Pilot Application for Recommendation on whether to Lead a Project Agile or Waterfall

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Abstract: - Nowadays, three main approaches are used to manage projects - traditional, agile, and hybrid (or combining the previous two). Traditional project management methods involve the entire project life cycle in several phases, where the next phase can only start if the previous phase is completed correctly. The customer then receives a near-final product, which can be costly to change. At the same time, the customer also needs a complete picture of the final product. Agile methodologies are based on a regular inflow of products at regular intervals. This allows the customer to provide feedback during its development. Choosing the appropriate project management style can be difficult, as there are many criteria to consider that influence this decision.
This article discusses creating an application to help support a project manager's decision on which project management style to choose - agile or waterfall, or how much to involve agile elements. The application uses a previously built ANP model based on the PRINCE2 ® Agile standard, the Agile Manifesto, and the SCRUM framework. This work presents a pilot version of the decision-support tool. The underlying ANP model and application have not yet been validated against real project outcomes; their calibration and validation using historical data and expert assessment are left for future research.

Key-Words: - Agile, Analytic Network Process (ANP), Decision-support tool, Hybrid project management, Pairwise comparison, PRINCE 2, Project, Project Management, Waterfall

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1 Introduction

Project management (PM) is a set of skills, plans, delegating, monitoring, and controls that are intended to ensure project success. It means delivering project results with appropriate risks in the required time, cost, scope, quality, and benefits [1]. We use three approaches to manage a project. These approaches are (1) traditional project management, followed by a waterfall, (2) agile project management, and (3) hybrid approaches [2].

Traditional approaches split projects into phases (for example, requirement analysis, design, development, testing, and deployment) that follow each other like the steps of a waterfall. The next phase can begin once the previous one is fully completed. This leads to a potential problem: the customer can hardly imagine the final product and provides feedback, for example, to the technical specifications, not to the final product itself. The final product has to be precisely defined by expected results, work packages, responsibilities, and deadlines from the project kick-off to the competition. The focus is to follow the plan as precisely as possible [2], [3], [4]. Also, implementing changes based on customer feedback is barely possible. Customers in the IT area usually have a vague idea about the final project, and the final product can differ from the customer's idea. This problem is solved by the agile PM approach.

The agile manifesto introduced a new way of managing projects, reflecting the flexibility and dynamism of the IT area [5]. The focus is on communication, customer feedback, and continual working output of the project instead of following a plan. They use incremental addition in short cycles (interaction or sprint). Customers can provide feedback based on working output in regular time [2], [3], [5]. In summary, traditional PM assumes

everything around the project is predictable, the scope is clear and well-understood, and the project can be planned in depth. Agile PM relies, among other things, on customer feedback and product adjustments, emphasizing the delivery of parts of the project. If the traditional or agile approaches are not convenient, we can use a combination of these approaches. The question of how far to combine these two approaches is addressed by [6].

The hybrid methodology is a combination of traditional and agile approaches. They combine suitable properties from traditional and agile approaches to create a more flexible and tailored methodology. Hybrid methodology attempts to use the advantages of both methodologies while balancing their disadvantages [7]. It is crucial to determine a suitable approach to manage the project. It is necessary to consider many criteria to support the decision of how to lead a project. These factors have different preferences (weights), which makes the decision process more complex. We use a multi-criteria decision method. In these methods, uncertainty and vagueness can affect the decision-making process. Different stakeholders have different priorities, objectives, and interests. The significance of subjective preferences and individual stakeholder attitudes can be an issue. We use mathematical processes (Analytic Network Process) to minimise these issues and support complicated decisions.

An Analytic Network Process (ANP) has already been used in similar sectors, like project management, strategic planning, and marketing research [8]. [9] takes the ANP approach for deciding agile success factors influencing quality and project success in the software industry. [10] also uses ANP in the area of project management, more specifically to measure the influencing factors of project complexity. In ANP, we determine interdependencies and relations between decision elements from the same or different levels of the hierarchy of the decision-problem network [11]. ANP is a generalization of the Analytic Hierarchy Process (AHP) [11], [12].

