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Human resource allocation management in multiple projects using sociometric techniques

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Abstract

This article describes a new application of key psychological concepts in the area of Sociometry for the selection of workers within organizations in which projects are developed. The project manager can use a new procedure to determine which individuals should be chosen from a given pool of resources and how to combine them into one or several simultaneous groups/projects in order to assure the highest possible overall work efficiency from the standpoint of social interaction. The optimization process was carried out by means of matrix calculations performed using a computer or even manually, and based on a number of new ratios generated ad-hoc and composed on the basis of indices frequently used in Sociometry.

Keywords: Sociometry; Team composition; Quantitative methods; Groups; Optimization; Cohesion

1. Introduction

A Team can be defined as a social system of three or more people, which is embedded in an organisation (context), whose members perceive themselves as such and are perceived as members by others (identity), and who collaborate on a common task (teamwork) (Aldefer, 1987; Guzzo and Shea, 1992; Hackman, 1987; Wiendieck, 1992).

The domains of organisational behavior and industrial and organisational (I/O) psychology have served as the principal caretakers of team research and, over the last decade, have made considerable strides in advancing knowledge on team functioning (Hollenbeck et al., 2004). The literature on Human Resource Management (HRM) has focused more closely on the individual members of work teams (Campion et al., 1993) HRM's adoption of team-level phenomena is beginning to occur in the scientific domain but is lagging in the field of practice (Baiden and Price, 2011; Hollenbeck et al., 2004; Zwikael and Unger-Aviram, 2010), especially in project-oriented companies (Huemann et al., 2007).

Empirical research on the management of multiple projects in the project manager level is still rare and well behind its rate of utilization in the industry (Patanakul and Milosevic, 2009). Besides, the problem is that recent research is peppered with examples of nonintuitive, and sometimes counterintuitive, findings about how best to compose teams, train them, and combine their individual members' contributions (Hollenbeck et al., 2004; Maurer, 2010; Zwikael and Unger-Aviram, 2010).

Recent scientific research has shown that the Group's success or failure is often dependent on the interdependence between a group's teamworking skills, its integration, trust and

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the technical skills of each of its members (Baiden and Price, 2011; Campion et al., 1993; Chansler et al., 2003; Maurer, 2010).

Additionally an appropriate level of cohesion is necessary for a team to stay together, collaborate, and thus to build the basis for high team work quality (Hoegl and Gemuenden, 2001).

Generally, technical competence is the attribute most commonly studied in the literature on team design, particularly with regard to characterizing tasks and team members (Fitzpatrick and Askin, 2005; Hadj-Hamou and Caillaud, 2004; Hlaoittinun, et al., 2007; Tsai et al., 2003; Tseng et al., 2004; Zakarian and Kusiak, 1999). However, Social identity theory suggests that the more members identify with their respective groups, the more likely they are to actively contribute to the welfare of the group and work toward common goals (Maurer, 2010). Indeed, empirical research indicates that members of these groups display higher affective commitment and have higher unit performance than groups with low perceived cohesion (Andrews et al., 2008).

In this paper it has been posited that a team's outcome depends heavily on how individuals develop their social ties and group interactions. Thus, if it were possible to maximize several groups' cohesion joining certain team members, selecting them from a pool of resources whose social ties are known (both positives and negatives), an optimum outcome should be expected whenever technical skills are fulfilled beforehand by the individuals. An 'optimum outcome' is referred to the best performance possible taking into account the circumstances and quality, quantity and social bonds between group members. For this, a case study is examined and a calculation procedure is established in order to give an example and to illustrate how the proposal can be used in any other team formation situation from the standpoint of social interaction.

So far, several studies proposed tools and techniques for scarce resource allocation, which include integer programming, heuristic methods, queuing theory, fuzzy optimization by genetic algorithms, fuzzy linear programming, etc. (Dean et al., 1992; Hendriks et al., 1999; Morse et al., 1996; Tong and Tam, 2003; Wu, 2007). However, these techniques were proposed for a use in the functional level, so they usually tend to generate organisational conflict between project managers and functional managers (Laslo and Goldberg, 2008). Besides, they may not be applicable to an operational-level for a multiple-project manager to allocate resources across his/her projects (Patanakul and Milosevic, 2009). A new approach is going to be proposed trying to maximise group cohesion while solving these other problems.

2. Group cohesion

The concept of group cohesion has been extensively studied in the field of sociology. (Eisenberg, 2007). Group cohesion is defined as the degree to which group members feel accepted or rejected by each other (Beal et al., 2003) or the degree to which the members of a group desire to remain in the group (Cartwright, 1968).

Groups may be more or less cohesive and the force keeping the group united may vary over time and be different from one group to another.

The integration of members of a group in a work team depends on the following (Baiden and Price, 2011; Piper et al., 1983): team identity, shared vision, communication, collaboration and participation, issue negotiation and resolution; reflection and self-assessment (Dwivedula and Bredillet, 2010). Therefore, a team's outcome depends heavily on how individuals develop their social ties and group interactions (Zwikael and Unger-Aviram, 2010).

