Knowledge Management Models Supporting Causal Analysis in Project Design Creation

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Abstract: Correct implementation of the processes of building causal analysis frameworks is one of the critical elements to ensure success in the proper preparation of project designs. These frameworks are the foundations on which the provisions of the theory of change are based, and logic models illustrating causal links between input resources, activities, outputs, results (outcomes) and impacts, as well as identified problems related to the needs of stakeholders and their proposed solutions. The proper run of causal analyzes requires collecting and using significant resources of explicit and tacit knowledge related to the conducted community mapping, stakeholder analyzes (their needs and expectations), priorities of financing organizations, feasibility studies, and strategic analyzes of internal and external factors. Adequate support for managing this type of knowledge is essential to ensure the possibility of appropriate improvement of the planning, monitoring, and evaluation systems of projects and programs. One of the potentially available directions for developing research in supporting the management of valuable knowledge in the processes of causal analysis in project design creation may be solutions applying the extensive achievements of ICT systems modeling. The study discussed in this paper was carried out to find answers to the following research question: what is the possibility of using selected knowledge management models to support practical causal analysis that is beneficial in project design preparation? The primary purpose of this paper was to develop and pre-examine knowledge management and logic models in terms of their usefulness in the implementation of project design creation processes. Theoretical considerations related to the proposed models were supplemented with the offered possibilities of their implementation and the development of further research on the potential of improving designing systems, in particular when taking into account explicit and tacit knowledge valuable in the correct implementation of stakeholder expectations management processes for the success of projects and programs.

Keywords: knowledge management models, causal analysis frameworks, logic models, project design, ICT systems modeling

1. Introduction

Causal analysis is one of the essential elements of planning development projects and building their results chains, causal mechanisms in the theory of change, logic models for monitoring and evaluation systems that can be useful not only for ordinary linear models, but also for modern circular business models (Mattos *et al.*, 2022). This analysis is based on causal and relational hypotheses that support learning and storing knowledge about planned causal linkages identified between an intervention and the expected changes, results, outcomes and impacts. This knowledge is of an explicit and tacit nature and requires implementing effective management mechanisms related to its identification, collection, sharing, learning processes, and generating new knowledge. The related difficulties result from the multifaceted nature of this knowledge, the source of which may be analyzes of the needs and expectations of stakeholders, mapping processes of local and regional communities, project sponsors' expectations, comprehensive research results related to conducting feasibility studies, and strategic analyzes taking into account internal and external factors. Overcoming the difficulties and challenges associated with managing this type of knowledge creates an appropriate basis for ensuring the possibility of adequately improving the planning, monitoring, and evaluation systems of projects and programs.

The key solution applied when building monitoring and evaluation systems is the Logical Framework Approach (LFA), which can effectively support the collection of useful multifaceted knowledge already at the project design creation stage. The basis for the initiation and proper implementation of these systems is causal analysis, which can be successfully carried out with the use of LFA-based models. Carrying out causal analysis within this type of models can effectively support the collection of the necessary knowledge resources and lay the foundations for risk management already during project planning. Properly enriched LFAs can be used not only to gather knowledge necessary for risk management, but also to improve aspects related to sustainability (Rodríguez-Rivero and Ortiz-Marcos, 2022). Better and in-depth knowledge of the identified existing major problems and potential solutions also facilitates building causal logic models. They describe simplified and linear causal relationships and can clearly reflect and explain the logical relationships between the essential elements of the analyzed projects, e.g., related to the current difficult situation and diagnosed problems occurring in specific local areas and regions. These dependencies include inputs (resources involved), planned and then implemented activities, outputs, as well as multidimensional outcomes and impact. The process of building logic models usually requires the following steps: initial structuring of the evaluation process; data collection; analysis of the

project environment, problems, goals, and strategies for achieving them; saving the analysis results in a graphic or table form; building project design as well as using logic models for monitoring and evaluation (Newcomer *et al.*, 2015).

Information and knowledge resources play an essential role in all the steps involved in building causal logic models. Experts can carry out the preliminary structuring of the evaluation process using knowledge resources resulting from the conducted SWOT analysis, concept mapping, etc. In the next stage of collecting the necessary data, information and knowledge, it is possible to rely on primary data and knowledge (e.g. interviews or observations) or secondary sources (e.g. existing documents or multimedia digital repositories). Additional important information and knowledge resources can be gathered as a result of identification, analysis, and consultation with stakeholders who may differently influence the project implementation and be classified in different ways. Stakeholders can be defined as: primary or secondary, internal (involved in the project implementation) or external (being positive or negative), positively or negatively affecting the achievement of the assumed goals. Research proves that it is worth looking for new methods and tools enabling decision analysis of project success factors and analyzes of stakeholders, who may play important positive and negative roles, and also, e.g., effectively influence decision-making processes related to the management of investment projects (Belay *et al.*, 2022).