The main aim of this paper is to introduce a pilot application, which helps to decide what approach to take to lead the project, whether a traditional, agile, or hybrid approach. We use the ANP model as the background of the application. Because the relation network of the decision problem is complex. As a result, the application recommends how much agile should be involved in managing the project based on input preferences, and which of the project management approaches to choose. At this stage, the application should be regarded as a pilot version of a decision-support tool rather than a fully validated system.

2 Problem Formulation

2.1 Traditional Approach in PM

An example of a traditional approach is the waterfall management methodology introduced in 1970 by [4]. The Waterfall model (Figure 1) has six stages: Requirements, Design, Implementation, Testing, and Maintenance. After completing one project phase, it is impossible to return to it [13].

Waterfall methodology is suitable when it stays the same during the project, and the project plan is followed. The advantages are: (1) several resources are predefined and minimal, (2) more accessible to implement, and (3) the stages are well defined. On the other hand, the disadvantages are: (1) going back in phases is not possible, (2) changes are hard to implement, (3) less involvement of customers, and (4) mistakes in one phase can impact other stages [13].

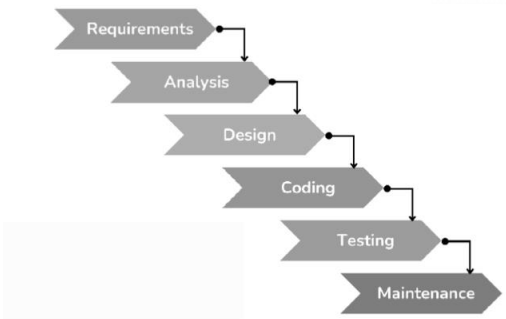

Fig. 1. Waterfall project management, Source: [14]

2.2 Agile Approach in PM

IT professionals created a new approach to developing software. They met in 2001 at a conference in Utah and created the Agile Manifesto. Agile methodologies rely on twelve defined principles, focusing on dynamics and interaction within the project team and a customer representative [5].

The agile approach (Figure 2) is based on iteratively repeating phases: Plan, Design, Develop, Test, and Evaluate [13]. Agile teams deliver smaller product increments to the customer in short intervals (called sprints). The advantages of the Agile Approach are (1) Frequent product delivery results in satisfied and informed customers, and (2) it is more adaptive to change. On the other hand, Agile disadvantages are (1) Complicated in bigger teams or more teams involved in one project, (2) Increasing requirements beyond the planned project requirements (scope creep), and (3) less predictive than the traditional approach [15].

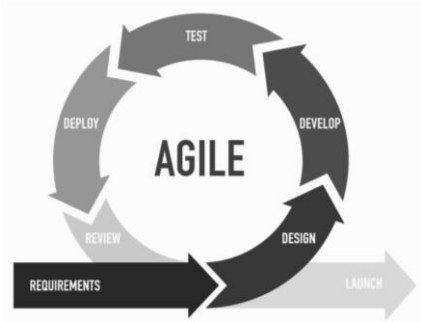

Fig. 2. Agile project management, Source: [16]

2.3 Agile and traditional methods in contrast

The main responsibility of a project manager is to deliver a project in the required time, assigned cost, and defined scope [17]. PRINCE ® 2 extends these criteria for benefits, quality and risks, which is called Project Hexagon [1]. Project Hexagon defines, which of these criteria have to be unvarying (fixed) or varying (flexed). Project Time is typically fixed in agile, because it is bounded by the sprint length.

From fixed Project Time implies fixed Project Cost. On the other hand, Project Scope is variable, because it changes based on the customer feedback. Variable Project Quality means, the incremental product is not delivered in full quality during the development. In the waterfall, Project Scope and Quality is fixed (Figure 3). Fixed variables can flex intolerances, and they would be adaptable to management by exception.

