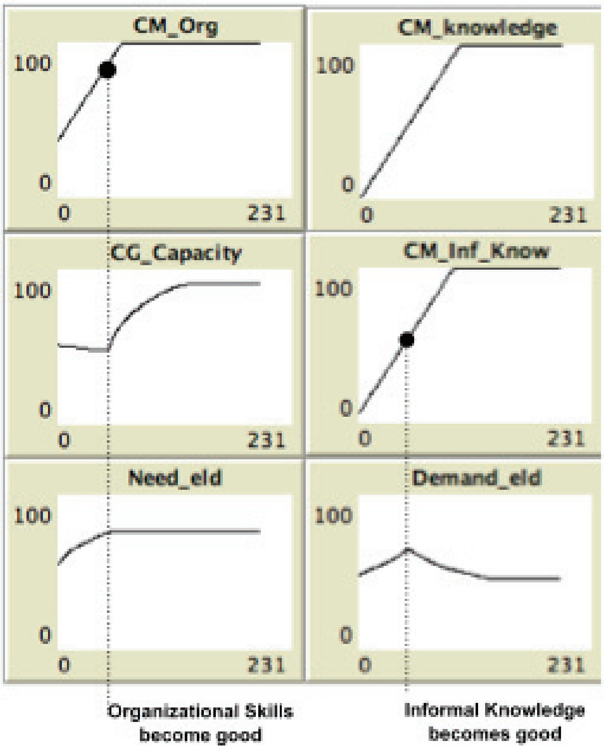

Figure 2: Illustrative Output. Mean Evolutions of the Case Manager's Organizational Skills, Knowledge and Informal Knowledge (CM_Org, CM_knowledge, CM_Inf_Know); the Caregivers' capacity (CG_Capacity); the Needs and Demands of the Older persons (Need_eld and Demand_eld).

3.5. Information Flow

It emerged in the discussion that in fact, in an ideal setup, there is no need for a case manager. This ideal situation would suppose that perfect information about each elderly person is distributed among all caregivers in real time. This was formulated by one of the expert, referring to the conceptual frame (Figure 1): "Somehow, interaction 2 is the same as interaction 1, only modulated by interaction 3".

These remarks highlighted possible enhancements in the design of our conceptual frame. First, the caregiver may be able to understand the informal demands as well. In fact, the limit between a caregiver and a case manager may be thin and modulated by the transfer of information between the different actors. Second, links between the caregivers could be usefully used to consider the sharing of information and the organization of the care.

A possible setup to enhance the transmission of the information could involve a team of caregivers performing case management via intercommunication and meetings. However, this scenario appeared too ideal. But in most projects, this transfer of information has been implemented via a software solution. In other cases, the entire purpose of a project was to ensure that information is dispatched among the care network of the elderly person.

3.6. Institutional Context

Discussing with the experts, it appeared that the institutional context (political and financial) was responsible for the creation of obliged topologies and profile distributions between case manager and caregivers, which were not always optimal. Two cases were reported. In one case, financial incentives created competition between the caregivers. In another, political competencies required that the organization skills and the knowledge skills (needs assessment of the older person) could not be attached to one same case manager. This might result from the Belgian-specific repartition of competencies among different authorities.

Hence, a good comprehension of the initial context and its evolution is an advantage for every case manager. Finally, it appears that a harmonization of the institutional context could help.

Regarding this point and the preceding ones, it appears that one specific ideal style of case manager does not exist. A case manager should be suited to the institutional context and take into account the capacities of each actor of the care. Moreover, mandating too explicitly the ideal profile of the case manager might be counterproductive.

3.7. Organization of Care

In answer to the low quality of care and increasing needs of patients in some simulated patterns, some adaptation processes were described as experienced by the projects.

First, one project created a distinction between older persons with urgent needs and persons requiring less attention. Second, some projects decreased the size of the targeted population. Finally, at the opposite, in some projects supplementary caregivers needed to be added to fulfill the needs of the population.

These patterns highlight the fact that the model was missing information about the turnover of the caregivers and elderly persons. This might also be an important indicator regarding the adaptive patterns of the project.

4. DISCUSSION

4.1. A Valuable Cognitive Process

The simulation model presented here should be seen primarily as a tool for thinking and learning about the case management of home-dwelling older persons (Edmonds 2010). Several aspects of the methodology contribute to a valuable cognitive process.