The dynamic development of modern ICT and AI solutions is an excellent opportunity to use the existing achievements in these fields to support knowledge management useful for causal analysis in project design creation. Therefore, the following inspiring research question arises: what is the possibility of using selected knowledge management models to support practical causal analysis that is beneficial in project design preparation? This question defines a scientifically interesting research problem, the solution of which will be facilitated after formulating the goal, which is to develop and pre-examine knowledge management and logic models in terms of their usefulness in the implementation of project design creation processes.

Theoretical considerations related to the implementation of this goal are also accompanied by practical comments, in particular regarding the implementation of the proposed IT solutions and the possible development of further research on the possibilities of improving solutions, mainly in terms of more practical consideration of explicit and tacit knowledge reflecting the expectations of the project and program stakeholders. This paper attempts to demonstrate that the proposed knowledge management models are well suited to support the causal analysis in project design creation processes that underpin the building of logic models for various projects and programs. The presented research results may be interesting in terms of improving planning, monitoring and evaluation systems of various types of projects.

2. Knowledge Management in Causal Logic Models

Causal analysis in project design creation is primarily related to logic models, which in a simplified and linear way reflect the more complicated dependencies that occur in a complex reality. They mainly concern the specificity of interventions and the assessment of their impact in a way suitable for monitoring and evaluation systems of projects or large socio-economic programs. The lack of properly performed causal analyzes and the appropriate logic models built on this basis may result in the inability to collect knowledge useful in discovering and exploring the success factors of the projects and programs assessed. It also reduces the possibility of conducting synthetic analyzes, preparing practical evaluation reports, which contain examples of good practices that may be beneficial when applying long-term outcomes of completed projects, as well as during the planning and implementation of subsequent programs. Logic models are particularly valuable during the implementation of intervention planning processes because they provide effective solutions for capturing evidence identified before starting the implementation of planned solutions. The lack of use of logic models is particularly manifested in the form of difficulties with conceptual clarity, replicability, scalability of interventions and opportunities resulting from learning from failure (Hanson and Jones, 2017).

Causal logic models can effectively support knowledge management during the practical application of the program theory-driven evaluation concept. The joint use of logic models and theory of change enables the appropriate inclusion of various groups of stakeholders during the creation of design of project and program, their implementation, and taking into account the systemic environmental impact (Meyer *et al.*, 2021). However, using the theory of change could provide a clearer picture compared to the logic model, which is usually closer to reality but more challenging to put into practice in the planning processes of building project designs. For this

reason, in the practice of monitoring and evaluation, causal logic models play a fundamental role as they enable adequate support of analysis processes aimed at conducting stakeholder analyzes, identifying existing problems and their desired solutions, improving communication with stakeholders in terms of communicating the essence of planned projects and programs, clear descriptions of logical structures of planned activities and their effects, as well as building effective monitoring and evaluation systems.

Causal analysis used in logic models is based on studies of the environment and context of projects and programs, and concerns the analysis of the relationship between identified vital needs and problems occurring in local areas and regions. Thanks to this research, it is possible not only to identify the reasons for the occurrence of these problems but also to define solutions necessary for project implementation, which would meet the needs resulting, e.g., from analyzes applying the theory of change. Logic models are often used together with an extensive set of various approaches, methods, and tools such as SWOT analysis, stakeholder analysis, community mapping, feasibility studies, problem/objective trees, strategy selection, solution tree analysis, and others (Grzeszczyk, 2018; Zhang and Liu, 2020).

The application values of logic models result from the tabular and graphic images of the causal sequences, which are clear and understandable for practitioners. In the case of public finance projects, tabular presentations in the form of Logframe (Logical Framework Matrix - LFM) have been popularized, which are used as part of the more general Logical Framework Approach (LFA). Interesting research was conducted related to building knowledge management logic models, which can, e.g., be used to support the work of health professionals and to properly use the effects of implemented projects in healthcare systems (Ohkubo *et al.*, 2015).

The LFA is often applied in parallel with the well-known Project Cycle Management (PCM) methodology, which is based on the assumption that, although the projects are unique in nature, it is possible to distinguish repetitive stages having a similar form - even within very different projects. This assumption allows conducting analyzes taking advantage of the cyclical nature of projects and define repetitive stages that can be separately assessed during the planning and implementation of unique projects. Transparent and easily digestible images of current and forecast relationships (obtained thanks to tabular logic models) facilitate building effective project management systems as well as their monitoring and multifaceted evaluation.

