

HOW IMPORTANT IS TEAM STRUCTURE TO TEAM PERFORMANCE?

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ABSTRACT

This paper discusses the effects of team structure on the performance of design teams. Three types of team structures are differentiated on the basis of the functional and social groups that result from task dependencies and interaction opportunities. The reported findings are based upon results from simulation-based studies using a computational model. Differences across the team structures are investigated through a series of simulations in which the team membership and the workload busyness of the team members are independent variables, and the team performance and formation of team mental models are the dependent variables. Team performance is measured in terms of the ability of the team members to coordinate the set of tasks the team needs to perform. Findings suggest that, in general, flat teams facilitate formation of team mental models, while functional teams are best for efficient task coordination.

Keywords: team structure, team performance, team mental models, social learning, member retention, busyness

INTRODUCTION

The design of engineered products is a complex activity that requires decomposition into tasks according to product function or (modular) sub-system [1]. Design teams are usually formed to perform a set of tasks that require specialized knowledge such that the team of specialists can collectively complete them. The roles and responsibilities of the team members need to be clearly defined, and aligned to their areas of expertise. The performance of the design team depends on how effectively the team members coordinate the tasks, roles and responsibilities with the other members of the team. Working in design teams requires additional actions beyond those related to the task [2]. These actions correspond to prosocial aspects of teamwork such as knowledge sharing and communication [3] [4]. The prosocial activities contribute to the entrainment of their behavior to one another. In the absence of such opportunities, merely collecting a knowledgeable engineering design team may not ensure high performance [5]. Effective teamwork requires team members to have well-developed mental models of each other and that of the tasks, processes, context and competence specific to the project [6-7], where mental models are the simplified internal representations of the world [8]. This paper deals with the formation of team-related team mental models (TMMs). The formation of team-related team mental models involves team members developing mental models of each other's competence and expertise, which allows them to coordinate the different tasks by assigning the right job to the right people.

While there are a number of factors that influence the formation of the TMM, this project investigates the structure of the team and the opportunities for socialization, as these variables are difficult to control in empirical studies. How the team is organized in terms of the task allocation and social observation opportunities should affect the formation of TMMs, and the ability of the team of experts to coordinate the tasks. The following three types of team structures are differentiated:

Flat teams have no hierarchy and no sub-divisions. Such teams are generally used for consultation, task-force and design exploration [9]. There are no nominated leaders. A leader may emerge over time, based on the interactions within the team.

Distributed flat teams: With the increased use of communication technology, design teams are often distributed across geographies, e.g., global product development teams [10]. In such teams, sometimes social cliques develop, where the team is divided into two to three collocated clusters. Thus, even if the teams are flat for the purpose of management, the opportunities for social learning are skewed due to the physical boundaries [10].

Functional teams: Many work teams are organized into functional sub-teams [11-12]. In such teams, the task is passed to the members from the sub-teams with relevant domain knowledge. Even if the

hierarchy is not pre-defined, hierarchy emerges as the task is decomposed into sub-tasks, and members are chosen to coordinate those tasks. A team member from each sub-group emerges as the group leader as the project progresses. This member also coordinates the activities of that group, at the higher level, with the other group leaders.

Opportunities for socialization can be encumbered in a number of ways, and this paper will focus on two variables, which are, again, difficult to control in empirical studies. Design teams are mostly project-based. Project-based teams are commonplace in large organizations, joint ventures, SMEs and in virtual teams [13-15]. Team composition may vary and affect the formation of TMMs and the team performance in such teams. To achieve higher team performance, managers and project leaders strive to maximize the number of team members who have previously worked together on a similar project [16], which we define as *member retention*. However, retaining the entire team or some team members from one project to the next may not always be possible, and members will likely work on more than one project at a time. Second, organizing the available human resources in project-based teams allows firms and organizations to simultaneously engage experts in multiple projects and teams [17]. The resulting workload and distributed attention across the different teams may influence the TMM formation and the team performance because team members' attention is diverted from prosocial team activities to learn about other agents [18]. That is, their *workload busyness* will diminish their opportunities for socialization, which can decrease chances for TMM formation.

