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TEAM-ROLES IN MECHANICAL DESIGN

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ABSTRACT

This paper presents an approach for identifying team-roles. The proposed approach is based on the interpretation of a design process in terms of the behavior of the members of the team. Behavior is codified in terms of the team member's process and physical activities. In this study a collaborative design process was recorded on video-tape and analyzed in detail. The process was decomposed into distinct sections called events. In every event each team member was assigned a team-role taking into consideration the activity of the team member, i.e. what the team member does, how the team member does it, and the context of the event. A graphical representation of the results called 'role-profile' was developed making it possible to clearly identify a basic team-role for every subject in the observed design process.

1 INTRODUCTION

This paper presents the results of a preliminary study intended to identify the roles assumed by engineers in a design team. Understanding these roles has the potential to improve team performance and to teach team building and maintenance methods to engineering students. Researchers have experimented with using the Myers-Briggs personality profile to improve team work understanding and as a teaching tool (Wilde 1994, Ullman 1996). Although effective, this model does not give sufficient insight into the team's activities and results. In this paper another model is explored that has the potential to offer better management and instruction of team activities. The methodology and results show promise, but they are preliminary.

Research begun in the 1970s by Meredith Belbin (Belbin 1981, Belbin 1993) showed that management teams need a mix of certain personalities in order to be productive. His main findings centered around the observation that particular individuals took on particular roles in an effort to maintain a role balance that had a crucial effect on the outcome of the team's activities. Regardless of the functional competency of the team members, a poor role balance produced a poor outcome. The role composition of a team - a subject almost totally neglected by contemporary thought - therefore proved to be of crucial importance.

In a collaborative process team-roles are different from the functional roles of the team members. Functional roles are based on the individual member's technical skills and knowledge. Team-roles on the other hand are based on the personality of the subject and their range of possible behaviors. Each individual on a team play certain roles based on personality.

Belbin identified a finite range of useful behaviors that make an effective contribution to team performance and arranged these behaviors into nine team-roles. In this paper Belbin's team-roles have been re-defined for mechanical design research purposes. The nine team-roles and their respective definitions are listed in Table 1.

Belbin claimed that teams need a mix of all nine possible behaviors in order to be productive regardless of functional expertise. All-star sports teams sometimes perform poorly due to the inability of the stars to play the needed roles to make a winning team (Smith 1993). It is the same with engineering teams.

Hales (1986) also attempted to classify the members of a design team using Belbin's team-roles. He observed an industrial design process over a time span of more than two years and classifying the designers into specific team-roles by means of questionnaires. Hales reported that "Although the questionnaire was completed without adverse reaction by the contract staff, it was regarded with

Table 1 Team-Roles

Team-Role	Definition
Organizer	A reliable person concerned about the practical aspects of the design process
Motivator	A confident person in charge of the schedule and goals of a design team
Pusher	A dynamic person forcing a design team to work faster
Solver	A creative person predominately generating solutions
Gatherer	An extrovert person searching for information and communicating with others outside the team
Listener	A perceptive person perceiving and combining the ideas and statements of others
Completer	A conscientious person eliminating the last flaws of a design
Specialist	A dedicated person with extensive knowledge in a special field
Evaluator	A strategically thinking person concerned about alternative solutions

some suspicion by company staff, and the plans to gather such data for each phase of the project had to be abandoned."

Consequently, in order to learn more about team roles, the study reported on in this paper was undertaken that allowed detailed data to be collected without using a questionnaire. This approach is detailed in the next section.