The project manager manages the human resources available to achieve the objectives of the organisation (Asquin et al., 2009; Chiocchio et al., 2010; Ferrin et al., 2007; Zwikael and Unger-Aviram, 2010). Human capital is the essential component of the organisation and depending on whether there is a proper combination of employees, assignment of tasks, trust and motivation, very different results will be achieved (Maurer, 2010). This, as mentioned, is an important responsibility of project managers.

Some studies indicate that cohesion generally has a positive influence, significantly increasing the following (Dwivedula and Bredillet, 2010; Piper et al., 1983) : attraction to the group; degree of motivation; morale; compliance with group norms; coordination of efforts; synergy; resources available for the task; productivity; effectiveness in achieving objectives; number of positive and cordial interactions; cooperation; and satisfaction with the group.

On the other hand, cohesion can be influenced (or sometimes even conditioned positively or negatively) by factors such as compatibility of character, culture, gender, ethnicity and needs among group members.

Cohesion can be assessed through various methods (Campion et al., 1993):

- Sociometric tests or sociometric choice tests
- Work environment studies
- Analysis of motivations
- Analysis of interactions; study of quality and frequency

The first of these four methods is a quantitative method which provides a large amount of factual information, and consequently, it has been used in this study.

3. Sociometry and sociometric matrix

Sociometry, a method created by Jacob Levy Moreno, studies the structure of groups through the web of interpersonal relationships that occur within it (Moreno, 1961). Sociometry conceives the human being as possessing infinite creativity and spontaneity, and as being born, growing and dying in a social context (Bezanilla and Miranda, 2008).

The sociometric test (Moreno, 1961) is the instrument used by sociometry to understand the basic structures of relationships within the group. Each group member chooses or rejects other people as mates.

Differences in personality can greatly affect individual behaviour and thus, group performance within the organisation (Chen and Lin, 2004; Dwivedula & Bredillet, 2010). A true appreciation of the nature of personality differences allows project managers to manage effectively, thereby enhancing the individual and group performance of the their subordinate units (Asquin et al., 2009; Gordon et al., 1990). However, sociometry does not address how and why social interactions occur among individuals but rather quantifies them, characterises their distribution and even represents them, for which purpose the sociogram is used.

In addition, the Sociometric test describes various aspects in a particular group (Moreno, 1961): informal structure; communication system; leadership; and possible formation of subgroups, pairs and trios.

Other separate data can also be analysed from the results obtained using a sociometric test (Moreno, 1961): Number of personal choices made; Number of personal choices received; Number of mutual or reciprocal choices; Number of choices within a group; Number of negative choices or rejections made; Number of personal negative choices or rejections received; Number of mutual or reciprocal negative choices or rejections; and Number of negative choices or rejections within a group.

The results of sociometric research can be represented graphically (sociogram), but also as an array, which is henceforth to be used for matrix optimization purposes to form work groups. One example of Sociometric matrix will be shown later in Table 1.

In Table 1's cells: a +1 means a "Choice", a −1 means a "Rejection" and a blank or a 0 mean an Omission, made by the individuals of the left column in regard to individuals displayed in the heading row.

Note that the matrix need not be symmetric, since any member can choose another group member, but in turn, the latter member may choose to reject the former.

The degree of cohesion can be observed through indicators, such as the total number of choices made within a Group or the number of mutual choices. The number of choices received by each individual also provides important information, for example, in relation to leadership.

Group members are classified by the number of choices and rejections received, yielding four types of sociometric individuals (Moreno, 1961):

- *Popular individuals or leaders:* receive a large number of choices and a low or normal number of rejections
- *Average:* obtain an average degree of acceptance, and medium-low rejection.
- *Forgotten, ignored or isolated:* have low acceptance and also medium-low rejection.
- *Rejected, excluded or marginalized:* with a high degree of rejection and medium-low acceptance.

Table 1
Sociometric matrix of DAM's case study.

Interviewed▼	Chosen►						
	A1	A2	A3	B1	B2	C1	D1
A1	0	1	−1	0	1	0	0
A2	−1	0	−1	0	1	1	1
A3	0	0	0	1	−1	−1	−1
B1	1	1	1	0	1	0	0
B2	−1	−1	1	0	0	1	1
C1	0	1	−1	1	0	0	0
D1	0	−1	−1	1	1	0	0

This classification is obtained using the following *Individual Sociometric Indices* (Moreno, 1961):

Popularity or positive status: number of choices received/(n − 1). It represents the proportion of members who choose the subject in proportion to the full number of possible choices (n − 1), where n is the total number of group members.
Antipathy or negative status: number of rejections received/(n − 1). Proportion of members who reject the subject to the full number of possible rejections.
Positive expansiveness: number of choices made/(n − 1). Proportion of members who are chosen by the subject.
Negative expansiveness: number of rejections made/(n − 1). Proportion of members who are rejected by the subject.
Positive reciprocity: number of reciprocal choices.
Negative reciprocity: number of reciprocal rejections.