In summary, this study compares the effects of team structures on TMM formation and team performance through two independent variables, *team member retention* and *workload busyness*. This research adopts a computational approach, which facilitates the control of parameters such as busyness levels and team structure, which are difficult to control in empirical studies. The computational model has been validated in earlier studies for its usefulness and consistency in generating and testing organizational and social behavioural theories in terms of TMM formation [19]. Team performance will be measured in terms of the amount of team communication. Teams requiring fewer message exchanges to coordinate the same set of tasks are deemed to be higher performing teams [20].

DESCRIPTION OF THE COMPUTATIONAL MODEL

The computational model is implemented as an agent society with team agents as the team members. There is a client agent in addition to the team agents that allocates the task to the team and selects one of the team agents as a team leader at runtime. The model is briefly described in this section.

Team structure

The three types of team structures are implemented by defining the task allocation and social observation conditions, Table 2. Flat teams allow members unrestricted access to all the agents in the team for task allocations as well observations. In functional teams, not only is an agent's ability to observe the other agents limited within the sub-team, but even most of the task-allocation interactions are within the sub-team. In distributed flat teams, agents can allocate tasks to any other agent in the team, but their ability to observe the other agents is limited to the members within their social cliques. In all the simulations, the leader is chosen by the client agent.

Table 2. Team types and corresponding scope for task allocation or social observation

Team type	Task allocation	Scope of observation
Flat teams	Any member of the team	Any member of the team
Distributed flat teams	Any member of the team	Only members of the social group
Functional teams	Only members of the task group	Only members of the task group

Agent learning

Rather than modelling cognitively rich agents that improve their own performance through experience, the model implements (1) the types of social experiences that have significant influences on individual learning, and (2) how cumulative individual experience increases individual proficiency when agents have the ability to learn from others [21] about what others know so that the agents can be more

efficient at coordinating work [22]. To do this, the model adopts the mechanisms of knowledge transfer that are social [23]. It is assumed that individual agents have sufficient knowledge of the process and context of the task to be performed by the group, all that the agents need to learn about is others' competence. Agents learn as they interact with each other and the task that they are performing. Agents also learn by observing the interactions between the other agents or the interaction of some other agent with their task.

The model is grounded in the Folk theory of mind, which claims that the ability of humans to understand others as intentional beings, similar to oneself, allows individuals to learn from the social interactions and observations [23-25]. All agent actions in this model are assumed to be intentional, which allows agents to build a mental model of the other agents in the team. Agents learn about the other agents in the team based on the actions of the others, which are observable [26-27]. During these interactions and observations attention plays a critical role such that the learner is concerned with only a subset of all the things that can be perceived at the given moment [25]. Observation is subject to an agent's availability to attend to the observable data, and, hence, mitigated by the level of busyness [18]. What the agents learn is based on a set of rules [19] derived from the mode of social learning:

1. Personal interaction (PI): Personal interactions are the most direct form of learning. Agents learn by directly interacting with other agents or from personal experience with the task. An agent learns something about the task and the agent that it directly interacts with. For example, if A talks to B about task T^1 , then B learns something about A with respect to T^1 .
2. Interaction observations (IO): When agents have the opportunity to observe the interaction among other agents they learn something about the agents that are interacting. For example, if A observes B allocating task T^1 to C, then A learns something about the relationship between B and C with respect to T^1 .
3. Task observations (TO): Agents may also have the opportunity to observe other agents while they perform a task and learn something about the observed agent and the task. For example, if A observes B performing the task T^1 , then A learns something about B with respect to T^1 .

Modelling tasks

The agents work on a routine design problem that can be decomposed into subtasks. Each agent has the knowledge to complete some of the subtasks, but the entire design solution is not known in advance [28]. Each agent's (sub)task may have more than one (non-unique) solution. Task coordination requires finding agents who have the skill to complete the task. The speed at which the agents complete the entire set of tasks is dependent upon the time it takes for the agents (as a team) to provide one possible solution as a combination of each agent's solution to its assigned subtask. The agents' aggregate solution must satisfy the specified requirements.