When constructing tabular representations of causal sequences, a systems approach is used to define assumptions as well as causal and relational hypotheses that are very valuable in project planning and structuring evaluation processes. These hypotheses are verified in the course of project implementation and learning about the fundamental relationships of activities leading to the required results and impact of the projects.

Proper and readable mappings of causal logics in simple logic models make it possible to consider multiple causalities and contingent dependencies that do not differ much from the multidimensional theoretical models constructed using the sophisticated theory of change, which enables explaining complex reality using a large number of factors. Causal logic models are also a reasonable basis for applying practically useful tools supporting the planning and implementation of even large and intricate projects. These types of tools include, e.g., very popular evaluation matrices, which are a solution valued by practitioners, supporting the analysis of the theory of complex interventions, creating project and program designs, as well as a clear presentation of multilevel dependencies and results chains, ranging from identified problems and needs to planned project outcomes and impacts. The use of these tools is based on the experience and knowledge of experts and requires the management of this knowledge and the collection of additional resources from project and program stakeholders. Introducing appropriate knowledge management systems enables the creation of clear images of causal relationships and logic of projects and programs.

Effective knowledge management supporting the proper mapping of causal logic should be carried out in a holistic and multilevel manner, i.e., covering organizations, projects, and development programs. In addition to explicit knowledge, it is also necessary to consider tacit knowledge resources that can be captured in project evaluation processes (Grzeszczyk, 2020). Significant difficulties in collecting and using this sort of knowledge arise from the fact that these types of resources are usually widely dispersed among stakeholders as well as team members and users who occur in different subjective contexts and environments related to various processes, programs, and portfolio projects strategically important for organizations (Payne *et al.*, 2019).

A holistic approach to building knowledge management models related to project management takes into account multidimensional analysis based on human resources, ICT, and the specificity of the organization, and should also incorporate the following three levels of analysis: about projects and programs (containing the characteristics of performance monitoring indicators and outcomes, organizational structures and effects of skills management), in projects (including the use of repositories, discussion results, the use of IT systems supporting decision-making) and from projects (best practices and lessons learned) (Damm and Schindler, 2002).

Complex and dynamic dependencies often occurring in causal analysis frameworks require the use of adequate ICT instruments supporting knowledge management. In accordance with the holistic view, it is necessary to ensure the proper implementation of multilevel processes of collecting and applying knowledge about causal dependencies using constantly developed methods and techniques resulting from the latest achievements in various scientific disciplines.

3. ICT Support for Knowledge Management in Causal Analysis

The interdisciplinary nature of issues related to ICT-based knowledge management systems should be considered when studying the possibilities of improving causal analysis in project design creation processes. Such valuable systems include, e.g., mind mapping, On-Line Analytical Processing (OLAP) and On-Line Transaction Processing (OLTP) technologies, data mining, data warehouse and knowledge repositories, knowledge-based decision support systems, project simulation based on AI, Business Intelligence, knowledge-based systems and expert systems. Solutions using Case-Based Reasoning (CBR), Natural Language Processing (NLP) systems, rule-based systems, and deep learning may also be useful.

Potentially valuable machine learning methods use deep learning, namely various types of neural networks that can be the basis for building universal data processing systems with significant computational capabilities. Their disadvantage is usually a long learning process before they can be practically applied. Spatial knowledge is unreadable to experts because it depends on the type of network, its structure, and the weight values associated with the connections between neurons. From this point of view, expert systems and systems using knowledge bases are friendlier. They have the positive feature of using symbolic knowledge representation and learning through the use of adaptation and self-improvement from examples based on empirical data. Such examples can be of a subjective and qualitative nature that is difficult to process automatically with other methods.

Systems applying knowledge bases enable automatic data processing, knowledge discovery and building its structured representation based on patterns that are difficult or impossible to discover as a result of manual data inspection. One of the more popular methods of this kind is based on association rules representing logic relations with the corresponding items appearing in an antecedent and a consequent. A significant number of association rules mining algorithms and their newer modifications have been developed so far (Diaz *et al.*, 2021). Many rules can be generated in computational processes, and it is necessary to leave only the ones that are interesting and strong. A strong rule is characterized by the values of support and confidence values greater than the adopted minimum values (Rui *et al.*, 2022).