Nevertheless, there are also *Global Sociometric Indices* (Moreno, 1961), three of them are:

Cohesion or association: number of reciprocal choices/possible number of reciprocal choices. It is the proportion of positive reciprocity.
Dissociation: number of reciprocal rejections/possible number of reciprocal rejections. It is the proportion of negative reciprocity.
Social intensity: (Total number of choices + Total number of rejections)/(n − 1).

There is a widespread fundamental proposition that the success of the work performed by a team depends, beyond the amount and accuracy of the design of work activities, on how well the members cooperate or interact (Hoegl and Gemuenden, 2001). Most of the sociometric indices shown describe the quality of the internal interactions of a group at the individual level and on the level of the group as a whole.

4. Case study

The sociometric test detects the "social atoms" built by each individual and their social network, consisting of the choices made and received by this person; by contrast, it is unable to detect the causes that have led to a specific social structure (Moreno, 1941).

The method developed in this paper aims to form multiple work teams from a group of individuals in order to make them as efficient as possible, and numerically quantifies this efficiency from the standpoint of expected social interaction. However, social interactions are never to be observed in silos:

while an individual working on a project may experience interactions with other team members in that project team, he/she may also be influenced by the interactions of other members in other project teams (even if there is no face-face interaction). Therefore, the method proposed later represents a new line in the application of sociometry and the artificial forming of work groups, since it addresses the kind of issues mentioned above.

The method was tried out in a private company ('Depuración de Aguas del Mediterráneo' or DAM hereinafter) devoted to design, construction, exploitation and maintenance of big Waste Water Treatment Plants, most of them located in Spain.

DAM is a medium-sized company which currently employs more than two hundred and fifty people, most of them either technicians and/or engineers. DAM's personnel are organised on the basis of a matrix type where different company's departments exist vertically (construction, exploitation, maintenance, R&D, quality, accounting and management) and each project/contract the company develops co-exists horizontally (for instance, each WWTP awarded usually constitutes a single project).

The method was applied to the allocation of human resources in 12 new WWTP construction projects and monitor their performance. Projects ranged from about 30.000 € to 120.000 € while their duration were from 1 to 5 months. Each new project required from one-person-dedication (though this may mean 50% of two workers' time or 100% of one person's dedication) to seven people's dedication, depending mainly on its importance, strategic value, time available and/or contract budget.

For the purpose of this study, four out of the twelve projects carried out have been picked out to show how the sociometric algorithm was implemented. Thus, the scenario has been strongly simplified in order to keep it as simple as possible, especially for facilitating understanding. Nevertheless, the core of the problem has been kept intact so the usefulness of the Sociometric application is shown as well.

The fact of implementing sociometric tools was the vehicle that enabled the company to rationalize the selection and allocation process of human resources. In fact the new sociometric method developed allowed measurement (from −1 to +1) of the expected Efficiency of each group selected to work together, as long as to increase the overall Efficiency, considering several projects as a whole.

Next, it will be illustrated that the whole process of assigning employees as efficiently as possible, as it was approximately implemented in DAM. Nevertheless, the explanations will be given as if they were addressed to any company with the same problems. Therefore, from now on, DAM's case will be considered just like a generic Company.

4.1. Problem formulation

Take a company that develops projects of any nature. Such a company, whose organisational structure can range from a matrix type organisation to an organic type organisation operating exclusively from the basis of project development, is composed of different individuals each belonging to an area of expertise or to a functional department.

Also, assume that a project manager of this company who is responsible for managing several projects at the same time (or Multiple-project Manager) and who is empowered to choose his staff from the available employees in the company, is required to implement a number of projects that will add value to the company.

Assuming that all the employees available to the project manager have the same technical level and sufficient skills and knowledge to carry out the tasks required, the aim of this case study is to develop a human resources combination method enabling the project manager to select individuals to form work (project) groups with the highest possible overall efficiency.

Interpersonal relationships between the different employees considered as human resources are quite varied: positive, negative, and in other cases, neutral or non-existent. This problem will be solved using classic sociometric techniques combined with the calculation of matrix optimisation.

4.2. Nomenclature

Prior to solving this problem and for clarification purposes, the nomenclatures of the indices which will represent the various elements to be studied are as follows:

$i = 1, 2, 3, \ldots, n_i$ is each employee (resource pool) within the same area of expertise or functional department. Seven people were used ($n_i = 7$), there were more people but they was not available at that moment.

$j = A, B, C, \ldots, n_j$ are each of the areas of knowledge or functional departments of the company for which the manager is required to maximize the benefits derived from their projects. In this case study, there were four departments ($n_j = 4$): Construction (A), with three people; Exploitation (B), with two people; Maintenance (C), with one person; and R&D (D), with one person as well.