For a given task, multiple solutions may exist, and an agent can only provide a solution that lies within its capability range, where the capability range of an agent is the range of solutions that an agent can provide for a given task. The capability range is a proxy for the degree of skill for an agent. Two agents assigned the same task may provide different solutions because they may have different capability ranges for the same task. Therefore, the task performers (agent) need to identify the solution space acceptable to the evaluator (some other agent or the client). The client has a desired range of parameters for the requirements of the overall solution. The team agents are required to collectively generate a solution that falls within the client's acceptable range. The teamwork involves coordination and evaluation of the sub-solutions such that all the sub-solutions are compatible.

One task may branch out into multiple sub-tasks and their solutions need to be compatible. Hence, the tasks require solution integration and compatibility check. This may require reallocation of the same tasks to the same or some other agent. The solutions are evaluated at the integration stage, following a top down approach, i.e., the solutions for higher-level tasks are completed first. Initially, the client approves the overall acceptable solution range. The team leader, appointed by the client on the basis of a competitive bid, considers this approved range as the boundary limit when evaluating the solutions for the corresponding sub-tasks. Once the team leader approves sub-tasks provided by other agents, those agents consider the approved solution as a benchmark to refine the acceptable solution range for the solutions to be coordinated at the next lower level. This cycle continues until all the tasks are decomposed into the lowest levels. If the integrated solution exceeds the boundary conditions, the agent evaluating and coordinating the integrated solution, i.e. the evaluator, chooses one of the sub-

solutions to be reworked. This cycle of task evaluation and rework continues until the sub-solutions are compatible at each level.

Simulating TMM formation

As agents interact, they build mental models of each other. The development of their TMMs involves learning about the competence and skills of each agent for each of the different tasks the team needs to perform. The mental model for an individual agent is termed the Agent Mental Model (AMM), and collectively, the AMMs within an agent for all other agents form a TMM. The TMM formed by each agent may be different to the TMM of another agent because the agents will have differential opportunities for social learning.

Implementing mental models

An agent's AMM is represented as an m -dimensional vector showing the competence values and the capability range in the m possible tasks within the team. The TMM is represented as an $m \times n$ matrix where n is the total number of agents. When an agent receives a positive or negative feedback on another agent's competence, the corresponding values are updated in the TMM matrix.

Using the TMM for task allocation and handling

Agents allocate the task to the agent that they believe to have the highest competence in the given task. When the simulation starts (at time $t=0$), all the agents have the same default value for the competence in each task. In such a scenario, agents allocate the task to a random agent. Once the agents have gained experience working with each other, there will be differences in known competence of the agents in a given task. It is possible that more than one agent has the highest competence value. In that case, the agent creates a shortlist of all the agents with the highest competence value, and the task is allocated to an agent randomly selected from this shortlist.

Agents propose solutions based on their own capability range and the range of acceptable solutions for the agent that allocated the task, i.e., the task allocator. The task performer looks up the TMM for the capability range of the task allocator, corresponding to the given task. For the selected solution to be accepted, the solution must also overlap with the solution range acceptable to the task allocator. Once the agent has identified a shortlist of solutions that it can provide and that are also acceptable to the task allocator, it can choose any of the solutions from the shortlist, provided the chosen solution has not already been proposed in the same project. Since the agent constantly updates the task allocator's acceptable solution range as soon as it gets a feedback, the task performer is able to adapt the solution to suit the task allocator. Thus, teams with a well-developed TMM are expected to perform faster.

Measuring TMM Formation

TMM formation is measured as a ratio of the number of TMM matrix elements for which the values are different from the initial values by the end of the simulation. At the start of the simulation, since each agent starts with a default value for each element in the matrix, the values in each element will change only if the agent has learnt it through social interactions and observations. Each value in the TMM matrix should proceed towards 0 or 1, that is, that another agent cannot or can complete a specified design task.

For example, let there be 10 agents in the team and a total of 10 tasks to be performed by the team. In that case, the TMM is represented as a 10×10 matrix such that there are 100 elements in the TMM. When the simulation starts, all the elements have a default competence value $= 1/2$ because there is an equal likelihood that a given agent may or may not be able to perform any of the given task. As the agents interact with and observe each other and the task, they learn about each others' capabilities in the different tasks, and update the values of the corresponding elements in the TMM. By the end of the simulation, let us assume that 60 of these values were updated such that the value of each of these 60 elements is different from $1/2$. Thus, the TMM formation in this case is 60%.

