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Matrix-based Evaluation of Project Management Approaches

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Abstract: One promising application of the matrix-based methods is handling and modeling flexible (e.g. agile) project management approaches. The goal of this research is to model both different kinds of flexible projects by matrix-based techniques and project managers (as agents) who follow different kind of project management approaches. The matrix-based project planning methods allow characterizing customer claims as score values besides the time/cost and resource demands. This study explores different kinds of flexible project structures with various time/cost/resource/score constraints and determines, which project management approach produces the most successful/shortest/cheapest projects.

Keywords: Project management, agile projects, agent-based modeling

1 Introduction

Project success becomes more and more critical to business performance, however, many projects still suffer delays, overbudgeting and even failure. CHAOS Annual Reports (see, e.g. (SGI, 2015)) shows that flexible project management techniques like agile project management (APM) approaches produce more successful projects, while following APM, project duration and the budgets can be kept more easily (Chow and Cao, 2008). The inspiration of this study was to understand why and when agile project management approaches produce expectedly more successful projects (Research Question 1, furthermore: RQ1). Should we combine flexible (like agile) and rigid (like traditional) project management approaches, or not (RQ2)?

1.1 Matrix-based project planning methods

Matrix-based methods, along with network planning techniques, are mainly used for planning and scheduling production development projects according to (Eppinger et al., 1994; Danilovic and Browning, 2007). While the first version of DSM assumes fix logic structures, further studies (Yassine et al., 1999; Kosztyán and Kiss, 2010a; Tang et al., 2010) showed that uncertain relations can be specified between two tasks. According to (Kosztyán and Kiss, 2010b) probabilities or priorities or just so called score values (of task completion) can also be assigned to the completion of the tasks. This matrix called as Project Expert Matrix (PEM). In this way flexible dependencies and uncertain task completions can also be modeled, which is a key point of modeling flexible, like agile, projects.

Since, specifying the logic structure is only the first step of project planning and scheduling, according to (Danilovic and Browning, 2007), one way of extending DSM method is to specify multiple domains (e.g. costs, resources etc.). Since the traditional DSM focuses on a single domain, its analysis yields solutions deemed optimal from the point of view of that domain only (e.g. dependency between tasks). However, the Domain Mapping Matrix (DMM) provides means to represent interactions and relations between domains (e.g. task-resources: Who will do these tasks?).

Despite flexible task dependencies and uncertain task completions may produces a great number of possible project structures, (Kosztyán, 2015) proposes a fast polynomial method that determines feasible project scenarios and project structures regarding time, resource and cost constraints. Also orders these feasible project plans by their probabilities/importance or according to other score values. In order to handle time, cost, resource demands and constraints, Project Expert Matrix (PEM) is extended to the Project Domain Matrix (PDM), similarly to extending DSM to DMM. DMMs are already used for modeling project management problems (see e.g. (Danilovic and Browning, 2007; Browning, 2014), but the PDM can model also the uncertain task completions and uncertain task dependencies.

1.2 Modeling project managers' decisions

In this study, we model a decision maker (project manager), who follows a given project management approach. Three approaches are distinguished in this study: Traditional Project Management Approach (hereinafter: TPMA), Agile Project Management Approach (APMA), and the combination of these approaches, which is a Hybrid Project Management Approach (HPMA). Each management approach has a toolset of project management techniques, which is implemented as a computer algorithm (hereinafter: agent). Several projects, such as software development projects (SDP) and new product developments (NPD) allow you to follow different kinds of project management approaches, because tasks (e.g. features to be implemented) can be completed both in serial and parallel way. Implementing tasks usually prioritized, and some of them will be postponed to a following project or subproject (e.g., into a so-called sprint or iteration).

Following a traditional project management approach the question is how much it will cost to implement all these features? Thus, the scope is given and has to be completed, but time and cost are convertible if necessary. These problems can be specifies as trade-off problems (see e.g. (Demeulemeester et al., 1996; Feng et al., 2000; Azaron et al., 2005; Tareghian and Taheri, 2006)).