Association rules are well suited for supporting causal analysis in project design creation because their use is based on the simple form of the conditional statement: 'If antecedent then consequent'. This implication enables relatively simple modeling of causes and expected solutions. Following the basic understanding of the conditional statement, if the antecedent is considered true, then the consequent can also be regarded as true. Such statements may be of many types and applicable to different situations. For association rules and the application analyzed in this paper, causal implications are of the highest importance, where the causal relationships between antecedents and consequents are primarily considered. An additional important feature of this type of conditional statement is taking into account mainly the relationships that are discovered based on empirical data that result from people's behavior and the stakeholders' attitudes towards the analyzed projects.

The association rules method belongs to a set of popular data mining methods for implementing rule-based machine learning systems, in which knowledge bases are built using rules that are a readable form of the results of knowledge discovery processes. In particular, these rules are applied to uncover non-trivial, meaningful, and practically useful correlations and associations between variables in large empirical datasets. A typical example of the application of association rules is market basket analysis to study the purchasing habits of customers

(Hamzehi and Hosseini, 2022). In addition, many other instances are known, such as e.g. cyber security issues, intrusion detection systems (Zhang *et al.*, 2022), Web usage mining (Husin *et al.*, 2022) or analysis of data from social media - discovering virality patterns in Twitter (Saquete *et al.*, 2022). Causal analyzes carried out with the use of association rules may constitute a significant supplement to the qualitative analyzes carried out including and consulting stakeholders of planned projects and programs, involving particular experts, project implementers and potential beneficiaries.

Association rules have many present and potential future applications as they form the basis of many statistical data processing and mining systems. In the case of simple analyzes, the processes of generating a symbolic knowledge representation using little complex a-priori algorithms do not require the definition and use of many parameters. Usually, it is enough to focus on the minimum support (which determines the number of frequent item sets) and the minimum confidence (which supports the assessment of the reliability and the probability of existence of rules in the analyzed empirical datasets). In addition, the following less significant parameters can be considered: the minimum correlation, the maximum item set size in body / head and maximum item set size in head.

Considering these significant achievements in new computing, ICT technologies and association rules based approaches, it is worth mentioning the possibilities of using such approaches to build knowledge management models supporting causal analysis in project design creation. These models may be helpful in the context of problems related to the multifaceted nature and the many dimensions of the causal analyzes performed. Additional problems are the dynamically growing resources of information and knowledge related to the planning and implementation of contemporary projects and programs, as well as the frequently occurring ambiguity, imprecise and uncertain data, which are the basis for building knowledge resources related to making important decisions. The research carried out using a selected model supporting causal analysis in project design creation is an attempt to deal with these problems.

4. Methodology and Results

The research process was performed in two phases. First, preliminary research was carried out on the analysis of the literature on the subject, analyzes of the possibilities provided by the available logic models in graphical and tabular versions, as well as the diagnosis of possible cognitive technologies and AI. Based on the results of these preliminary studies and analyzes, a research question was formulated (given in the Introduction section) regarding the possibility of finding and using selected knowledge management models to support practical causal analysis that is beneficial in project design preparation. The goal was also specified, which was to develop and pre-examine knowledge management and logic models in terms of their usefulness in implementing project design creation processes. Such a goal became an inspiration for selecting research methods, conducting planned theoretical research, and building a model of knowledge management that can effectively support causal analysis in project design creation.

It was decided to use the following research methods and techniques: literature research, observation of evaluation processes, document analysis, and statistical computational experiments. Before the simulations and computational experiments were carried out, programming documents and draft versions of documents from panels of experts who evaluated public projects were analyzed. First, the documents presenting the principles of carrying out and the results of the project evaluation processes were investigated. Computer modeling and calculations were also run using the a-priori algorithm for mining association rules available in TIBCO Statistica 13.3 software.

The scope of considerations and analyzes was limited to the causal analysis stage, which is usually the first stage in the planning and project design creation processes. It is also the most challenging stage because it requires building a stable and reliable basis for the next stages of constructing correct logic models. This stage of analysis and calculations is related to the logical course of reasoning and the formulation of hypotheses regarding the forecasted positive tactical and strategic changes expected as a result of the implementation of a given project. These expected changes (resulting from the delivered desired project products) can be verified using the hypotheses formulated during the planning and building of the project design. Statistical computational experiments were based on association rules models, which can support knowledge management, as they enable discovering frequent patterns and knowledge in empirical datasets, examining relationships between variables, and studying causal structures as well as correlations and associations.

The primary justification for the use of this type of model is its universality and usefulness in analyzing data from various sources, i.e. only empirical data collected specifically for carrying out these analyses are not required. Therefore, data collected through interviews with stakeholders and residents of the local area where the development project will be implemented can be used. However, one can also rely on data collected for other needs and related to, e.g., previously implemented projects, surveys, etc. Such features were obtained because data exploration and unsupervised learning processes were implemented based on an algorithm for discovering patterns from unlabelled data.