Each agent maintains a separate TMM, which it updates based on its own interactions and observations. Therefore, by the end of the simulation, it is expected that each agent's TMM will be different. However, overlap and similarities across the TMM of the agents is likely. The overall TMM formation for the team is calculated as an average of the TMM formation for each agent in the team. For example, in a team of 10 Team agents, if 4 agents have 60% TMM formation, 4 agents have 40%

TMM formation, and 2 agents have 50% TMM formation, then the overall TMM formation for the team is 50%.

Overview of a simulation loop

At the start of the task cycle, the client calls for a bid for the first task from all the agents. A single agent may have expertise in multiple tasks such that multiple agents may have expertise in the same task. Agents that can perform the “firstTask” bid to lead the task. The client shortlists those bids that are closest to its acceptable range of solutions. If more than one bid is shortlisted, a random bid is chosen from the shortlist, with the bidder as the Team Leader. Thereafter, the team coordinates the task allocation and handing as described in Section 3.3, until the project is completed.

A single simulation run consists of two simulation rounds (1) training round and (2) test round. In the training round the agents start with default (experimenter-defined) values and none of the agents has any TMM formed at this stage. Once the training round is completed, the test round is run. All the agents carry over the TMM formed during the training round to the test round. The results from the training round are used to measure TMM formation. Measurement of team performance (team communication) is based on the results from the test round.

The Simulation Controller is responsible for managing the simulation rounds and the number of simulation runs, which is 60 unless reported otherwise. Once the test round is complete, the Simulation Controller checks the number of pairs of simulation runs completed. If more simulation runs are required, all agents are reset to their default (user-defined) values and the next simulation run is activated. If the required number of simulations is completed, the simulation platform is shut down.

Simulation of membership retention

The level of membership retention is taken as the number of agents retained from the previous project such that if all the agents are the same in the training round and test round, the level of membership retention is 100%. If the membership retention is 100%, all the agents retain their TMM. If the membership retention is less than 100%, new agents are introduced into the team such that each new agent acquired in the team replaces an agent that was part of the training round. For example, let there be 10 agents, A^1 to A^{10} that were part of the team in the training round. If the desired membership retention in the test round is 80% then the new team has 8 agents retained from the training round, and two new team agents, for example $A^{3'}$ and $A^{7'}$ such that they replace the other two agents, for example A^3 and A^7 , that were not retained from the training round.

While all new agents (i.e., $A^{3'}$ and $A^{7'}$) start with a default TMM, the agents retained from the training round (i.e., A^1 , A^2 , A^4 , A^5 , A^6 , A^8 , A^9 , and A^{10}) reset their AMM of the agents that have been replaced (A^3 , A^7) while retaining the AMM of the rest of the agents (i.e., A^1 , A^2 , A^4 , A^5 , A^6 , A^8 , A^9 , and A^{10}). That is, the retained agents retain part of their TMM, while the other part that may not be useful (i.e., related to A^3 and A^7), is reset to default values (to be used for AMM of $A^{3'}$ and $A^{7'}$).

Simulation of busyness levels

Busyness is implemented as the probability that an agent is not able to sense the observable data. Observable situations include interactions with other agents (PI), interactions among other agents (IO) and task-performance by some other agent (TO). The busyness levels are varied in the training round itself and not in the test round. The effects of busyness on the level of TMM formation is measured in the training round. However, the effects of that busyness and resulting reduction in social learning during the training round needs to be observed in the test round, where the team's performance is expected to have improved since the training round because of the social learning achieved and mediated by busyness in the training round.

SUMMARY OF SIMULATION RESULTS

Initial simulations were conducted with busyness levels=0 and membership retention=100% to understand the relative contributions of the different social learning modes, i.e., PI, IO and TO, to the team performance, Figure 1, and formation of TMM, Figure 2, across the three team structures. The team performances in Figure 1 are normalized such that the worst team performance (maximum number of messages) is considered 1. For each case, the normalized performance value is obtained by dividing this maximum value by the number of messages. For example, if the worst case has 147

messages, and the best case has 32 messages, then the normalized performance for the best case is 147/32. The three learning cases shown in Figure 1 and Figure 2 are:

- PI+IO+TO: All three modes of social learning are available to the agents
- PI+IO: None of agents can observe others perform the tasks. However, they can observe interactions among other agents if team structure conditions allow.
- PI: All agents learn only from personal interactions.