The traditional project management (TPM) approach is widely supported by traditional project scheduling methods (see (Brucker et al., 1999) for an excellent summary of traditional methods). All of these methods based on fix logic structure or a set of predefined alternatives (Eisner, 1962; Pritsker, 1966). In contrast to traditional techniques, the agile approach allows and sometimes requires to restructure the project.

In the APMA the question is how many of these features can be included within the given budget and time interval? The goal is to realize the scope at the highest possible degree.

APMA and TPMA seem to be different approaches, however the real SDPs and NPDs frequently combine the TPM and APM techniques. The combination of APM and TPM methods (see e.g. (Fernandez and Fernandez, 2008; Rahimian and Ramsin, 2008; Tyagi et al., 2014)) is often called as a hybrid project management (HPM) approach.

A HPMA combines traditional and agile approaches. This approach can also be modeled by computer algorithms. Generating different kind of flexible project structures and using different kind of agents (which simulates the project management approaches through the decisions of project managers) may help us to answer: Why following agile project management approaches produces more successful projects (RQ1)? Should we combine approaches in order to increase the chance of project success (RQ2)?

1.3 Modeling project success

Although the reliability of Chaos Reports' results are criticized by several scholars (see, e.g. (Eveleens and Verhoef, 2010; Lech, 2013), their objective classification of project success (SGI, 2015) became widely used by both scholars and practicing project managers; thus in this paper this classification is used.

This study follows the classification of the Chaos Reports (SGI, 2015) that categorizes projects into 3 classes:

1. The project is *successful*; if project scope is satisfied within the time/cost/resource constraints.
2. The project is *challenged*; if project scope is satisfied, time, cost or resource demands are higher than the pertinent constraints, but these demands are within an expanded (but permissible) tolerance.
3. The project is *failed* otherwise.

One of the most interesting results of the Chaos Report was that the IT projects managed by agile project management approaches was 3 times more successful than the traditional waterfall projects. This considerable result is confirmed by other surveys and scholars (see, e.g. (Belout and Gauvreau, 2004; Lech, 2013; Dan, 2016)).

Most success criteria (like involving customers to the development process, strong executive support, being capable to cope with emergent requirement, etc.) require adaptive and flexible thinking for the project management. In the agile project management approach the completion of the project is more flexible, and project structure can adapt to the customer's claims.

In this research we focus only the success criteria of Chaos Report. Why could be more successful a project management approach than another ones.

2 Applied methods

Since numerous (more than 10,000) project plans are generated and explored, only fast, exact, polynomial algorithms are used as agents. For example studies on time-cost trade-off problems (TCTP) have been using various kinds of cost functions such as linear (Fulkerson, 1961), convex (Lamberson and Hocking, 1970), concave (Falk and Horowitz, 1972), discrete (De et al., 1995, 1997) or stochastic (Feng et al., 2000). In this study the continuous version of TCTP (furthermore, CTCTP) is used, because this method can be solved within a polynomial computation time.

If the cost function is linear, the problem can be solved with a very fast algorithm (see, e.g. (Ahuja et al., 1991; Orlin, 1993), therefore in the simulation phases, linear cost function have been considered and the Orlin's method is used in order to accelerate the run of the proposed traditional and hybrid project management agents.

2.1 Generated project matrices and structures

We developed a project generator to produce different types of project plans. Only the value of complexity (number of nodes, connectivity factor (*cf*) and ratio of supplementary tasks and dependencies (hereafter flexibility factor, *ff*)) need to be specified to create the logic domain of a single project. The result is a *n* by *n*+4 PDM matrix, which contains an *n* by *n* logic domain (LD), *n* by 2 time domain (TD), and n by 2 cost domain (CD) respectively.

The values of time and cost demands followed [0, 20] and [0, 30] uniform distributions, respectively.