$k = 1, 2, 3, \ldots, n_k$ are each of the subgroups (from one or more employees who belong to one or several functional departments of the company) to be formed corresponding to the different projects which must be developed by the company and managed by the manager; in principle, at the same time. In our case, four simultaneous projects ($n_k = 4$) were developed: G_1, G_2, G_3 and G_4.

4.3. Sociometric data collection

Assume that the project manager has the results of a relatively recent sociometric test describing the social interactions between the available staff.

If this were not the case, just as happened in DAM, it would be necessary to create such test. Literature on how to collect data regarding on the manner in which to implement sociometric techniques in professional settings is scarce. However, one such case was studied in depth (Jones, 2001). In the present case, where confidentiality is ensured throughout the process of collecting the data and its subsequent use, the approach would be as simple as asking each employee two questions:

1. Which workmates would you like to form a work team with?
2. Which workmates wouldn't you like to work with together in a team?

The sociometric matrix can then be made from the responses to the two previous questions, in which each of the employees has classified his relationship with his workmates as: positive (+1), i.e. those chosen in question 1; negative (−1), i.e., those chosen in question 2; or neutral or ignored (0), i.e. those not named in response to either of the two questions.

The most recommendable way to obtain recent and accurate data, especially in order to identify all the negative interactions, is to survey or interview each member of a work group or project in respect of their workmates when their work has been completed. In this survey or interview each individual is required to privately assess the work performance and results of each of his workmates.

If the manager were ultimately to lack such data and were to consider the possibility of obtaining it easily to be unlikely, it would be advantageous to speak to the other peer project managers to attempt to infer an approximate sociometric matrix, i.e. to attempt to subjectively classify the relationships between subordinates according to their project managers. Obviously, this method would be much less accurate.

4.4. Pool of resources

As was previously stated, this study illustrates the process of assigning seven people (A_1, A_2, and A_3; B_1 and B_2; C_1; and D_1) from four different departments (A, B, C and D) to four different and simultaneous projects (G_1, G_2, G_3 and G_4). These data with the up-to-date sociometric tests made possible the sociometric matrix (S) graphed in Table 1. Note that the left column represents the employees interviewed and the top row represents the employees whom the interviewed individuals want or do not want to work with.

Although not strictly necessary for the subsequent mathematical calculations, the main group sociometric indices Cohesion and Dissociation have been calculated, for the purpose of obtaining an improved description of the example group as a whole (see Table 2).

Where:

n_i the number of individuals making up the full group available (sum of all employees from all departments, $n_i = 7$ in this case)

NC is the total Number of Choices (17 in this case, see Table 1).

NRC is the Number of Reciprocal Choices (3 in this case, see Table 1 or under the diagonal in Table 2).

NRC_{max} is the maximum number of possible reciprocal choices. It can be directly calculated from n as: $n*(n-1)/2$ (21 in this case).

Table 2
Calculation of the main group sociometric indices of DAM's pool of resources' case study.

	A1	A2	A3	B1	B2	C1	D1
A1	–	0	0	0	0	0	0
A2	0	–	0	0	0	0	0
A3	0	0	–	0	0	1	1
B1	0	0	1	–	0	0	0
B2	0	0	0	0	–	0	0
C1	0	1	0	0	0	–	0
D1	0	0	0	0	1	0	–
ni =	7	NRR =	2	NRRmax =	21	Dissociation =	0.10
ni =	7	NRC =	3	NRCmax =	21	Cohesion =	0.14

NR is the total Number of Rejections (11 in this case, see Table 1).

NRR is the Number of Reciprocal Rejections (2 in this case, see Table 1 or above the diagonal in Table 2).

NRR_{max} is the maximum number of possible reciprocal rejections. Its value is always the same as NRC_{max} (21 in this case).

Group sociometric indices:

- Cohesion: calculated as NRC/NRC_{max}. Its range of values is between 0 and 1.
- Dissociation: calculated as NRR/NRR_{max}. Its range of values is between 0 and 1.
- Social intensity, calculated as $(NC+NR)/(n-1)$. Its range of values is between 0 and n.

The reciprocal rejections are represented above the diagonal and the reciprocal choices are represented under the diagonal in Table 2. Social intensity" is calculated by adding together the absolute value of the cells of the sociometric matrix (S), which amount to around 28, (sum of choices and rejections) divided by "n − 1", which equals 4.

Generally, the values of cohesion, dissociation and social intensity are low, i.e. the least cohesive, although no major hostilities are evidenced. The group of available resources does not yet appear to have achieved a stable structure. This coincided with the fact that three out of the seven group members had a seniority of less than 3 months when the Sociometric algorithm was implemented in DAM.

4.5. Projects to be developed

The company needed to develop four projects. First it would be necessary to define how many and what kind of experts each project needs.

The project manager in charge of the supervision of the four projects estimated that the following generic staff would be required for each project:

- Project G_1: would require a group formed by 1 A_i, 1 B_i and 1 C_i
- Project G_2: would require a group formed by 1 A_i and 0.5 D_i

- Project G_3: would require a group formed by 0.5 A_i, 0.5 B_i and 0.5 D_i
- Project G_4: would require a group formed by 0.5 A_i and 0.5 B_i

As observed, given the specific needs of each project, part-time employees are allowed.