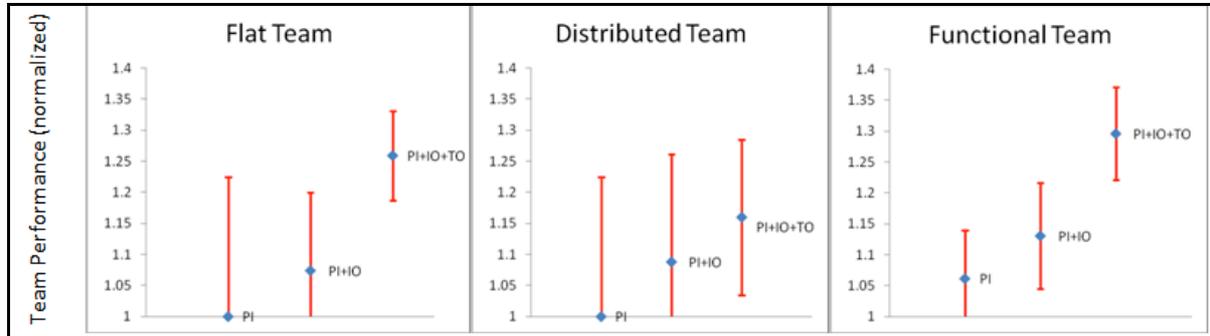


Figure 1. Effects of team structure and modes of learning on team performance

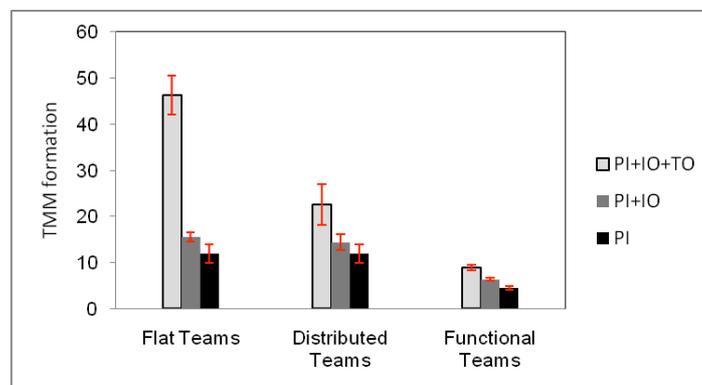


Figure 2. Effects of team structure and modes of learning on TMM formation

The simulation results suggest that both IO and TO contribute to team performance, Figure 1, as well as TMM formation, Figure 2. Across both measures, the contributions of TO are higher than IO. The differences across the learning cases are higher for TMM formation than it is for team performances. Thus, social observations contribute more to TMM formation than to team performance.

TMM formation is much higher in flat teams, compared to distributed flat teams and functional teams. Since flat teams have no sub-groups or internal boundaries that obstruct social observations, all agents in the team have more opportunities to form their own TMM, collectively leading to a higher rate of increase in the overall TMM formation.

Effects of busyness

Busyness reduces the opportunities for social observation. Hence, the effects of the reduction in social observations due to higher busyness levels should be higher in flat teams, where the contributions of social observations to formation of TMM are higher, as compared to distributed flat teams and functional teams. Similarly, the effects of busyness should be higher on TMM formation as compared to the performance of the team.

Figure 3 and Figure 4 show the effects of busyness on team performance and TMM formation respectively. The plots of team performance are shown in the negative so that an increasing number of communications results in a decrease in performance. These results are for experiments with 100% member team member retention. A decrease in team performance and TMM formation with increase in busyness levels is observed across all team structures. However, the effects of busyness on team performance are marginal compared to the effects on TMM formation. As conjectured, the effects of busyness on TMM formation on flat teams are much higher than in the distributed teams or the functional teams, Figure 4.

