Fuzzy Logic in Team Design

A. Stickley*, B. Grabot**

*TQM Research Engineering Design Centre, City University
Northampton Square, London, EC1V 0 HB, England

**ENIT, Laboratoire Génie de Production BP 1629 - 65016 Tarbes, France

Present team selection do not assure effectiveness. Using existing teams, team profiles can be constructed from interpersonal combinations of member's main intrinsic motivators, called Drivers. With their team effectiveness ratings, these profiles provide a model to aid team design. The uncertainty and imprecision of subjective measures will be reduced by using fuzzy logic and the theory of possibility as a modelling tool.

1. INTRODUCTION

Teamwork is an area of product design and development where there is much interest by industry and academics and a lucrative one for management development consultants. However it is an area which is not well researched. Teams are a variable concept in the reality of industry with little common ground on what constitutes a team, or more precisely what is the composition of an effective team. Team members are chosen primarily on the basis of their availability and skills, and whether someone would make a "good team member" on vague subjective criteria. In the new quality era, functional areas too have to be represented though sometimes restricted to "where appropriate", and there is a growing awareness of the value of including customers, users and suppliers. What passes for good team design is team building or team development using models such as team roles [1], psychological traits [2] or Process Communication [3], and the evidence of any team success is merely a subjective claim or is anecdotal. There has also been no descriptions found so far in the literature of quantitative evaluation methods for the effectiveness of teams, except for that of one of the authors [4], who has developed a Team Effectiveness Rating from research work described in [5].

This paper looks at Team Design from a sound theoretical basis of Transactional Analysis Drivers, a five category system of a person's habitual learned responses and expectations of him- or herself and others [3]. These Drivers form interpersonal compounds, links of underlying understanding or expectations, with the Drivers of all other team members which can be summed and combined to form a Team Profile. This team profile is made unique by assigning it a performance indicator got from the Team Effectiveness Rating questionnaire above which were completed for each team by the team leader, project manager and one other involved manager, preferably a stakeholder in the team's work.

The subjective measures of both an individual's Drivers and the managers' team rating are full of imprecision, ambiguity and uncertainty. This applies also to team composition, which in turn affects the clarity of the Unique Team Profile and its usefulness in prediction of a team's success. Statistics alone does not resolve these problems which lie in the realm of possibility rather than probability. Fuzzy logic can be used as a tool here. The ultimate aim is to develop a model of teams with a prediction of a better chance of success, which can help project managers make decisions on team design from the mix of people available in addition to the other criteria they already use.

2. THE UNIQUE TEAM PROFILE MODEL

A team profile can be constructed as a histogram of interpersonal compounds. An interpersonal compound is a one-to-one link between a "Driver" in one person to a "Driver" in another. A Driver is a complex belief system which can be considered as an habitual unconscious expectation we have of ourselves and others. When a person is being influenced by one of his Drivers, others can observe the behaviour belonging to that Driver, and agree on the category of the Driver. Checklist questionnaires can also be used to determine a person's Drivers [6].

2.1 Drivers

Drivers, are a development of the Transactional Analysis theory of life scripts, "a life plan made in childhood, reinforced by the parents, justified by subsequent events, and culminating in a chosen alternative" [7]. The Drivers are the initial behaviours observed when entering our mini-script, the short-term reinforcement patterns of our life-script. It does not follow that we must always enter completely into the pattern described above. This is important in team building and team development, as well as in the attendant individual member's personal growth, because awareness and recognition of the Drivers in ourselves and others gives us options to remain in a healthy interpersonal cooperative state.

There are five Driver categories here described briefly with their descriptive names.

1. Please Me, (or Be Pleasing), can have warm relations with others, but may at times seem self-centred or manipulative.
2. Be Perfect, (or Be Right), do well in areas of careful reasoning and detail, but can also get bogged down in details instead of working on the important aspects. They can also be highly critical.
3. Be Strong can show responsibility and be cautious, but can also at other times seem slow or withdrawn.
4. Hurry Up can be decisive and dynamic, but can also be impatient and demanding or slow themselves down by making mistakes or having accidents.
5. Try Hard can undertake challenging and important work, but may also make mountains out of molehills, or put more energy into going things our own way rather than in achieving the goal. He can also be rebellious.

The Driver Checklist used in the team investigations was originally developed and validated in [8]. There are two parts to the checklist, the first part (cf. figure 1) required that the individual team member ticked the list along with someone else who knew him well, and was willing to be frank. He added his ticks as he perceived the individual whether there was agreement or not. This was to help overcome the

problem in self-reporting since someone else can often be more aware of our habits than ourselves. None or all of the nine elements in each driver section may be ticked. The second part was a one choice tick out of five concerns that the individual had himself and which he filled out on his own.