2 RESEARCH APPROACH

Team-roles are defined as sets of related behaviors. Thus, the primary goal is to identify behaviors that can be used to classify each team member's role. Since roles change over time, one critical issue is the granularity with which a team member shows only one distinct behavior (i.e. the time in which a single behavior will be shown). In this study, the smallest segment of time over which an individual might show a distinct type of activity will be called an event. In order to find the minimum time for an event, four empirical studies of mechanical design (Stauffer 1988, Tang 1989, Dylla 1991, Fricke 1993) are used as a basis. A comparison of the

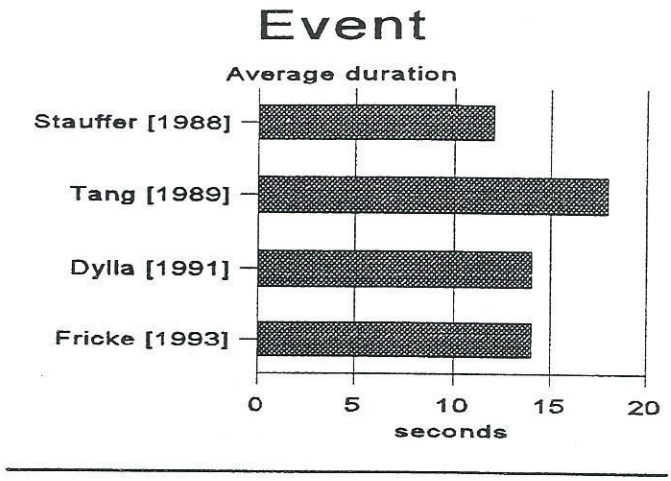

Figure 1 Average Event Duration

average length of time for unique activity in these studies exhibits strong agreement, Figure 1.

Based on the data in Figure 1, designers may change their behavior after a time-span of 15 seconds. A preliminary investigation of team-roles therefore, requires a fine decomposition of the team activity and so, an event will be defined to have a length of 10 sec to insure no information is lost.

Another question to address is how to account for the number of people involved at any one time in the team activities, i.e. the team configuration. A pre-examination of the data described later in the paper allowed researchers to examine of amount of time team members spent working together. At times all three members worked together as a team, at other times they worked as a pair with one member working alone, and sometimes they worked as three members working alone, Figure 2. As shown, all members were working together only 50% of the time. Individual work accounted for 30% of team activity. Team members working alone or in sub-teams play roles that contribute separately to the group process. When two or more team members are working together, one usually plays a more active role and the others are more passive. The configuration of who plays the active role changes from one event to the next reinforcing the need to study fine grained events and the need to assign team-roles within events separately for each person in the design team. The identification of the team-role is based on each team member's behavior. Behavior was identified by examining the team member's problem solving *process activity* (what is being working on), the member's *physical activity* (how it is being worked on it), and the context in which the member is working (why it is being worked on).

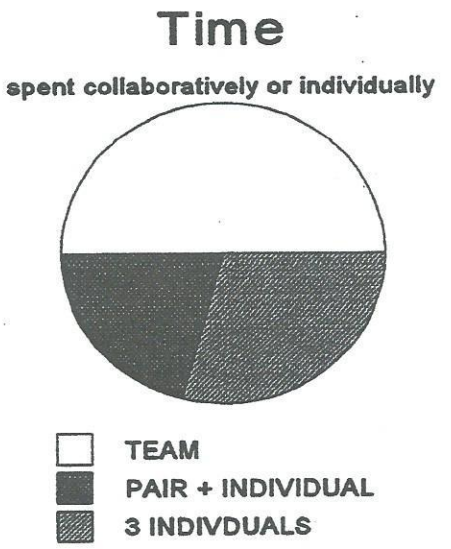

Figure 2 Collaborative and Individual Work

Process activity is defined as what the subject does in an event, i.e. the type of problem-solving effort the subject provides. Hales (1986) classified the different process activities which allowed him to classify every section of the observed process. His classification system consists of 33 different activities. Our study covers only a small part of the design process covered by Hales, only ten of the activities identified by Hales could be observed. These ten are defined in Table 2.

It is important when assigning team-roles to capture the physical activity (the how). Dylla's classification of physical activity, defined in Table 3, was followed. It is worth noting that Dylla considered these "media" however, these types of activities include media and body language (e.g. hand gestures and facial expressions). We have added five physical activity categories to the classification system of Dylla to account for team activities. The additional media categories are listed in Table 4 together with their respective definitions.