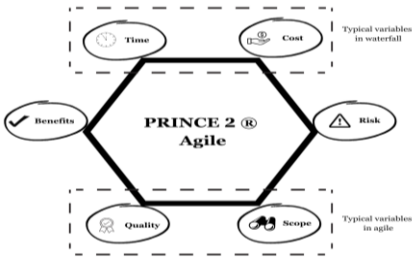

Fig. 3. What to fix and what to flex, Source: [1]

Agile methodologies were created mainly for smaller teams [18]. Nowadays, we use frameworks, for example, SAFe ®, Spotify or LeSS (Large Scaled Scrum), to implement agility in the whole organization [19], [20]. [18] recommends that 7 team members keep one-to-one communication. Also, as mentioned in [1], team members should cooperate and agree on the procedure and the result. Another difference is in the delivery method. As mentioned above, agile teams work in a periodical time (sprint), and after each sprint, the team presents an increment done in the sprint. [1] recommends appointing a team by generalizing specialists (T-shape) with detailed knowledge of one skill and less knowledge of others.

2.4 Hybrid Approach in PM

The hybrid approach combines traditional and agile approaches in different phases. In Water–Scrum–Fall (Figure 4) [21], we use the traditional approach in the initial phases, determining the requirements and planning the project. In the development phase, we use the agile methodology Scrum, and for testing and deployment, we use traditional methods again. The project phases are completed individually, and each must be completed before moving on to the next [22]. The Waterfall–Agile (Figure 5) model is quite like Water-Scrum–Fall, but there is a difference in the final phases. Water–Scrum–Fall uses a traditional approach, but Waterfall–Agile uses an agile approach for testing and deployment [22]. Differences between Water-Scrum-Fall and Waterfall-Agile are in Table 1.

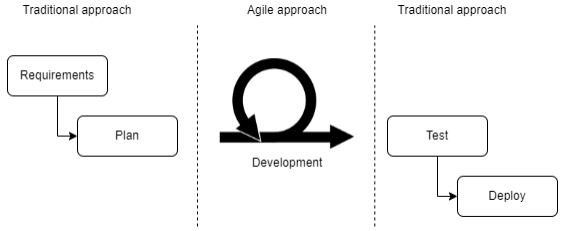

Fig. 4. Water–Scrum–Fall scheme, Source: [21]

These hybrid methodologies lead to the satisfaction of management, which needs a more structured and fixed method. The project has a predictable budget, estimable duration, and low uncertainty. Developers benefit from high flexibility and adaptive scope [15].

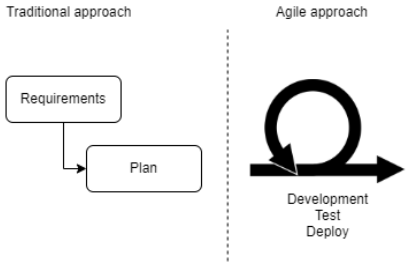

Fig. 5. Waterfall – Agile scheme, Source: [22]

Table 1. Differences between Water-Scrum-Fall and Waterfall-Agile, Source: [21], [22]

Project phase	Water–Scrum–Fall	Waterfall–Agile
Requirements	Traditional approach	Traditional approach
Plan	Traditional approach	Traditional approach
Development	Agile approach	Agile approach
Test	Traditional approach	Agile approach
Deploy	Traditional approach	Agile approach

2.5 Analytic Network Process (ANP)

A range of decision-making issues may be solved using the Analytic Network Process (ANP), a decision-making method. The ANP uses a pairwise comparison method to identify which elements of each pair are preferred. The ANP, which generalizes the Analytic Hierarchy Process (AHP), considers the numerous interactions between the elements at all levels of the decision network of the issue structure hierarchy [11], i.e. the interdependencies between the decision structure's constituent parts.

Numerous decision problems involve many interactions and dependencies between decision elements (higher-level elements on lower-level elements in a decision structure hierarchy and between the same-level elements), making it impossible to structure them hierarchically or into an AHP model (for an introduction to AHP theory, see [12]). As a result, ANP is represented as a network rather than a hierarchy; it is more suited for complex decision-making problems [11], [12], [23].

Steps in the ANP process:

1. The structure of a decision-making problem explains the interdependence of decision components. The ANP permits both the outer dependency among several sets of clustered items as well as the inner dependence within a set of elements.