DRIVER CHECKLIST

1. BE PLEASING 1. smile or laugh a lot when I am talking to someone 2. leave when things go wrong instead of facing them now 3. nod my head when I talk or say "You Know?" 4. dress skilfully to show my own special style 5. laugh to smooth things over when I am a little nervous 6. say nice things before asking for something 7. act cheerful to cover my bad feelings 8. automatically give first priority to others 9. am usually restless when I am by myself. 2. BE RIGHT (PERFECT) 1. point out the mistakes of others, or challenge them to justify 2. am often quite early 3. tidy up and put away, or don't use a clean waste bin 4. move with a very erect posture 5. criticise what people think or do 6. collect, or display, interesting things or information 7. get things just exactly right 8. show, or hide, a lot over what is not very important 9. do not trust others to do things well enough 3. BE STRONG 1. am outwardly calm even when upset 2. consider long before deciding 3. think how to do without things 4. carry around more than I need 5. make the best of a bad situation for much too long	6. do things for others that they should do for themselves 7. am extra cautious 8. use my face to hide my feelings 9. can be physically uncomfortable a long time and not notice 4. HURRY UP 1. hurry when it does not matter 2. do not get around to buying clothes 3. say "Are you ready? Let's go", and leave quickly when I start 4. tap my fingers, wiggle my feet, or jiggle my knees up and down 5. do too much too fast 6. bump into people or things 7. interrupt to hurry people along, or start leaving before they finish 8. pace back and forth while waiting 9. walk fast, eat fast, or talk fast 5. TRY HARD 1. have trouble finishing 2. realise that I have done it the hard way 3. tell myself that this time I will do it right, and then don't 4. have difficulty with things that go smoothly for others 5. don't get around to important things for too long 6. ease off and delay when I get close to finishing 7. have many things disorganised, or let dirty dishes accumulate 8. am sometimes quite late, or do not get there at all 9. delay too long before starting

Figure 1. Driver Checklist

Results have shown that this second part may not be reliable in all cases in our present organisational culture. Hazell's data were from volunteers. The Team Design research data came from teams within UK engineering industry, with projects managers administering the questionnaires. Individuals were not necessarily volunteers, nor committed. This methodology was an unavoidable reality, and may have led to confidentiality issues. Some discrepancies between the two parts were noticed and investigated which showed there were mismatches. For that reason the second part results are not being used at present.

Scoring was two points for numbers 1, 3 and 5, and one for the others.

2.2 Team Profiles

Although we all show aspects of all five drivers, usually only two are considered important to us. This intrapersonal pair forms links, interpersonal compounds, with all of the other team members, each team pair forming four links of underlying understanding, or perhaps misunderstanding. Two people with similar main Drivers are considered to have a better chance of understanding each other and work

together because they have the same expectations. Dissimilar drivers may or may not have the same effect. The absence of a main interpersonal compound of similar Drivers, for example "Be Right - Be Right", would make an unbalanced team, with less chance of being effective. A team of five is the minimum number in this model needed to avoid the certainty of a missing main interpersonal compound, although it remains possible with larger teams.

For a team of five, there are ten member pairs making a total of forty compounds, and a team of nine thirty-six pairs and one hundred and forty-four compounds. It is the distribution of these interpersonal compounds into the possible fifteen that makes up the team profile histogram. An example is given in figure 2 of an existing team.

Figure 2. Team Profile

Some individual's results showed close scores in the second and third top drivers. In order to take this into account, and to address the imprecision inherent in a subjective questionnaire, the one line team profile was changed into a band. This was achieved by adding (-1) to the two top drivers and (+1) to the others for the whole team and recompiling the team profile. This profile was the overlaid onto the original.

However, only considering the two top drivers means that much information is ignored.