Finally, the context of the problem solving activity is important. Context reveals why the team member was working on a particular topic. This activity is dependant on the activities of the others, the knowledge of the team member and other, as yet unknown factors. No clear codification of this measure has been developed. In our study, context was treated subjectively.

The design process was decomposed into 10 second events. During each event, each team-member's behavior was examined separately and classified through process and physical activity,

Table 2 Process Activities

Activity	Definition
Clarifying problem	to analyze the need that has to be addressed
Preparing specification	to elaborate a detailed description of the task
Searching for solutions	to generate solution principles for the various sub-functions of a design problem
Combining principles	to elaborate overall solutions from the combination of solution principles
Evaluating	to measure and compare concept variants
Reporting/ reviewing	to generate and perceive verbal and written project reports
Cost estimating	to estimate design costs, labor costs, hardware costs, ...
Planning work	to plan personal activities day-by-day, to schedule
Information retrieval	to process information of all kinds
Social contact	to interact socially outside other categories

context during the event. As will be discussed later, the logic for classifying the behavior is still being refined.

3 DATA COLLECTION

Data for this study was collected by video-taping a team of three graduate students at Oregon State University. They redesigned the swivel joint of a wall mounted mechanism, a design task used by Dylla (1991), Fricke (1993) and Blessing (1994) in their empirical studies of mechanical design. The particular problem calls for the design of a swivel joint at the base of a column, which carries an optical device. This devise must be able to swivel in two orthogonal directions as defined by angles α and β in Figure 3. The students were given drawings of one possible, yet unsatisfactory solution from Dylla, together with a list of the drawbacks of this specific solution.

Two cameras recorded the design team activities. One stationary camera focused on the workspace used by the three members, the other one was actively focused on individual team members by a camera person. A very important aspect of

Table 3 Physical Activity

Physical Activity	Definition
Writing	to transfer data to an external information storage
Lettering	to supply a sketch or drawing with an inscription
Transferring size relations	to transfer measurements within a view or to another view
Correcting	to correct notes, sketches, and drawings made by one of the members
Searching for information	to investigate external information resources, e.g. reading catalogs
Measuring	to exactly measure by means of a ruler or other measurement equipment
Thinking	no external activity, non-verbal signs give the investigator the impression that the subject is thinking
Calculating	to use a calculator
Illustrating	to illustrate spatial relations, size relations, or movements by means of gestures or other tools
Drawing	to carefully draft an engineering drawing
Sketching	to roughly draft a sketch
Showing	to show something in a sketch or drawing in order to clarify an expression

mechanical design are sketches and drawings made during the process (Ullman 1990). The camera focused on the workspace made it possible to identify by whom, when, and in which context each sketch or other mark-on-paper was made. A back-up audio recording was also made.

Drawing materials, catalogs, a description of the Department workshop and two mechanical engineering handbooks were provided for use by the team members. They were encouraged to ask the experimenters questions at any time. After a brief explanation of the design task, the team members were asked to work together in order to solve the design problem.

Table 4 Additional Team Physical Activities

Physical Activity	Definition
Listening	to perceive a verbal expression of another subject
Observing	to perceive a predominately non-verbal action of another subject
Asking	to express a question verbally
Explaining	to support the understanding of a drawing or sketch by means of verbal explanation
Verbal expression	verbal expressions other than questions or explanations