2. The pairwise comparisons matrix is constructed when pairwise comparisons of the decision items are conducted both inside and between clusters of elements [11]. These comparisons must be controlled for consistency. A consistency ratio, or CR, established by Saaty serves to quantify the rate of consistency:

$$CR = \frac{CI}{RI_n}$$

where RI_n represents the random inconsistency index. The *CI* stands for consistency index, and for a comparisons matrix, is calculated as:

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

where λmax is the largest eigenvalue of Saaty's comparisons matrix and *n* is the number of criteria. A pairwise comparison matrix is considered inconsistent for CI>0.1, CI>0.15 for matrix of size 10 or higher respectively, according to [23], [24].

3. The priorities are formed by the Unweighted (original) Supermatrix [12], [25] using pairwise comparisons on the proper position. The Weighted Supermatrix is created after the Unweighted Supermatrix has been adjusted using cluster weights. The Unweighted Supermatrix has the following form:

$$W = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_N \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_N \end{array} \\ \begin{bmatrix} W_{11} & W_{12} & \dots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ W_{n1} & W_{n2} & \dots & W_{nn} \end{bmatrix} \end{array}$$

where each block ***Wij*** of the supermatrix consists of:

$$W_{ij} = \begin{bmatrix} w_{11} & w_{12} & \dots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n1} & w_{n2} & \dots & w_{nn} \end{bmatrix}$$

where: $\sum_i^n w_{ij} = 1, j \in \langle 1, n \rangle$

4. Increasing the Weighted Supermatrix to powers, which creates the Limit Supermatrix, results in stable overall preferences. These preferences are used to analyze (and rank) the preferences of the various decision-making components. For a description of the basic processes in the Limit Matrix calculation.

Combining pairwise comparisons from more decision makers:

In the case of processing the priorities of individual decision elements from numerous decision-makers (members of development team), there are two options for processing their results. The first option is to process the limit matrix of each decision-maker (the number of limit matrices equals the number of decision-makers) and then average the results of the limit matrices to obtain the final priorities on the decision elements. However, this processing method assumes that we get all pairwise comparisons from each decision maker, i.e., we obtain a complete unweighted matrix from each decision maker.

Suppose the decision maker only makes some pairwise comparisons (due to many pairwise comparisons, some are not required of the decision maker - implemented in our case study). In that case, the limiting supermatrix cannot be processed from its result. Therefore, the second way of combining pairwise comparisons of multiple decision makers is based on combining their results already in the unweighted supermatrix (original). For example, suppose we have already constructed an unweighted supermatrix from previous research by averaging the results of pairwise comparisons of multiple decision makers, and another decision maker comments only on some aspects of the whole significant decision problem (fills in only some blocks $\mathbf{W}_{ij}$ of unweighted supermatrix) and thus does not fill the whole unweighted supermatrix. In that case, we can incorporate his results into the previous research obtained unweighted supermatrix by adding his values to the values of the unweighted supermatrix

with a certain weight. In this way, the resulting unweighted supermatrix is formed.

$$w_{ij} = v * w_{ij}^{d} + (1 - v) * w_{ij}^{p}$$

where v is weight of results pairwise comparisons of decision – maker, w_{ij}^{d} is the results of pairwise comparisons of the decision-maker in the evaluated block and w_{ij}^{p} is the result of pairwise comparisons in the evaluated block from the unweighted supermatrix obtained the previous research.

The decision maker can decide to what extent to consider the values (results) of the unweighted supermatrix obtained from previous research. If he chooses a weight v = 1, he only takes into account his results and does not take into account the results of previous research. On the other hand, v = 0 means that it does not consider its results but only the results from previous research.

2.6 Decision Model Construction

The model construction was introduced at the Model-Driven Organizational and Business Agility 2023 conference [26], and a pilot study of its use was introduced at the 41st International Conference on Mathematical Methods in Economics [8]. We used the ANP method to support the decision to lead an agile or waterfall project (with agile elements). We build a decision model through a relational network of individual decision elements (Figure 6 - Apendix). We also identified individual clusters and their decision elements for model construction with the ANP method, carried out by the SuperDecisions software [25]. The selection and justification of these clusters, decision nodes and their interdependencies is described in detail in our previous work [8], [26].