To define a project with a desired complexity an upper triangle matrix have been created. The size of the matrix (the number of rows) will specify the number of nodes/tasks. The connectivity factor $s_{ij}(a)$ affects the number of the dependencies in the project's logic domain. The probability of that the *j*-th task follows the *i*-th task is specified by the $s_{ij}(a) = min(j-i-1+a)^{-1,3},1)$ function, where $j>i$; $i,j \in \mathbb{N}^+$ and $a \in \mathbb{R}^+$. If *a* is 1 then the critical path contains all the tasks, lower *a* values give fewer task dependencies in the off-diagonal cells, therefore we get a more parallel project structure. In this simulation $a \in \{0,1\}$ and furthermore we called *a* as connectivity factor (*cf*). *cf*=0 produces a more parallelized project structure. If $cf \in \mathbb{Z}^+$, the algorithm produces *cf* number of parallel paths. In the next step the necessity of the task implementation and the previously defined strict predecessor-successor relations between the tasks (selected randomly) are relaxed at a given ratio of tasks and dependencies (*ff* alternates between 0.05 and 0.2 with a 0.05 step), and the score values modified from 1 to a uniform distributed value between 0.5 and 1.

Table 1 shows a PDM matrix, where *cf*=1, *ff*=0.2, *n*=30. Diagonal values of the LD represent the score of task completions. 1 means, that the task has to be completed, if this value is lower than 1 the (agile) project manager can decide whether this task will be included in the project or will be excluded from it (and will be scheduled to the next (sub)project). The off-diagonal value 1 represents a strict dependency between tasks, if this value (score of dependency) is lower than 1, but greater than 0, an (agile) project manager can decide how to complete these tasks i.e. it is performed in a parallel or a sequential way.

Table 1. An example of a generated PDM (*cf*:=1, *ff*:=0.2. *n*:=30)

PDM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	t_{min}	t_{max}	c_{min}	c_{max}
1	0.71	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.59	12.20	15.59	17.08
2	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.27	10.87	24.38	28.66
3	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.95	17.45	16.71	20.68
4	0.00	0.00	0.00	0.92	0.67	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.56	1.94	8.51	9.33
5	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.55	15.87	22.12	27.45
6	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.99	5.89	21.05	23.39
7	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.14	3.89	15.45	16.13
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.62	3.70	14.52	16.17
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.16	18.76	26.78	27.04
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.71	15.68	21.07	24.74
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.21	10.93	22.25	22.28
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.94	15.97	7.60	8.57
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.87	11.29	11.60	12.20
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.19	18.04	10.51	11.53
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.21	18.73	16.18	19.32
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.61	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.75	16.67	22.45	26.97
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.94	7.29	20.53	25.47
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.10	12.94	16.49	18.52
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.05	7.79	9.17	9.69
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.45	17.92	26.13	26.20
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.87	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.40	19.36	20.44	22.71
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.11	15.02	21.45	22.56
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	1.00	0.00	0.00	0.00	0.00	0.00	0.00	10.22	12.60	14.81	16.22
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.96	0.00	0.00	0.00	0.00	0.00	17.64	19.56	16.13	16.17
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	13.97	16.17	12.33	14.04
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	14.13	15.11	9.79	10.36
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.71	0.00	1.00	15.62	16.92	22.02	26.91
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.96	0.00	15.22	17.01	6.83	8.24
29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.92	13.82	14.25	18.11	19.81
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	8.93	9.96	17.68	18.48

In every simulation $cf \in \{0,1\}$, $ff \in \{0.05, 0.10, 0.15, 0.20\}$, $n \in \{30, 60, 90\}$. However, (Kosztyán, 2015)'s method allows cycles in a project plan, we assumed that there is no cycle in the project (therefore the LD can be reordered as an upper triangular matrix). For the sake of simplicity only finish to start dependencies are generated between each pair of tasks.

Two kinds of time and two kinds of cost demands are assigned to each task. For the fast calculation linear function is assumed between time and cost demands. The *normal task demands* characterized as $(t_{\max}, c_{\min})$ values, while so-called *crash task demands* characterized as $(t_{\min}, c_{\max})$ values.