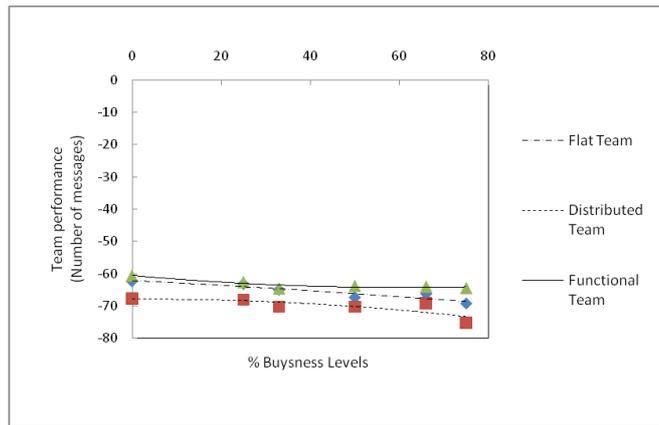


Figure 3. Effects of team structure and busyness levels on team performance

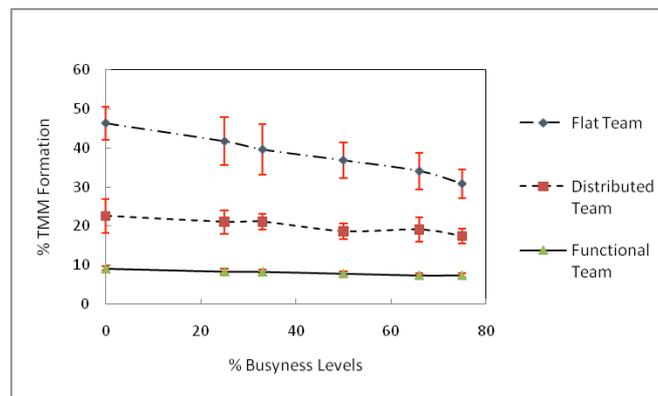


Figure 4. Effects of team structure and busyness levels on TMM formation

Effects of membership retention

The increase in team performance with the increase in membership retention is higher for flat teams and distributed flat teams than that for the functional teams, Figure 5. In functional teams, even at lower levels of membership retention, which means lower pre-developed TMMs, the agents' search space for the relevant task experts is narrowed within the corresponding task-group rather than the entire team. This smaller search space compared to the flat teams or distributed flat teams inherently reduces the effort in coordinating the tasks, giving functional teams an advantage in performance.

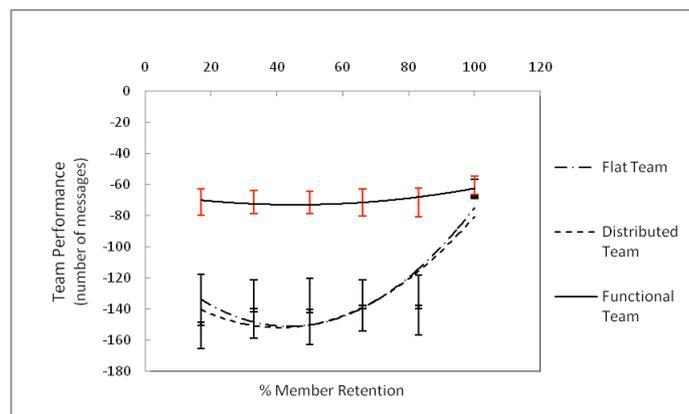


Figure 5. Effects of membership retention and team structure on team performance

In summary, team performance is higher if the teams are organized as functional teams, Figure 6, while TMM formation is higher in flat teams, Figure 7. For the same amount of TMM formation, teams in a flat structure will not perform as well as teams in a functional structure because of the larger search space for task coordination in flat teams. These results indicate, that although TMM quality and team performance are correlated [29], there is another effect of team structure that relates

to the efficiency of TMM formation and its influence on team performance. Efficiency of TMM formation is a new measure introduced in this research to complement the existing measures of TMM quality, which include similarity, accuracy and density (amount) [6] [29].