We made minor changes to our model from the Model-Driven Organizational and Business Agility 2023 conference [26]. We divided the Project Properties cluster into Project Risk, Project Benefits, and Project Quality. We removed the cluster Project Type from our model because we focus only on IT projects. We added a Project Information cluster to obtain information about the project from the application user. We divide the model into two parts. In the first part, we obtain more detailed information about the user´s specific project using the Project Information cluster. In the second part, there is a general opinion on the individual elements of traditional and agile approaches.

The model aims to identify whether a project should be managed using an agile or waterfall approach (with agile elements). It provides decision support through pairwise comparisons of decision factors, allowing the decision-maker to set preferences for each cluster and decision node. The model then recommends a suitable project management style. Based on the references mentioned earlier, we defined the decision nodes, clusters, and their relationships in the ANP model (see Figure 6 - Apendix).

3 Problem Solution

The decision of how much to involve agile in project management is complicated and relies on many factors; it is suitable to use helpful tools to make this decision. For example, the international standard PRINCE2 Agile uses the Agilometer Methodology [1]. We can use many software tools to create an application, such as programming languages (Python, C#, etc.). However, we used Microsoft Excel and its built-in functions for our pilot application. We use form controls on an Excel worksheet for user preferences. For the background calculations, we use standard Microsoft Excel formulas; for checking consistency, we use macros and Microsoft Excel Solver.

When the decision–maker opens our application, he sees a form (a showcase of one part of this form is in Figure 7). Since our tool is still in the pilot phase, it has not yet been widely applied; the goal was first to verify its feasibility before evaluating its usability or scaling it up. Then, he responds to the questions of pairwise comparison by setting his preferences using form sliders. These preferences range from 1 to 9 on both sides, where 1 means equal preference and nine means strongly preferred decision node—clusters, where there are three or more decisions, there can be decision inconsistencies. After setting the preferences, the decision-maker can check their decision-making consistency. Then, the macro is launched and, as a result, provides the decision-maker if his decision is consistent. As a result of the filled form, the application recommends how to lead a project – agile, waterfall, or hybrid.

For example, What type of communication with the customer do you foresee in the project that has two decision nodes and can be milestone or ongoing? The value shown in Figure 7 shows that the decision maker moderately prefers ongoing communication to milestone communication. In this way, the decision maker sets all his preferences in 28 questions related to the cluster project information and all clusters connected with it.

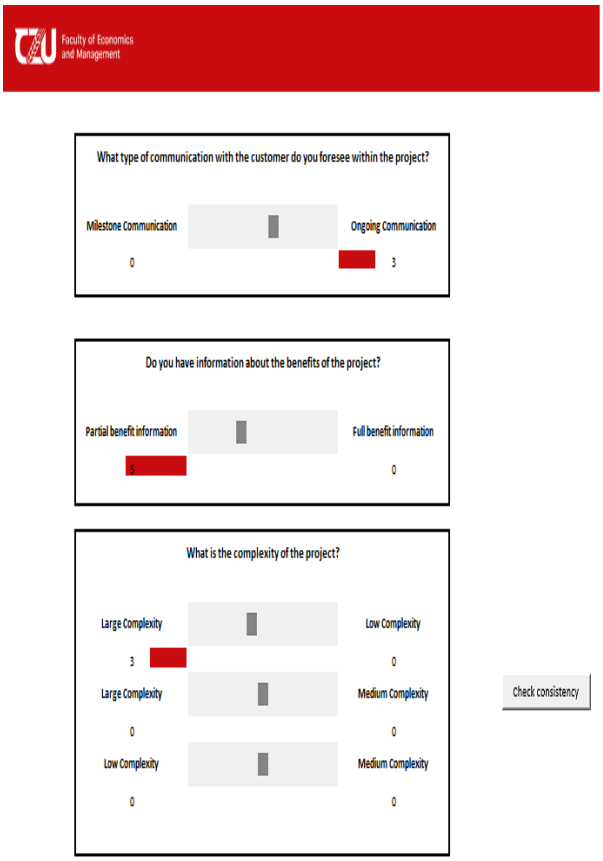

Fig. 6. Application form screenshot, Source: created by the authors

3.1 Pilot Study – Selecting Suitable Project Management Style

We conducted a pilot study based on our improved model, where respondents determined preferences between decision nodes using pairwise comparison based on the relations in the ANP model. Our responders are from the IT sector, where agile methodologies are commonly used, in total, three IT project managers from the Czech University of Life Sciences Prague participated in this pilot study. In Table 2, there are global preferences from our second part of the model (mentioned in chapter 2.6), which we use with the responses from the application form to support whether to manage the project agile or waterfall. Individual responses from the application form affect the values of the decision elements listed in Table 2.