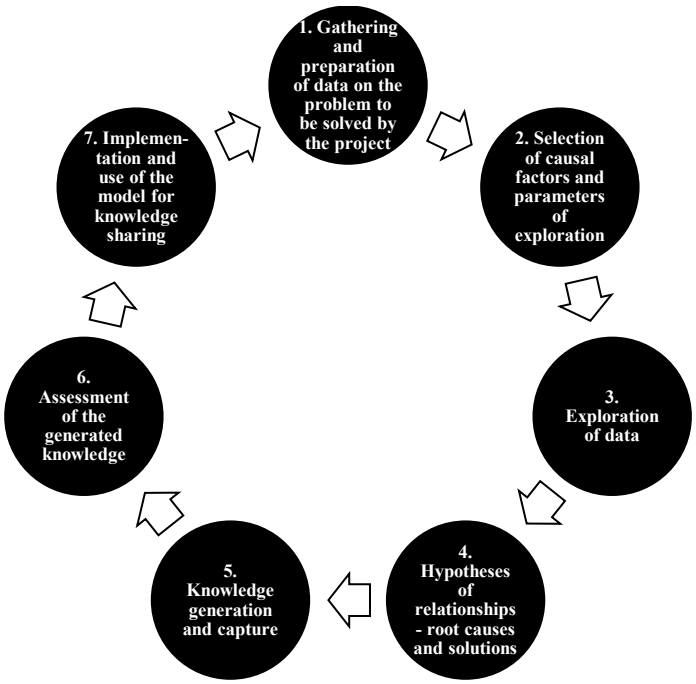

Figure 1: Knowledge Management in Causal Analysis Frameworks (source: own study)

The following seven stages of knowledge management in causal analysis frameworks were adopted (Figure 1). As part of the first stage of gathering and preparation of data on the problem, research data was collected, but most of all, already existing data from secondary sources were gathered. As a rule, data from various sources require standardization and appropriate preparation. In the next stage, the selection of causal factors and parameters of exploration were made. Causal factors were the variables taken into account during the next stage of data exploration. The essential parameters of exploration considered during the analysis were the minimum support and the minimum confidence. In the next stage concerning hypotheses of relationships, dependencies related to causal analysis were taken into account and examined within logic models in project design creation.

As previously mentioned, the algorithm in the selected software was used for the calculations; and knowledge generation and capture were performed with its application. A very important stage in the research process concerned assessment of the generated knowledge, because the obtained results were often not beneficial. For this reason, the cyclical nature of the calculations and analyzes was assumed. The individual stages were repeated many times until the results that could be considered satisfactory from a practical point of view were obtained. Only after achieving a positive assessment of the generated knowledge (in the form of appropriate association rules), it was possible to gather complete results from the last stage of implementation and use of the model for knowledge sharing.

Solving the problem of knowledge management support in causal logic models in the form of a system-based approach ensures considerable flexibility and scalability of the proposed solution. It is also the basis for potentially available implementation and further development options.

5. Conclusions

Logic models play a crucial role in the development of project design and the design of monitoring and evaluation systems for projects and programs. These processes can and should be supported with the use of new ICT. Their

bolder introduction is justified because they can be the basis for implementing solutions constituting significant support for experts involved in modeling causal relationships regarding projects and programs. The literature analysis shows there is relatively much research on machine learning methods, but still too few proposals related to project management support. It is worth noting significant achievements related to, e.g., modern methods of AI and knowledge engineering, which can be observed in connection with research in the field of computer science concerning knowledge-based systems. In project management area and the social sciences, there is a rationale for research into ICT applications, as it leads to new solutions in the fields referred to.

The research's primary goal (concerning the development and initial study on knowledge management and logic models in terms of their usefulness in implementing project design creation processes) was achieved. In addition to theoretical considerations, the results of preliminary empirical research related to the use of association rules were also presented, which proved their usefulness because of their form facilitating the study of causal relationship hypotheses describing potentially possible interventions and their results stemming from the implementation of the designed projects and programs.

The conducted research shows that the developed knowledge management model, which can support causal analysis in project design creation, has significant practical values and can be an essential supplement to the existing solutions based on logical models used in monitoring and evaluation systems for various projects. The application of the system approach creates good opportunities for the use of interdisciplinary achievements related to the development of ICT tools. The general form of the model and the reliance on the system approach allow for a relatively simple expansion and further improvement of the currently proposed model. Further advances in cognitive sciences and AI could lead to the emergence of other valuable solutions to enhance the model's capabilities.

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