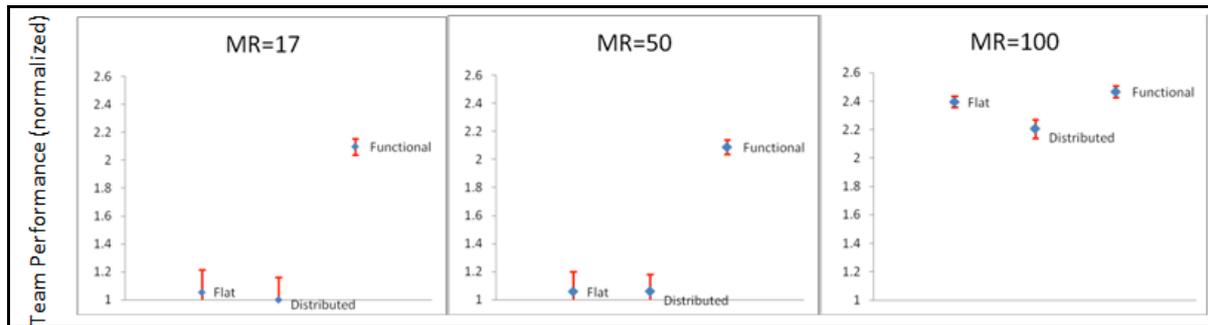


Figure 6. Effects of membership retention (MR) and team structure on team performance

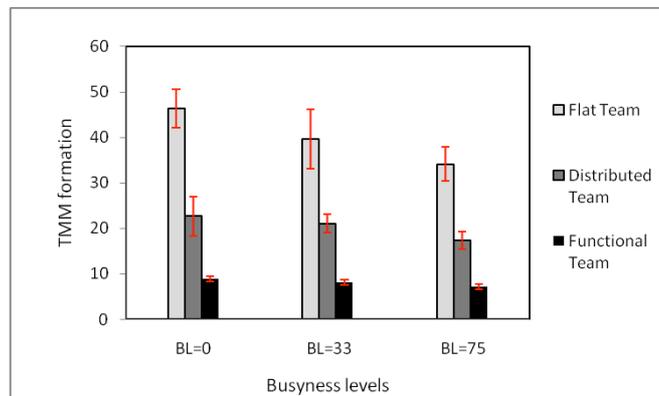


Figure 7. Effects of busyness levels (BL) and team structure on TMM formation

The differences in team performances across the different team structures becomes even more critical if the teams have lower levels of member retention, Figure 6. Thus, if the membership retention is low and team performance in terms of task coordination is the immediate goal, rather than team building, then a functional team structure is recommended. However, if the immediate goal is team building and developing a shared understanding across the team for future projects then flat teams are recommended.

DISCUSSION AND CONCLUSIONS

It may not be possible to develop strategies of teamwork that are equally applicable across all design teams. However, general recommendations and strategies can be applied based on specific project requirements and conditions. The findings reported in this paper are applicable to design teams working on routine tasks, where task coordination is the key performance criterion rather than the creativity or the quality of the design outcomes. Findings suggest that the increase in team performance with the increase in member retention is higher in flat teams compared to functional teams. Thus, in scenarios where team performance is critical but team retention is low (or personnel turnover is higher) functional teams are recommended. In scenarios where team building and TMM formation is the immediate project goal, the team can be initially organized as a flat team and then re-grouped as functional teams in later phases. Results indicate that for the same amount of TMM formation, teams in a flat structure will not perform as well as teams in a functional structure. Thus, the efficiency of TMM formation in enhancing team performance is higher in functional teams. This claim and understanding of the efficiency of TMM formation needs further investigation.

Team members should have higher social learning and observation opportunities, which mean collocated flat teams are more suited for team building projects. In addition, the workload distribution of team members should be managed to ensure sufficient opportunity for them to follow the team activities. Distributed flat teams constrained by other factors can reinforce the social interaction and observation opportunities through technological and communication media where all team

communications, updates and activities are available to all the team members. Therefore, in distributed flat teams, how the team communication is organized and accessed will play a critical role in TMM formation. In functional teams, the lack of social observations and interactions across the task-groups in the functional teams may create silos that are detrimental to the team when measured across other parameters not dealt with in this paper such as cohesion.

To conclude, this paper discusses the effects of team structure on team performance and TMM formation based on simulation studies. The underlying assumptions in the model and the simplifications of the simulation scenarios resulting from controlled parameters need to be considered in interpreting the results.

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