Table 2. Limit Matrix of ANP model - raw values, Source: created by the authors

Alternatives: Project Management Style	Agile	0,0872133
	Waterfall	0,0763449
Customer Communication	Milestone Communication	0,0178106
	Ongoing Communication	0,0225755
Project Benefits	Befenfits Incomplete Information	0,011027
	Benefits Full Information	0,0158971
Project Complexity	High Complexity	0,0084508
	Low Complexity	0,0078918
	Medium Complexity	0,0085792
Project Cost	Fixed Cost	0,0268298
	Flexed Cost	0,0270184
Project Risk	Cost Risk	0,0075592
	Quality Risk	0,0065172
	Scope Risk	0,0057451
	Time Risk	0,0071027
Project Team Size	Large Size Team	0,0124246
	Medium Size Team	0,0137053
	Small Size Team	0,0161866
Project Delivery Method	Delivery all at once	0,0175824
	Ongoing Delivery	0,0228037
Project Quality	Quality Full Information	0,0170619
	Quality Incomplete Information	0,0098621
Project Scope	Fixed Scope	0,0285569
	Flexed Scope	0,0252913
Project Team Communication	Cooperation Communication Style	0,0193059
	Directive Communication Style	0,0161205
Project Team Location	Onsite Team	0,0187915
	Virtual Team	0,0152178
Project Team Member	I-Shape Person	0,0245297
	Pi-Shape Person	0,041142
	T-Shape Person	0,036647
	X-Shape Person	0,0093992
Project Time	Fixed Time	0,0253418
	Flexed Time	0,0285063
Project Working Style	Collaboration Working Style	0,0379112
	Individual Working Style	0,0262522

Table 2 also shows the values of global preferences. These values correspond to the model's structure and the IT area's results. In some clusters, values lead to the use of a more agile approach, for example, in the cluster of Project Delivery Method, because Ongoing delivery is much more preferred than delivery at once. In some clusters, values lead to a more waterfall approach, for example, in the cluster of Project Quality, because Quality Full Information at the beginning of the project is much more preferred. Most clusters have almost the same preferred nodes, leading to a hybrid approach.

Furthermore, the results show that Pi – Shaped persons are the most important to be involved in the project team. This type of person is suitable for all project management approaches. Then, the decision maker fills in data about their project into our application form. The filled data are shown in Figure 8.

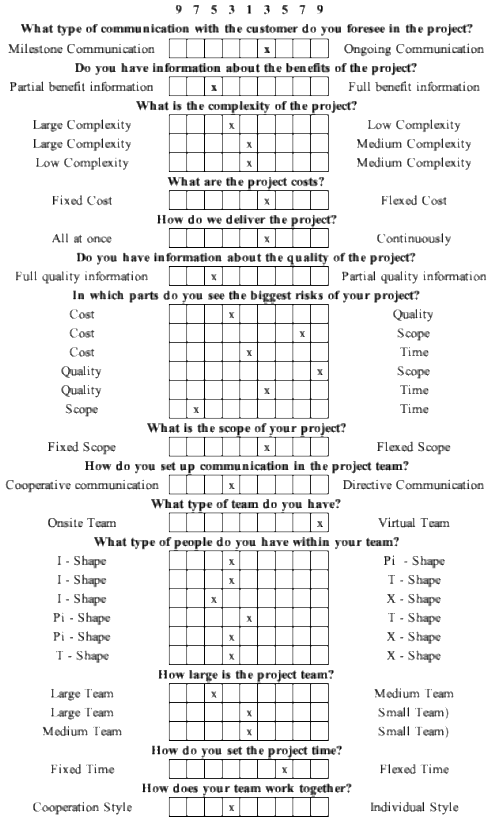

Fig. 7. Decision-maker responses about the project, Source: created by the authors

As a result, our application recommended using agile in his project in 54.2 %. It is not fully agile, but this value leads to a hybrid approach. To determine whether to use Water-Scrum-Fall or Waterfall-Agile, we selected clusters that affect which type of hybrid to use. These clusters are: (1) What type of communication with the customer do you foresee within the project, (2) How do we deliver the project, (3) How do you set up communication in the project team, (4) What type of people do you have within your team, and (5) How does your team work together.