Every implemented agent produces an *n* by *n*+2 project structure matrix (PSM), which is a special PDM matrix. In the PSM every flexible task dependencies and every uncertain task completion is decided to include to or exclude from the project ($\mathbf{LD} \in \{0,1\}^{n \times n}$). **TD** and **CD** are *n* by 1 vectors. Therefore, the total project cost (TPC) and the total project time (TPT), can be calculated by traditional way.

The total project score (TPS) can be calculated as follows:

$$\mathrm{TPS} = \sqrt[n]{\prod_{i:=1}^{n} S_i}, \text{ where } S_i = [\mathbf{PDM}]_{i,i}, \text{ if } [\mathbf{PSM}]_{i,i} = 1;\ S_i = 1 - [\mathbf{PDM}]_{i,i} \text{ otherwise.} \quad (1)$$

2.2 Specifying constraints

According to (Kosztyán, 2015) the minimal/maximal time/cost/score demands can be calculated in one step. Minimal (maximal) project duration occurs, if every uncertain task completion and flexible dependencies are excluded (included) and the minimal (maximal) durations are assigned to the tasks. Similarly, minimal (maximal) project cost occurs, if every uncertain task completion is excluded (included) and the minimal (maximal) cost demands are assigned to the tasks. Since every score value of the uncertain task completion is greater than 0.5 in this case, according to Eq. (1) the minimal (maximal) value of the total project score occurs if every task are excluded (included).

Each range of the theoretical minimal ($c_x^{\min}$) and maximal ($c_x^{\max}$) values of time/cost/score demands (c_x) is treated as 100%, the theoretical minimal is the 0% (see Eq.s (2-3)).

$$c_x\% = (c_x - c_x^{\min}) / (c_x^{\max} - c_x^{\min}) \tag{2}$$

$$c_x(c_x\%) = c_x\%(c_x^{\max} - c_x^{\min}) + c_x^{\min} \tag{3}$$

In this study $c_x\% \in \{0.0,.0.1,..,1.0\}$. "*x*"="*c*" and "*x*"="*t*" are upper cost and time constraints, while "*x*"="*s*" represents a lower score constraints, which models the minimal requirements of the customers.

2.3 Agent-based simulations for characterizing project management approaches

Three project management agents (TPMa, APMa, HPMa) are implemented to test which approach is least sensitive for the changes of the constraints and demands. When implementing TPMa, we used a modified – matrix-based version of – (Orlin, 1993)'s algorithm. In this case, the project manager must follow the project plan. There is no way to restructure the project plan or exclude uncertain (less prioritized) tasks, however, in the range $[t_{\min}, t_{\max}]$ task durations can be reduced in order to keep deadlines. Every time reduction may cause the increase of costs, however, (Orlin, 1993)'s method will give us the local minimum of project duration (considering that every flexible dependency and every uncertain task completion is included to the project plan) if there are feasible solutions.

When implementing APMa (Kosztyán, 2015)'s Exact Project Ranking algorithm is used. In this case, there is no way to reduce time demands of tasks. We assume that every tasks scheduled with normal task demands $(t_{\max}, c_{\min})$, however, flexible dependencies can be resolved, while the TPS is greater than the specified score constraint (c_s) uncertain task completions can be ignored from the project.

HPMa is based on (Kosztyán, 2014)'s algorithm. This agent can also reduce the project duration and can restructure the project simultaneously.

3 Simulation results

In the simulation 11,420 PDM matrices and constraints had been generated. Every PDM matrix has been solved by the three project management agents. TPT, TPC and TPS values are calculated for every proposed project structures. Normalized project values are specified for feasible projects as follows:

$$c\% := \frac{\mathrm{TPC}}{c_c^{\max} - c_c^{\min}}, t\% := \frac{\mathrm{TPT}}{c_t^{\max} - c_t^{\min}}, s\% := \frac{\mathrm{TPS}}{c_s^{\max} - c_s^{\min}} \quad (4)$$

If we consider only the successful projects, *c*%, *t*%, *s*% are lower or equal than 1. Lower values mean lower project cost, duration and lower project scores.