A. End Results Rating (very poor, poor, fair, good, very good)

1 technical success	2 on time performance	3 on-budget performance
4 commitment and results orientation	5 innovation and creativity	6 concern for quality
7 willingness to change	8 ability to predict trends	9 involvement and energy
10 capacity to resolve conflict	11 communications effectiveness	12 team spirit/cooperation
13 mutual trust	14 membership self-development	15 interface effectiveness
16 high achievement needs		

B. B. Team aspects during Project Elements (very poor, poor, fair, good, very good)

1 clear objectives	2 sufficient resources	3 no recurring power struggles & conflict
4 involved management	5 job security	6 clear goals and priorities
7 interesting work	8 recognition	9 experienced manager
10 good direction and leadership	11 qualified team personnel	12 professional growth

Figure 3. Team Performance Rating Questionnaire

2.3 Performance Evaluation

In order to make a unique team profile, a Team Performance Rating checklist was used (cf. figure 3). This checklist was constructed from [7]. The first sixteen elements are result- and people-oriented measures of project performance which are correlated with the twelve enhancers and barriers to team effectiveness within

the team itself. Enhancers (B. nos 7-12) are used here to avoid confusion with their term drivers and Transactional Analysis Drivers. In constructing the checklist Thamhain's original barriers have been changed to their opposite to maintain a consistent rating scale.

An overall figure was obtained by addition of all the elements from the three managers who rated the team, taking their mean and expressing that value as a percentage of the possible total. This value was then plotted on the right hand side scale of the Unique Team Profile, and the previous profile aligned to it by the mean of the interpersonal pairs. This allows different teams to be compared graphically for patterns.

3. IMPROVEMENTS OF THE MODELS THROUGH FUZZY LOGIC AND THEORY OF POSSIBILITY

As pointed out in the previous section, there is a need for modelling tools in order:

- i) to take into account more than two drivers if their evaluations are close, and
- ii) to express the possible inconsistencies between the various sources of the performance evaluation.

Fuzzy sets and the theory of Possibility allow us to model both the imprecision and uncertainty of information, and can be used either to avoid threshold effects, or to express the consistency between data. The principles of these tools are shortly described in the next part, and their use in the case of team profiles and team performance evaluation is then described.

3.1 Fuzzy sets and the theory of Possibility

The membership of an element u to a fuzzy set is not expressed through a binary value (0 or 1) but through a value $\mu(u) \in [0,1]$ [9]. Such a set is then completely described by its membership function μ that associates to each element of the set its membership degree. A proposition that contains imprecise aspects can be modelled by a fuzzy set by mean of the choice of an attribute, and of an evaluation scale of this attribute. In that way, a proposition such as "John is young" can be translated by "John belongs to the set of the young persons".

Let us assume that John is 28 years old and that its membership degree to the set of the young people is 0.5. The postulate of the theory of Possibility is that the membership degree of John to the fuzzy set of the young people can be interpreted as the possibility that John is 28 years old, knowing that "John is young" [10]. The membership function μ is in that case considered as a distribution of possibilities.

With a unique formalism, it is then possible to express imprecision (through membership functions) and uncertainty (through distributions of possibilities).

3.2 Application of the theory of possibility to the team profile

Consider a team of four members (denoted A, B, C, D) as an example (teams usually have 7 ± 2 members) and the evaluation of their respective Drivers given by the table of figure 4.

The choice of two main drivers for each person raises some problems for A, because drivers III and IV are very close, and for D because II and IV are equals. Let us consider the table of figure 6, where each line has been divided by the value of the maximum driver of the line. Each number can be considered as the possibility that the corresponding driver is the main one for a person. The possibility that a

link exists between two main drivers can then be expressed by the minimum of the possibility degrees of the two drivers considered. In fact, it is not necessary to take into account all the drivers, and a threshold can be chosen in order to eliminate the lowest ones.

		DRIVERS				
		I	II	III	IV	V
TEAM MEMBERS	A	9	3	6	5	2
	B	6	6	4	3	3
	C	1	1	7	5	1
	D	3	6	7	6	3

Figure 4. Evaluation of the Drivers members of a team

	I	II	III	IV	V
A	1	0.33	0.66	0.55	0.22
B	1	1	0.66	0.5	0.5
C	0.14	0.14	1	0.71	0.14
D	0.42	0.85	1	0.85	0.42

Figure 5. Possibility that a driver is the main one

Let us consider that it is not worth taking into account the influence of a driver below a possibility degree of 0.5. The possibility of links between main drivers is shown on figure 6 with the original models number of links on the left hand side (same driver part links, e.g. IIxII are multiplied by 2 to adjust for combination counting):

Number of links (original model)	Interpersonal Pairs	Possibility links
2	IxI	1
3	IxII	1,0.85,0.85
5	IxIII	1,1,1,1,0.66,0.66
2	IxIV	0.85,0.85,0.71,0.71,0.55
0	IxV	0
2	IIxII	0.85
5	IIxIII	1,1,0.85,0.66,0.66,0.66
2	IIxIV	0.85,0.71,0.71,0.55
0	IIxV	0
6	IIIxIII	1,0.66,0.66,0.66,0.66,0.66
2	IIIxIV	0.85,0.71,0.66,0.66,0.66,0.66,0.55,0.55,0.55
0	IIIxV	0
0	IVxIV	0.71,0.55,0.55
0	IVxV	0
0	VxV	0