In hybrid project management, different phases require different team competencies. Sequential models such as Water-Scrum-Fall, where planning and testing follow waterfall practices, are better suited to I-shaped professionals with deep single-domain expertise [22]. More agile-oriented models like Waterfall-Agile depend on cross-functional collaboration during iterative development, making T-shaped professionals more appropriate. Although not explicitly stated in the literature, this follows from how hybrid models combine traditional and agile phases. We therefore assign the cluster's decision nodes to the relevant hybrid approach (see Table 3).

Table 3. Decision nodes sorting based on hybrid models, Source: created by the authors

Cluster	Water-Scrum-Fall	Waterfall-Agile
1	Milestone Communication	Ongoing Communication
2	All at once	Continuously
3	Directive Communication	Cooperative communication
4	I - Shape	Pi - Shape T - Shape X - Shape
5	Individual Style	Cooperation Style

Based on the inputted values in Figure 8, all clusters that affect the type of hybrid Waterfall-Agile prevail over Water-Scrum-Fall. Based on these data (Table 4), we recommend using a hybrid approach, specifically the Waterfall-Agile one.

Table 4. Hybrid models – raw values, Source: created by the authors

Customer Communication	Milestone Communication	Water-Scrum-Fall	0,3728176
	Ongoing Communication	Waterfall-Agile	0,6271824
Project Delivery Method	Delivery all at once	Water-Scrum-Fall	0,3331789
	Ongoing Delivery	Waterfall-Agile	0,6668211
Project Team Communication	Cooperation Communication Style	Waterfall-Agile	0,6373062
	Directive Communication Style	Water-Scrum-Fall	0,3626938
Project Team Member	I-Shape Person	Water-Scrum-Fall	0,253633
	Pi-Shape Person	Waterfall-Agile	0,3608451
	T-Shape Person	Waterfall-Agile	0,3219357
	X-Shape Person	Waterfall-Agile	0,0635861
Project Working Style	Collaboration Working Style	Waterfall-Agile	0,6397345
	Individual Working Style	Water-Scrum-Fall	0,3602655

4 Conclusion

Choosing the appropriate method to lead the project is complex, and it is necessary to consider many criteria. We used a mathematical approach to support this decision via the ANP model. This method is commonly used in decision-making environments in the area of project management. The ANP approach to deciding which agile factors influence quality project success uses [9]. ANP uses also [10] to measure factors that influence project complexity.

In our pilot application, we used data from a pilot study involving only IT project managers. Because project management differs across environments (e.g., IT vs. construction), a separate supermatrix can be created for each environment to determine the appropriate level of agile involvement. The questions in our form are based on the PRINCE2® Agile standard [1]. In the future, the ANP model can be expanded with additional clusters or questions, and more expert data will be needed to increase the precision of the results. It is also necessary to refine the method for identifying which hybrid model is suitable when the agility preference lies around 0.45–0.55, since this middle range does not clearly favour either traditional or agile approaches. This requires

deeper contextual analysis of the questions distinguishing hybrid models, as discussed also by [6]. As more data are collected, maintaining consistency in comparisons with three or more decision elements becomes essential. In the pilot study, we used the revaluation method, but a more robust approach is needed, such as those proposed by [27], [28].