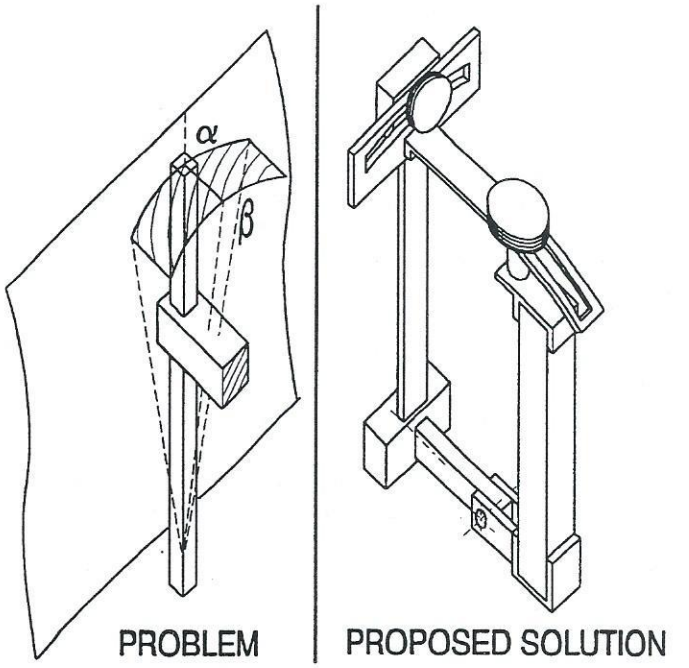

Figure 3 Swivel Mechanism: Problem and Proposed Solution (Dylla 1991)

4 DATA INTERPRETATION

The initial step of the data interpretation was to view the video-tapes and to decompose the session into events. For each subject in each event the process and physical activities were then determined. The design session lasted 1 hour; there were three team members; each event was 10 seconds, giving a total of 1080 events that were classified and entered into a database. Each data record contained information about only one person in one event. The description of an event in which three persons were working together required three separate lines in the data base. This arrangement was necessary in order to assign a team-role for each team member in every event of the design process.

Ten different process activities were observed in the design session. The proportions of work effort spent on these processes is shown in Figure 4. There were a total of 10,800 seconds of data. Table 5 lists the portion of the work effort spent using each type of physical activity.

The data was classified by a single observer viewing and reviewing the video tapes. Generally, because of the subjective nature of this type of data, at least two researchers are used. However, as this was a preliminary experiment, a single observer was deemed sufficient.

Based on the activities of the team members, team-roles were identified using the following logic. If the physical activity was "listening" or "observing", i.e., passive activity, the team-role was defined as "Listener." This "listening" role accounts for 4130 sec or 40% of the total time. If, during the entire project, two of the members listened to and observed the work of the third, this role would account for 67% of the total, so the result of 40% seems reasonable. The remaining classification was based primarily process activity.

If the process activity was "information retrieval" then the subject was either playing the role of a "Gatherer," a "Specialist" or an "Evaluator." The context of the activity was used in making the decision into which class to count the event. If the subject was "searching for solutions," then the role was either "Solver," "Specialist" or "Completer," again depending on context. If the subject was "planning" work then the role was either "Motivator" or "Pusher." A team member who "combined principals" was categorized as an "Organizer" and one who "clarified the problem" was considered a "Gatherer." Finally, if a team member was "reporting/reviewing" his/her own work s/he was classified as a "Solver"; if the activity was focused at another team member's work, s/he was considered an "Organizer." This rule system is still being developed and is subject to questioning. The team-roles for the team as a whole and for each individual were based on this classification.

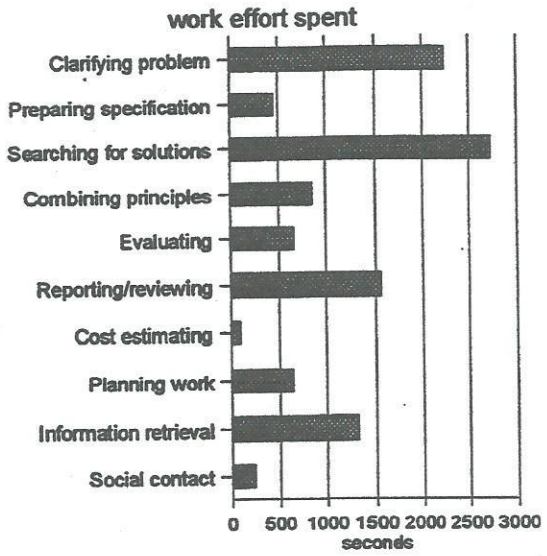

Figure 4 Process Activities

Table 5 Physical Activities

Physical Activity	Work Effort	Physical Activity	Work Effort
Writing	570s	Drawing	0s
Lettering	110s	Sketching	1440s
Transferring size relations	20s	Showing	400s
Correcting	0s	Listening	2570s
Searching for information	1080s	Observing	1560s
Measuring	0s	Asking	750s
Thinking	650s	Explaining	420s
Calculating	0s	Verbal expression	690s
Illustrating	170s		