First, the conceptual frame expressed in terms of variables provides a vocabulary and an architecture to properly elicit rules of dynamic interaction. The use of a formal language forces a non-ambiguous formulation of the rules and a clarification of the contextual effects.

Second, this formalism and the flexibility of RBM make it a powerful tool of communication and negotiation between experts, providing an interactive medium for social exploration (Edmonds 2001). The informative interaction between modelers and experts allows for improving and learning from the elicitation. In addition, while the experts might already have the right knowledge, the simulation can help them to phrase or adjust their internal representation. Better understanding and good communication skills can only improve their ability to manage and advise other stakeholders.

Finally, the discussion resulting from the confrontation is also beneficial to the experts. Indeed, the output of a simulation of the type of Figure 2 acts as a brainteaser on the experts' reasoning. If the dynamic of a simple rule might appear quite intuitive when taken independently, their aggregation becomes much more difficult to handle. Hence, from the output graph comes out a question, a possible answer is formulated, triggering a reinterpretation, and finally the experts associate the resulting dynamics to a case story of their own experience. This cognitive scheme enhances the expert's internal representation of the mechanisms underlying the interventions and ultimately prepares them to adapt better to unpredictable situation.

4.2. Usefulness of the Recommendations

The insights and the recommendations that emerged from the discussion might appear somewhat obvious. However, personal internal representations might lead to different interpretations of these recommendations. The participatory process involving field experts permits to ensure that each participant understands everyone's interpretations feeding a discussion eventually resulting in better generic formulations. Further, if RBM has been argued to be a tool for consensus reaching, it can also be used to further elicit points of disagreement.

Moreover the obviousness of some of the recommendations does not mean that they should be left out. Hence, the simulation model provides a structure for a systematic inventory of these recommendations, which is a valuable step in a decision-making process.

Finally, the recommendations issued from this type of exercise will likely have a strong advantage when it comes to field integration. Indeed, policies imposed from authorities may lead to failure because of a perceived or a real gap with the field (Hunter and Marks 2002). Instead, the confrontation with field experts and the resulting refinement aim at better generalizing their knowledge and experience as anchored in their day-to-day reality. Hence, such guidelines emerge from a bottom-up approach and may trigger a peer effect, facilitating their acceptance and implementation.

4.3. Validation and Limitations

At this early stage of the model creation, the level of complexity remains limited. However, the necessity to remain slow in the design process needs to be emphasized. Firstly, the time to analyze each step contributes to structure and formalize the experts' representations. Secondly, each rule needs to undergo a strong and rigorous evaluation by the experts to assess its stand-alone mechanics before being merged into the rest of the algorithm. Hence, this assessment contributes to a validation process in the simulation context.

In addition, the benefits of the learning process of the experts are neither immediate nor quantifiable (Berland and Rand 2009). As recommendations and rules might appear intuitive or obvious depending on the a priori knowledge and experience, the lessons learned might be different for every expert. New simulations are drawn within seconds and interpreted without consequences; actual application and benefits in real life situations linked to the simulation exercise would be hard to highlight.

Finally there is an inherent destabilizing feeling when the simulation model is presented. In a sense, experts feel uneasy with the oversimplification and the cliché of huge lines of code. However, the natural language of the rules quickly frees them and leaves room for enthusiasm and imagination. In addition, as general computer literacy increases more and more, a greater interest from experts is expected in the future.

4.4. Perspectives

The creation of a simulation model as designed, confronted to and fed by experts' opinion is an iterative process. New iterations of this process are required to refine the model taking into account the experts' remarks.

The adaptation processes mentioned should be all investigated. In order to test these processes, new scenarios should be implemented to simulate potential problems and assess how robust the solutions are.

Further questions will need to be investigated, regarding economic matters, time resources and institutional embeddedness as they seem crucial to the understanding of the problems encountered by the case management.

Finally, the simulated results should be compared using the quantitative data available to possibly recreate real project case story. For example, change in depression level can be used to assess project efficacy and evolution in terms of preserving or enhancing the well-being of the elderly person. Mixing quantitative and qualitative approaches through computer simulation methodology could only improve our insights of the causal mechanisms underlying complex interventions.

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