Figure 6. Possibility of links between main Drivers

These degrees of possibility define a discrete distribution of possibility on the number of links between drivers, e.g. the distribution of possibility of the number of links between driver II and driver III which is illustrated in figure 7 where the discrete distribution of possibility is represented as continuous in order to be easier to understand. The interpretation is then the following: it is entirely possible that there are two links IIxIII (possibility=1), another link is possible with a degree of 0.85, and three other are possible with a degree of 0.66.

The possibility distributions of the links can be expressed in the team profile using the thickness of the bars for the degree of possibility of the number of links, as shown in figure 8, and the team profile becomes in that way the summary of the possibility distributions of links between drivers. This profile is much more informative than the standard one, which is indicated in the same figure in grey when the drivers II and III are chosen for D.

Figure 7. Distribution of possibility of the number of links between two drivers.

We can see, for example, on figure 8 that the link IIIxIV is possibly much more important in this team than the link IIIxIII, on the point of view of the number of possible links, because the distribution of possibilities take into account the third or the fourth drivers of the members of the team if their score is large enough. The link IVxIV, which does not appear in the bargraph, is now present here with a maximum degree of possibility of 0.71.

Since the effect of threshold in the choice of the main drivers is attenuated, the possibility distributions described here take into account much more information than previously, and in a more synthetic way.

3.3 Application to the performance evaluation

The evaluation of the performance of the team raises the problem of the combination of information concerning the same datum, coming from different sources. The association of a note to a linguistic appreciation, and the calculation of the mean of the three evaluations is clearly not a satisfying answer. This problem can be shown by these two examples:

- the technical success of a project is considered as "fair" by the three sources that we consider here. The average result of the evaluation corresponds then to the note associated to "fair".
- the technical success is considered as "poor" by the first source, "fair" by the second, "good" by the third. As in the first case, the global evaluation is the note corresponding to the "fair" appreciation.

Figure 8. Team profile using possibility distributions

It is possible, thanks to the theory of possibility, that two different appreciations can be partially consistent if they are close. Figure 9 shows a classical way to model

linguistic appreciations on a numerical scale. The degree of overlapping of the triangles models the partial consistence of two consecutive appreciations. If several appreciations concerning the same information are available from different sources, two cases may arise [11]:

- the appreciation of the sources are partially or totally consistent. They can then be aggregated through an operation such as:

$\pi_{12} = \frac{\pi_1 * \pi_2}{\sup(\pi_1 * \pi_2)}$ where π_1 and π_2 are the possibility distributions of the appreciations of respectively source 1 and source 2, and * an operation of intersection of two fuzzy sets like the minimum. The division by $\sup(\pi_1 * \pi_2)$ is used here in order to normalise the resulting distribution of possibility. This normalisation is justified by the consistency of the sources.

- If the appreciations are not consistent, it is possible to combine the two distributions of possibility through a union operator, but the association of a notation to this combined distribution (for example through the calculation of the centre of mass of the shapes) has the same inconvenience as the calculation of the mean when a precise note is associated to the linguistic appreciation.

Figure 11. Fuzzy models of linguistic appreciations

Figure 12. Fuzzy models chosen

It is possible to solve the problem of the inconsistency by the choice of possibility distributions all having a certain degree of consistency, like the ones of figure 10. Consider two sources with respective appreciations of "poor" and "good". The hachured shape shows the combination of the appreciations through the min operator. The centre of mass of the resulting shape gives the notation that combined the two sources (here 5), while the high of the resulting possibility distribution can be considered as a measure of the consistence between the two appreciation (here 0.64). In that way, it is possible to have a notation on the result of the project, but also a measure of the reliability of this result.

The problem is a little bit more difficult in the case of more than two sources, because the combination of two identical appreciations would give the same possibility distribution. In order to show that the same appreciation from different sources reinforce the precision of the appreciation, we have used as a convention that:

- when one source gives an appreciation, it is modelled by the corresponding possibility distribution as described in figure 9. All the triangles have the [0,10] interval as a base. Figure 11 gives an example for the "good" appreciation, described by the possibility distribution noted (1) if only one source gives this appreciation.
 - if two sources agree on an appreciation, the base of the triangle that describes the corresponding possibility distribution is divided by two, which corresponds to a decrease of the uncertainty on the "real" appreciation. The possibility distribution corresponding to "good" given by two sources is noted (2) in figure 11.