While lower *c*%, *t*% values are positive property of project management agent, because it means projects can be completed with less cost/time demands than the budget/deadline, lower project scores may produce lower customer satisfaction.

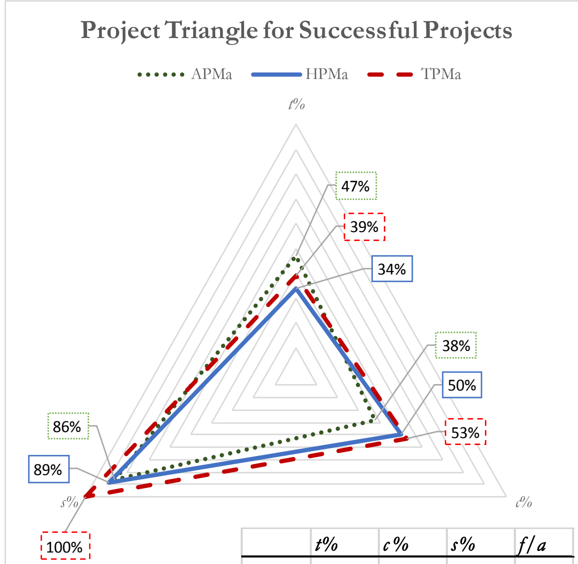
After using an Analysis of Variance (ANOVA) method, all independent variable (*ff,cf,N,*xPMa) were significant, and the adjusted Eta square were 0.734. Since the limitation of pages, just the summary table is shown (see Table 2).

The simulation results show that agile project management approaches can almost triple the ratio of successful projects of the traditional approaches. Table 2 shows that APMa's advantage is more significant (RQ1) if projects are more flexible (see *ff* factor), this advantage is less considerable if the project is more rigid. Table 2 also shows, that hybrid project management agent can produce even more successful project compared to the agile agent.

While HPMa can produces the most of the successful and the shortest projects, Table 2 shows that APMa produces the cheapest projects, and if a project can be managed by TPMa, this approaches guarantee only that all features will be implemented.

Table 2. Summary of the simulation results (*c*%, *s*%, *t*% are calculated only for successful projects, *f*/*a*= feasible / all projects) and the project triangle for the successful projects