Now it would be necessary for the project manager to assign each individual to the group where he will most contribute to the development of the project, thereby maximizing overall work efficiency and complying with the self imposed staff restrictions for each project in terms of number of employees and area of expertise or department. For instance, the random assignment of staff set in Table 3 would meet the staff requirements for each project, but we would still know nothing about his real suitability.

4.6. Calculation of Group efficiency and Overall Group efficiency

Hereon, the process described will exemplify and generalize a staff allocation procedure for forming groups to work on projects meant to maximise good social relationships (grouping together similar members) and minimise bad social relationships (not joining together antagonistic members in the same work groups).

Before implementing the calculation algorithm and in order to verify that the above distribution of employees (or any other) is the most ideal, an index must be designed for measuring the “Overall Efficiency” (E_G) of the different combinations of employees for each specific Group/Project.

One possibility would be to work simultaneously with cohesion and dissociation indices, but this would require comparing two values whose fluctuations are relatively independent. Therefore, it is to the author’s understanding that it is preferable to create a new index which will be called “Efficiency” and which will be calculated in this way for each group/project, taking into account positively any choice (made or received) and negatively any rejection (also made or received), rather than only reciprocal choices and rejections (as Cohesion and Dissociation are calculated).

Then, the Efficiency of a particular the group/project “k” (E_{Gk}) will be calculated as follows:

$$E_{Gk}=\frac{NC_k-NR_k}{n_{ik}} \quad (1)$$

Table 3
Random assignment of staff to the projects which were developed in the company DAM.

	G1	G2	G3	G4	Total
A1	1				1
A2		1			1
A3			0.5	0.5	1
B1			0.5	0.5	1
B2	1				1
C1	1				1
D1		0.5	0.5		1

Where:

n_{ik} the number of individuals composing group/project “k”

NC_k Number of Choices made or received between all members included in group/project “k”.

NR_k Number of Rejections made or received between all members included in group/project “k”.

And after calculating E_{Gk} for all groups/projects (in this case, four values for projects G_1, G_2, G_3 and G_4 are calculated), the Overall Efficiency (E_G) for the whole of the groups/projects is the weighted sum thereof:

$$E_G = \sum_{k=1}^{n_k} E_{Gk} \cdot W_{Gk} \text{ with } \sum_{k=1}^{n_k} W_{Gk} = 1 \quad (2)$$

Where W_{Gk} is the weight (importance or priority) of each group/project.

To assign weights (W_{Gk}) to each project, one or several criteria can be used. For example:

- Mathematical calculation of the W_{Gk} coefficients based on the ratio of employees assigned to each project “k” divided by the total staff available “n_i” (in our case $n_i=7$). This is the criteria used in the case study and mathematically is expressed as:

$$W_{Gk}=\frac{n_{ik}}{n_i} \quad (3)$$

- Mathematical calculation based on the investment budget for each project or the ratio of expected economic returns to the total amounts.
- Subjective assignment of weights based on the importance of each project/group, which depends on the specific strategy of the company or the restrictions of the economic, legal and social environment, etc.

In this case, the above calculations yielded the following results in Table 4.

In Appendix A, a detailed breakdown of the calculation of $E_{Gk.}$ coefficients is shown.

Table 4
Calculation of Groups’ Efficiency (E_{Gk}) and Overall Efficiency (E_G) based on the random assignment of staff (according to Table 3) to the projects to be developed in the case study.

	G1	G2	G3	G4	Total
A1	1				1
A2		1			1
A3			0.5	0.5	1
B1			0.5	0.5	1
B2	1				1
C1	1				1
D1		0.5	0.5		1
n_{ik}	3	1.5	1.5	1	7
W_{Gk}	0.43	0.21	0.21	0.14	1
E_{Gk} (Appendix A)	0.17	0.00	0.00	0.00	EG=▼
$E_{Gk}*W_{Gk}$	0.07	0.00	0.00	0.00	0.07

The Global Efficiency (E_G) of the chosen combination is equal to 0.07 (the E_G can range between −1 and +1). To assure that this combination of employees would be the most ideal, no other combination could have a higher E_G.

4.7. Calculation of the Expansiveness and Status of the resources

The positive or negative contribution of any of the individuals in the sociometric matrix (Table 1), i.e., the amount of choices and rejections made and received, are calculated based on which of these employees will finally be fellow members in each work group/project. However, to facilitate the optimization calculations, it is necessary to create an index that describes, although generally, how much a group member from the group in full (the whole pool of resources available) contributes to Overall Efficiency.