5 TEAM-ROLES

A team-role is the incorporation of a certain personality necessary in establishing a role-balance within the design team. For the team as a whole (i.e. the sum of all the team member's classification), the amount of work effort spent on the team-roles is shown in Figure 5. Three team-roles "Pusher," "Specialist," and "Completer" were not identified during analysis and thus, are not shown in the figure.

It is conjectured that the team-role "Specialist" did not appear, because the similarity in education of the three team members and because the problem required no special expertise. Likewise, the design session was not long enough for anyone to assume the role of "Completer." The lack of "Pusher" seemed to have had a negative effect on the role-balance because the team was not able to develop a solution within the time-frame. A dynamic "Pusher" might have been able to force the team into accepting a sub-optimum solution.

Although the roles look unbalanced in Figure 5, role-balance does not mean that the same work effort has to be spent incorporating each team-role. A single input from a dynamic "Organizer" can effect the role-balance more than a "Listener" perceiving something for several minutes.

The role of each individual team member is represented as a 'role-profile,' a chart introduced in this paper and shown for each of the team members in Figures 6-8. This profile is determined for each member by calculating the difference between the individual's work effort on each role relative to that of the team as a whole. Thus, in the figures, the bars indicate the work effort spent by one individual above or below the team average.

Subject 1 spent 620 seconds of work effort above the average in the team-role of "Solver." This is obviously the basic team-role of Subject 1. The very small amount of work effort spent by Subject 1 in the team-role of "Gatherer" corresponds to Belbin's perception that a problem solver is usually weak in communicating.

Figure 7 shows the role-profile of Subject 2. The basic team-role of Subject 2 is obviously "Gatherer" because Subject 2 spent 357 seconds above average incorporating this team-role. The time spent by Subject 2 incorporating the team-role "Motivator" is also slightly above average. The extrovert personality of a "Gatherer" is also helpful in motivating the team.

Figure 8 shows the role-profile of Subject 3. The work effort spent by Subject 3 incorporating the team-role "Organizer" was 210 seconds above average. Thus, "Organizer" is obviously the basic team-role of Subject 3. Subject 3 also spent above average work effort in incorporating the team-role "Evaluator," indicating a secondary team-role. Furthermore, Subject 3 is above average in the team-role "Gatherer" indicating that communication is an important part in the repertoire of an "Organizer."