- if the three sources agree on an appreciation, the corresponding possibility distribution is transformed to a precise number, e.g. a possibility of 1 for the centre of mass of the shape, and 0 everywhere else (noted (3) in figure 11).

Figure 11. Reinforcement of an appreciation

Figure 12. Example of combination

In figure 14, the hachured shape represents for example the combination of an appreciation of "good" by two sources, and "fair" by the other one. The resulting notation is 5.9, which is the abscissa of the gravity centre of the hachured shape, with a possibility of 0.74 which is the height of the shape.

4. FUTURE RESEARCH

We have now the tools which are necessary in order:

- to model the main characteristics of a team, through the team profile,
- to evaluate the project which have been realised by a team.

Teams need a consistent method of evaluation otherwise their selection will remain subjective and their success anecdotal. "What gets' measured, gets improved". Similarly teams need a measurable profile such as the one described here and which is a robust research unit. This work has so far given a stable platform for which to proceed. Further work will latest be needed to be done to refine and investigate both the Driver Questionnaires and the Team Profile Questionnaire.

The collection of data is now in progress in various companies. The next step of our study will be then to correlate the team profile to the performance evaluation in order to be able to select a team with the expected performance. Three methods will be tested in order to make this correlation:

- design of experiment. The goal of the design of experiment method is to obtain the best tuning of parameters without exhaustive tests. In order to do so, experimental models are designed; they allow a mathematical estimation of the effects of each parameter independently from the others through the definition of orthogonal arrays [12],
- design of an expert system, if it is possible to translate the expertise between the links between drivers and the performance of the project,
- use of a neural network, if a sufficient number of results are available. The main characteristics of neural networks is that they allow to constitute a knowledge base on a problem on the unique base of some experiments, while it is necessary to have a precise idea on the causal links between inputs and outputs in order to design an expert system. These three methods have for example been tested on the problem of the tuning of scheduling parameters in [13], with the conclusion that the neural

network approach is very interesting when strong expertise is not available on the problem, but when a lot of experiments can be made.

5. CONCLUSION

Effective teams need to be defined and evaluated. The teams here are defined in terms of the combination of our main Drivers or internal motivations, and the evaluation of each team is by a Team Rating by three managers. The uncertainty and imprecision of subjective measures is reduced by using fuzzy logic methodology, and is being applied to the data being collected.

Project Managers will have to pay some attention to Team Design rather than development in the new lean production quality paradigm, especially where there is a model to use. This will also encourage them to collect their own data to refine their own team compositions, and help the shift to a cooperative culture by being able to assess teams rather than individuals. The aim is to increase the efficiency and productivity of a team through better design.

REFERENCES

1. M. Belbin, *Management Teams: Why They Succeed or Fail*, Heineman, London, (1981).
2. R. Lewis, P. Lowe, *Individual Excellence*, Kogan Page, London, (1992).
3. T. Kahler, *Process Communication Model*, Little Rock, USA, T. Kahler Ass., (1979).
4. A. Stickley, *Team Design for effective projects*, 2nd International Conference on Concurrent Engineering and Electronic Design Automation, Bournemouth, Dorset, UK, April 7-8, (1994).
5. H. Thamhain, D. Wilemon, *Building High Performing Engineering Project Teams*, IEEE Transactions on Engineering Management, EM-34 N°3, pp.130-137, (1987).
6. W. Falkowski, K. Munn, *Interrater Agreement on Driver Questionnaire Items*, Transactional Analysis Journal, N°19, vol. 1, (1989).
7. E. Berne, *What do you say after you say hello?*, Corgi Books, (1988).
8. J. Hazell, *Drivers as mediators of Stress Response*, Transactional Analysis Journal, vol.19, N°4, (1989).
9. L. Zadeh, *Fuzzy Sets*, Information and Control, N°8, (1965).
10. L. Zadeh, *Fuzzy Sets as a basis for a theory of Possibility*, Fuzzy Sets and Systems, N°1, (1978).
11. D. Dubois, H. Prade, *Possibility Theory, an Approach to Computerized Processing of Uncertainty*, Plenum Press, New York, (1988).
12. G. Taguchi, *System of Experimental Design*, Unipub/Kraus International Publication, (1987).
13. B. Grabot, L. Geneste, A. Dupeux, *Multi-heuristic scheduling: three approaches to tune compromises*, to be published in the Journal of Intelligent Manufacturing, (1994).