This index, which will be called "Personal Contribution of the individual i" (C_i), is calculated based on four of the standard individual sociometric indices (Positive expansiveness, Negative expansiveness, Positive status and Negative status) previously described taking into consideration the "n_i" members of the sociometric matrix in full.

$$C_i = \frac{\text{Expansiveness}^{+} - \text{Expansiveness}^{-} + \text{Status}^{+} - \text{Status}^{-}}{2} \quad (3a)$$

This index can also be mathematically expressed more simply using the following equation:

$$C_i = \frac{NCm_i - NRm_i + NCr_i - NRr_i}{2(n_i - 1)} \quad (3b)$$

Where $n_i = 7$ in every calculation and:

NCm_i Number of choices made by individual/employee i.
NRm_i Number of rejections made by individual/employee i.
NCr_i Number of choices received by individual/employee i.
NRr_i Number of rejections received by individual/employee i.

C_i will have values between −1 and +1, and, the higher the positive value, the greater the positive Contribution (a priori expected) made by this individual "i" on his/her future group/project. On the contrary, an individual with high negative values will be seen as "toxic" to group health as a whole, and as an individual who will decrease the value of Group efficiency (E_G) whenever he/she is not sub-combined with other sympathizer co-workers (if they exist) and kept away from non-sympathizer co-workers.

Continuing with this example, the positive expansiveness, positive status, negative expansiveness and negative status of all the members of the matrix were first calculated according to what was exposed in Section 3 (see Individual Sociometric Indices):

Finally, for each group member, the positive expansiveness and status were added together, the negative expansiveness and status were subtracted and then, the sum was divided by 2 (according to Eq. (3a)) to obtain the Contribution Indices (C_i) of all the members.

The whole calculation procedure is shown in Table 5:

In the "Ranking" column, the individuals have been be ranked by department/area of knowledge (A, B, C and D) for assignment to the different groups/projects (G_1, G_2, G_3 and G_4) to the extent that they contribute a greater positive environment to the group in full, that is, depending on how high its C_i-value is.

Finally, the last column of Table 5 represents the Sociometric roles of each group member according to their positive and negative status (see types of sociometric individuals).

4.8. Results

In the case of the example, if the individuals are assigned in order from highest to lowest project weight "W_{Gk}" (assignment order: G_1, G_2, G_3 and G_4), and group members from highest to lowest C_i-values (area/department assignment order A: A_2, A_1 and A_3 ; area/department B: B_1 and B_2 ; areas/departments C and D only have one individual so there is no need to rank them) the results are as follows:

Appendix B shows the calculations of the coefficients $E_{Gk.}$

It can be observed that the Overall Efficiency value (E_G) rose from 0.07 (from the first distribution proposed) to 0.29 (the current value shown in Table 6). In this case, the combination finally shown is the most optimal of all the possible combinations, based on the resources and their good and bad relationships, and based on the staffing needs specified by the project managers for each of its groups/projects.

The solution is optimal given that neither of the two exception situations described later in Section 5.2 arise. In any other case, this fact should be checked.

If the restrictions set by the project manager are respected, any combination of the available team members will not lead to an Overall Efficiency exceeding 29%.

The worst possible Overall Efficiency (very poor combination) where staff is distributed in another manner among the groups proposed in the example problem is −2% (this distribution of staff is shown in Table 7). This result is given when the previously described optimisation criteria is applied in reverse order, that is, assigning individuals from lowest to highest C_i-values to Groups/Projects from highest to lowest weight "W_{Gk}".

Appendix C shoes the detailed calculations of the E_{Gk} coefficients.

These results indicate that the possible combinations of staff, taking into account the restrictions of the case study, allow the groups as a whole to work with Efficiencies ranging from −2% to +29%, which is a noticeable enough difference to be sufficiently analysed.

5. General calculation process

5.1. Computer and manual calculations

A computer application can be programmed to make these calculations. This application will take into account the staff assignment restrictions imposed by the project manager for each group/project and will calculate all the possible permutations in a matrix similar to that of Section 4.6 and Appendix A.

However, if calculations are done manually, a simple calculation process enabling an optimal solution or the solution coming closest to being optimal has to be established.

Table 5
Calculations of Positive and Negative Expansiveness, Positive and Negative Status Contribution Indices of each group member available as a resource in the case study.

Choices	A1	A2	A3	B1	B2	C1	D1	NCm i	Expansiv. +
A1	0	1	0	0	1	0	0	2	0,33
A2	0	0	0	0	1	1	1	3	0,50
A3	0	0	0	1	0	0	0	1	0,17
B1	1	1	1	0	1	0	0	4	0,67
B2	0	0	1	0	0	1	1	3	0,50
C1	0	1	0	1	0	0	0	2	0,33
D1	0	0	0	1	1	0	0	2	0,33
NCr i	1	3	2	3	4	2	2		
Status +	0,17	0,50	0,33	0,50	0,67	0,33	0,33	*n* =	7

Rejections	A1	A2	A3	B1	B2	C1	D1	NRm i	Expansiv. -
A1	0	0	1	0	0	0	0	1	0,17
A2	1	0	1	0	0	0	0	2	0,33
A3	0	0	0	0	1	1	1	3	0,50
B1	0	0	0	0	0	0	0	0	0,00
B2	1	1	0	0	0	0	0	2	0,33
C1	0	0	1	0	0	0	0	1	0,17
D1	0	1	1	0	0	0	0	2	0,33
NRr i	2	2	4	0	1	1	1		
Status -	0,33	0,33	0,67	0,00	0,17	0,17	0,17	*n* =	7