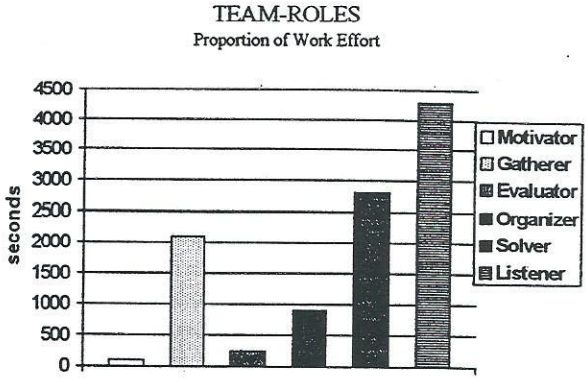

Figure 5 Work Effort Spent on Team-Roles

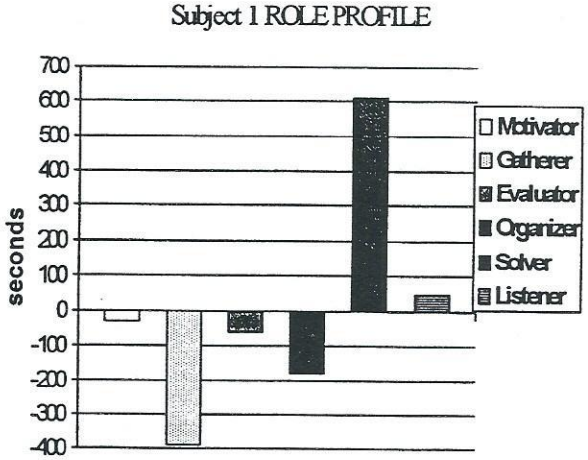

Figure 6 Role Profile for Subject 1

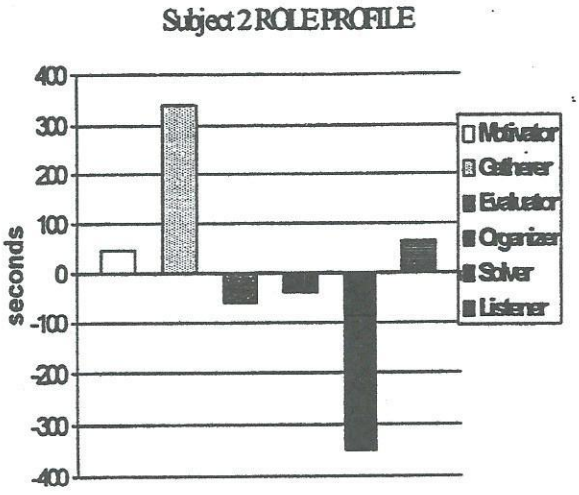

Figure 7 Role-Profile for Subject 2

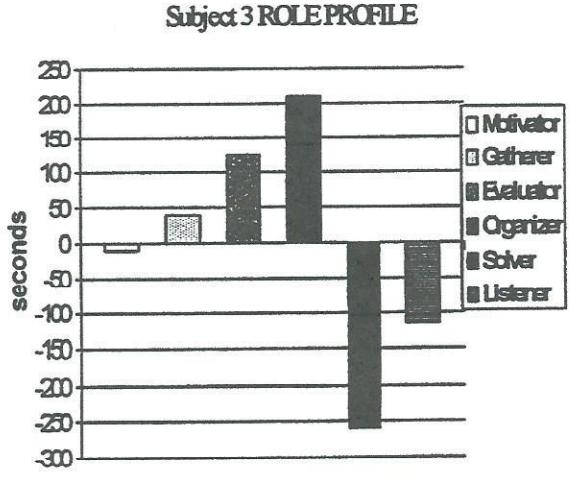

Figure 8 Role Profile for Subject 3

6 SUMMARY AND OUTLOOK

In this paper a method for identifying team-roles in mechanical design was introduced and a graphical representation of the results called 'role-profile' was presented. The approach was applied to a collaborative design session and making possible the clear identity of a basic team-role for each member of the observed design team. These results indicate that the proposed approach for identifying team-roles is suitable for exploring collaborative design. It is important to find easier methods for identifying these roles. To say that the roles are, or should be, obvious to the team members during the design process, may be true to some extent. However, as shown in other cognitive research, team members are seldom aware of their behavior. Further, if team-role was evident to team members, nonfunctional or less than optimum teams would be easily improved.

This investigation serves as a demonstration of the suitability of the proposed approach. More research is needed in order to derive conclusions about the impact of team-roles on design processes and the logic for identifying the roles needs to be refined. Finally, the method of data reduction used to identify the team roles was labor intensive and not suitable for application to sessions larger than that presented here.

Emphasis on teamwork is one of the defining features of the flexible organization of the 1990s (Fowler 1995). The possibility of identifying team-roles and determining the existence or absence of a role-balance within an existing team is important in industry and in engineering education. Teaching students to be aware of their roles and the role balance on a team may be key to insuring successful student team projects.

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