The main goal of this article was to introduce a pilot application to support the decision on whether to lead a project with an agile waterfall or hybrid model (where to use agile elements). To create this application, we used the improved ANP model introduced in the Model-Driven Organizational and Business Agility 2023 conference [26], which we have further improved and modified. This application supports decision-makers on how much agile should be involved in the project life cycle. In the next research phase, a questionnaire for pairwise comparison of the model's decision elements will be conducted among a broader group of project managers. The collected data will be used to develop a web-based interactive application supporting decisions on project management style. Aspects such as sensitivity analysis or comparison with tools like the PRINCE2 Agile Agilometer on real projects are relevant but fall outside this pilot study and are planned for future research. Limitations and future research. The current ANP model and application are calibrated only on a small set of expert judgements from IT project managers and have not yet been validated against historical project data or real project outcomes. Therefore, outputs such as the recommended agility share (e.g. 54.2%) or a suggested Waterfall–Agile hybrid should be seen as preliminary decision-support signals rather than empirically validated guidelines. Future research will collect a larger dataset of completed projects, back-test and refine the ANP model, and evaluate the tool's recommendations with experts in real project settings.

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Conflict of Interest

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APENDIX

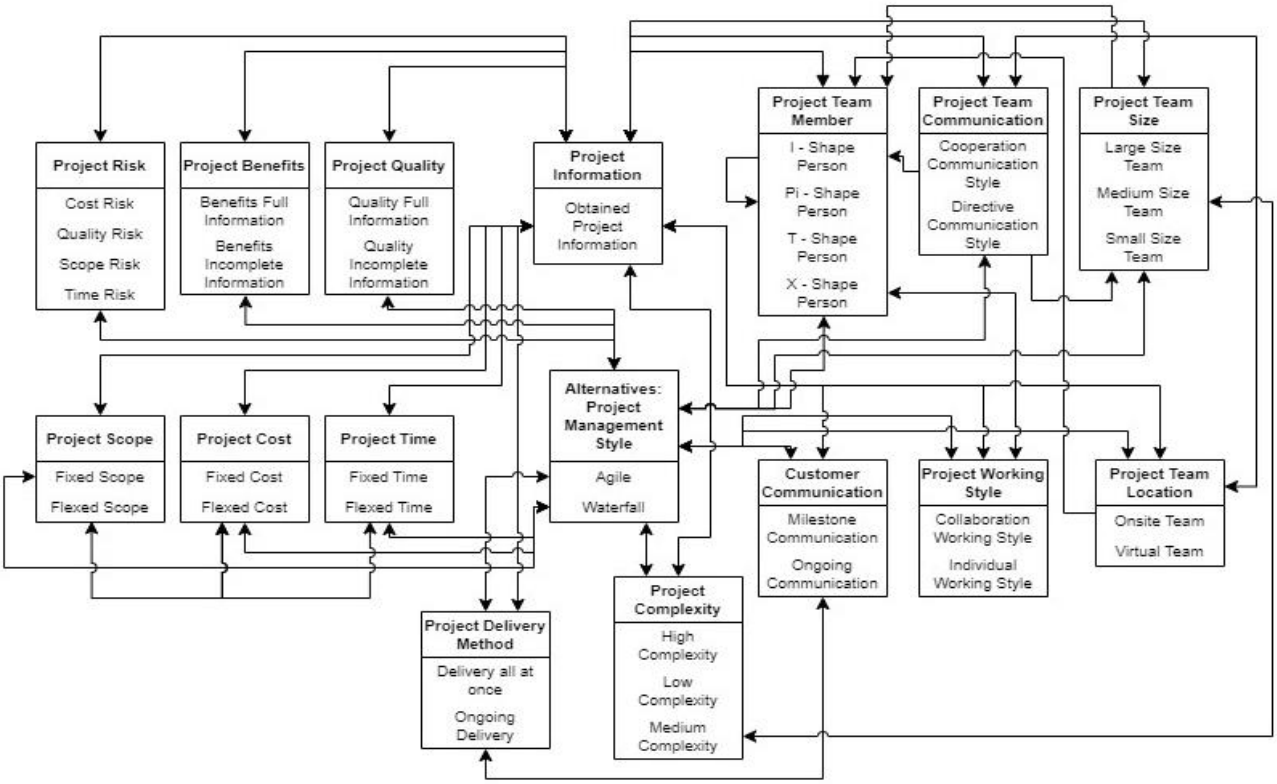

Fig. 6. ANP model, Source: [26]