Group member	Expansiv. +	Expansiv. -	Status +	Status -	Ci	Ranking	Sociom. Role
A1	0,33	0,17	0,17	0,33	0,00	2	Forgotten
A2	0,50	0,33	0,50	0,33	0,17	1	Average
A3	0,17	0,50	0,33	0,67	*-0,34*	3	Rejected
B1	0,67	0,00	0,50	0,00	0,58	1	Average
B2	0,50	0,33	0,67	0,17	0,33	2	Leader
C1	0,33	0,17	0,33	0,17	0,16	1	Average
D1	0,33	0,33	0,33	0,17	0,08	1	Average

Manually calculating the large number of permutations whose calculations are needed in groups with many members and/or many areas of expertise or departments, is impossible.

For informational purposes, it should be noted that the number of permutations possible in the example being used for the 4 groups/projects to be generated is 7. However, the number of permutations depends to a large extent on how much you want the assignment to be divided among part-time employees.

Recent research has shown that companies have problems setting multi-role assignments to workers that usually lead to role conflict in multi-project environments, causing, among others, job dissatisfaction (Turner et al., 2008).

Generally speaking, assignments of less than 33% are not recommended since this would affect the performance of the employee who would have too many projects at the same time. However, where it is accepted that based on the percent of work

Table 6
Optimal solution. Calculation of Groups' (E_{Gk}) and Overall Efficiency (E_G) based on the assignment of staff to the projects to be developed in the case study according to their assignment in decreasing order of Contribution Coefficients (C_i) and decreasing order of Weight factors (W_{Gk}).

	G1	G2	G3	G4	Total
A1		1			1
A2	1				1
A3			0.5	0.5	1
B1	1				1
B2			0.5	0.5	1
C1	1				1
D1		0.5	0.5		1
n_{ik}	3	1.5	1.5	1	7
W_{Gk}	0.43	0.21	0.21	0.14	1
E_{Gk} (Appendix B)	0.67	0.00	0.00	0.00	EG = ▼
$E_{Gk} * W_{Gk}$	0.29	0.00	0.00	0.00	0.29

Table 7
Very poor solution. Calculation of groups' (E_{Gk}) and overall Efficiency (E_G) based on the assignment of staff to projects to be developed in the case study where individuals are assigned in increasing order of Contribution Coefficients (C_i) and decreasing order of Weight factors (W_{Gk}).

	G1	G2	G3	G4	Total
A1		1			1
A2			0.5	0.5	1
A3	1				1
B1			0.5	0.5	1
B2	1				1
C1	1				1
D1		0.5	0.5		1
n_{ik}	3	1.5	1.5	1	7
W_{Gk}	0.43	0.21	0.21	0.14	1
E_{Gk} (Appendix C)	0.17	0.00	0.17	0.13	EG = ▼
$E_{Gk} * W_{Gk}$	0.07	0.00	0.04	0.02	−0.02

assigned to an employee, he can be assigned to different projects at the same time, the number of permutations skyrockets.

Returning to the example first referred to in Section 4.4, to find or limit the optimal solution easily by means of manual calculations (without a computer), the following work process should be performed:

1. The different groups/projects are first ranked from highest to lowest Weight (W_{Gk}), and the staff assigned to the most important group/projects and who contribute to the highest extent to the E_G are analyzed. In the example provided, the groups are already ranked in this order (from G_1 to G_4).
2. Within each group/project, the group members who meet the staffing requirements established by the project manager will be assigned in descending order of Contribution (C_i) until all posts are filled.

This procedure does NOT ensure that the result is optimal in all cases, especially in large groups where independent sub-groups may be formed, but it does ensure that the solution found is likely to be very close, with a very low number of calculations.

The above statement is based on the following fact: the Contribution indices (C_i) used to determine the assignment of human resources is of an overall nature for the group in full, meaning that it is calculated independently and prior to forming subgroups.

5.2. Observations on the calculation process

As mentioned above, if the simple calculation procedure is performed, not all the possible individual permutations are assessed and the most optimal solution may not be achieved. Obtaining a solution which is not optimal only occurs in two possible cases, and in both cases the groups would consist of a very large number of individuals:

Exception 1:

The case in which certain individuals all have high C_i, and they are assigned to work together in/on the same group/project but they do not happen to get along together.

Exception 2:

The case in which some individuals have low C_i, but they all work well together in/on a certain group/project. If they are assigned to different subgroups and in accordance with the manual calculation procedure they all end up in different groups/projects, the only possible combination that would increase Group and Overall Efficiency, i.e. having them work together, is lost.

It was pointed out that these two cases only occur in large groups, i.e. with many individuals. The rationale is that in these groups, the effects on the Contribution indices (C_i) leading to these "closed" groups (since they accept each other but reject everyone else) is diluted given their low weight in relation to the overall number of individuals.