Summary table			*c*%		*s*%		*t*%		*f*/*a*	
xPMa	*n*	*ff*	*cf*=0	*cf*=1	*cf*=0	*cf*=1	*cf*=0	*cf*=1	*cf*=0	*cf*=1
TPMa	30	0.05	0.36	0.63	1.00	1.00	0.13	0.53	0.47	0.24
		0.10	0.50	0.69	1.00	1.00	0.26	0.68	0.30	0.12
		0.15	0.55	0.85	1.00	1.00	0.36	0.81	0.20	0.06
		0.20	0.69	0.82	1.00	1.00	0.47	0.87	0.13	0.07
	60	0.05	0.37	0.65	1.00	1.00	0.18	0.68	0.46	0.13
		0.10	0.52	0.74	1.00	1.00	0.29	0.81	0.30	0.09
		0.15	0.60	0.85	1.00	1.00	0.43	0.84	0.19	0.08
		0.20	0.67	0.80	1.00	1.00	0.58	0.89	0.12	0.03
	90	0.05	0.35	0.74	1.00	1.00	0.20	0.76	0.50	0.13
		0.10	0.48	0.73	1.00	1.00	0.28	0.85	0.28	0.08
		0.15	0.57	0.83	1.00	1.00	0.46	0.88	0.14	0.03
		0.20	0.65	0.89	1.00	1.00	0.56	0.89	0.09	0.04
APMa	30	0.05	0.21	0.19	0.87	0.87	0.51	0.54	0.20	0.36
		0.10	0.32	0.29	0.84	0.86	0.42	0.54	0.35	0.56
		0.15	0.41	0.39	0.84	0.83	0.40	0.49	0.43	0.55
		0.20	0.47	0.45	0.85	0.85	0.45	0.47	0.50	0.64
	60	0.05	0.25	0.23	0.87	0.86	0.46	0.56	0.26	0.51
		0.10	0.38	0.36	0.88	0.89	0.47	0.52	0.45	0.71
		0.15	0.43	0.42	0.85	0.87	0.42	0.48	0.48	0.72
		0.20	0.47	0.48	0.85	0.88	0.42	0.46	0.62	0.72
	90	0.05	0.25	0.22	0.89	0.84	0.50	0.55	0.31	0.61
		0.10	0.36	0.35	0.88	0.88	0.44	0.51	0.43	0.77
		0.15	0.43	0.43	0.87	0.88	0.40	0.48	0.53	0.69
		0.20	0.49	0.47	0.88	0.86	0.42	0.49	0.64	0.77
HPMa	30	0.05	0.35	0.55	0.94	0.92	0.14	0.39	0.69	0.59
		0.10	0.45	0.55	0.90	0.88	0.21	0.45	0.72	0.65
		0.15	0.49	0.57	0.87	0.84	0.24	0.42	0.72	0.62
		0.20	0.54	0.58	0.87	0.86	0.31	0.44	0.68	0.67
	60	0.05	0.35	0.55	0.93	0.89	0.17	0.47	0.75	0.64
		0.10	0.45	0.55	0.92	0.90	0.24	0.49	0.76	0.76
		0.15	0.49	0.57	0.88	0.87	0.27	0.47	0.74	0.75
		0.20	0.50	0.57	0.86	0.88	0.34	0.44	0.76	0.75
	90	0.05	0.32	0.53	0.94	0.85	0.18	0.46	0.82	0.76
		0.10	0.43	0.56	0.92	0.89	0.24	0.47	0.78	0.82
		0.15	0.46	0.56	0.88	0.89	0.28	0.46	0.81	0.72
		0.20	0.52	0.56	0.90	0.86	0.33	0.47	0.78	0.79



	t%	*c%*	*s%*	*f/a*
APMa	47%	38%	86%	53%
HPMa	34%	50%	89%	73%
TPMa	39%	53%	100%	18%

4 Summary and conclusion

In this paper the agents model project management approaches. Simulated projects had been analyzed to compare; which project management approach can be adequate. We considered flexible project plans, which can represent an SDP or an NPD project environment. Results show that there is not a single absolutely winning strategy. In every decision of the project manager time, cost and quality requirements have to be harmonized. If there is no chance to deviate from the original project plan and it is not possible to restructure the project schedule, the only possible approach is the traditional PMa (in this case HPMa=TPMa) and the only methodological tool is some kind of trade-off method. If the project is flexible, agile approach produces the lowest mean values of project cost, HPMa produces the lowest mean values of project duration but TPMa produces the highest project scores (see Table 2 and RQ1). In all cases the hybrid approach can produce the most of the feasible project plans, therefore agile and traditional PMa should be combined (RQ2). If the project is not flexible, the hybrid and the traditional project management agents are identical, while the flexibility factor is increasing the behavior of hybrid and agile approach is getting very similar (see Table 2).

5 Limitation and future works

This paper is focusing on single projects, however in a multi-project environment (MPE), more than one project are running at the same time, in such case the resource sharing is also important within the running projects. In the next study we will focus on MPEs. The multi-project manager can also be modeled by agents and can represent different kind of approaches similarly to the single-project management agents used here. In this latter case the collaboration and information/resource sharing of project managers can also be modeled.

The other way is to extend the proposed framework is to simulate changes of project parameters and requirements, while the projects are in progress. Our hypothesis is that the results will be similar: HPMa should produce most of the feasible and most of the successful projects, however, it should be analyzed, whether and when we should change from one project management approach to another one. Can a delayed, overbudget project be managed and recovered by another project management approach or not?

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