On the other hand, the first exception can be minimised by verifying an additional item that does lead to a significant increase in the calculation weight: " The efficiencies of each group/project (E_{Gk}) should decrease to the extent that the groups/projects have a lower weight (W_{Gk}) or importance. If not, something similar to what happens in the case of exception 1 is likely to occur.

Exception 1 usually has the greatest effect on overall efficiency (E_G) since it occurs in groups/projects with greater importance (higher W_{Gk}), meaning that their eviction is a priority.

Regarding exception 2, this is only possible to discretely analyse in groups/projects with lower Efficiencies (E_{Gk}) by observing whether certain of the members divide themselves into a "closed" group such as the one described. The latter is a complex task given the number of individuals the groups have with many available resources.

Consequently, for very large groups it is proposed that a computer programming calculation procedure be used in which the Overall Efficiencies of all the possible permutations are obtained.

6. Discussion

The calculation procedure shown develops a new way of understanding classical Sociometry, as this is one of the first occasions Sociometry is put into practice in business issues and the first time that it has been used as a proactive tool.

This method enables any project manager to make better decisions when it comes to objectively deciding which human resources will perform better, from the standpoint of social interaction, if joining them with some other individuals from a given pool of resources. That this is probably the easiest way of getting the sociometric data required and the fact that the calculations may also be done by hand are two additional advantages of this proposal.

The broad spectrum this procedure is subject to be implemented in is the same as the Sociometry itself, since it applies exactly the same theoretical principles. If there is a possibility of choosing among different potential members to form one or several teams, the method described will be valid, and then, in a given social context and only from the standpoint of social interaction, an optimal outcome should be expected.

Furthermore, there is one more condition that must be fulfilled: the project manager must, as a first step, select which individuals are able to meet the requirements each project has (whether these be legal, technical or experience requirements, etc.). Once eligible individuals are identified, the project manager can apply the sociometric method explained with those particular members. If this is not so, teamwork might be compromised. For this reason technical requirements and capabilities will have to be reviewed before making the final decision of which resources to use.

Finally, despite the simplified case study shown in this paper, the algorithm described can be applied with functional departments broken down by other criteria, for instance, by groups of members with different experience or expertise levels. In that case, each group subdivision will have to be treated as a completely new independent group, from which it is possible to draw resources. These kinds of subdivisions can help when it comes to fulfilling specific technical requirements of the staff to be selected for different projects. Nevertheless, this aspect does not change the method at all, aside from increasing the number of groups and decreasing the possible permutations since the number of potential possible individuals per group is narrower.

7. Conclusions

By implementing classic sociometric techniques and seeking both to maximize positive group interactions and to minimize negative group interactions, a novel mathematical calculation procedure was developed to assure that, given the need to assign staff to different work groups or projects from a team of available human resources, their combination will be as efficient as possible from the standpoint of social interaction.

A computer application can be programmed to calculate all the possible matrix permutations, but a manual calculation procedure is proposed which is considered to be satisfactory enough and can be used by any project manager, in small and medium-sized groups.

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Appendix A

Partial calculations of the E_{Gk} coefficients of the proposed initial random combination of employees for their assignment to the four groups/projects.

G 1		A 1	A 2	A 3	B 1	B 2	C 1	D 1	E Gi1
	Assignment	1	0	0	0	1	1	0	
A 1	1	0	0	0	0	1	0	0	0,50
A 2	0	0	0	0	0	0	0	0	0,00
A 3	0	0	0	0	0	0	0	0	0,00
B 1	0	0	0	0	0	0	0	0	0,00
B 2	1	-1	0	0	0	0	1	0	0,00
C 1	1	0	0	0	0	0	0	0	0,00
D 1	0	0	0	0	0	0	0	0	0,00
ni1 =	3							EG1 =	0,17
								W G1 =	0,43
G 2		A 1	A 2	A 3	B 1	B 2	C 1	D 1	E Gi2
	Assignment	0	1	0	0	0	0	0,5	
A 1	0	0	0	0	0	0	0	0	0,00
A 2	1	0	0	0	0	0	0	0,5	0,25
A 3	0	0	0	0	0	0	0	0	0,00
B 1	0	0	0	0	0	0	0	0	0,00
B 2	0	0	0	0	0	0	0	0	0,00
C 1	0	0	0	0	0	0	0	0	0,00
D 1	0,5	0	-0,5	0	0	0	0	0	-0,25
ni2 =	1,5							EG2 =	0,00
								W G2 =	0,21
G 3		A 1	A 2	A 3	B 1	B 2	C 1	D 1	E Gi3
	Assignment	0	0	0,5	0,5	0	0	0,5	
A 1	0	0	0	0	0	0	0	0	0,00
A 2	0	0	0	0	0	0	0	0	0,00
A 3	0,5	0	0	0	0,25	0	0	-0,25	0,00
B 1	0,5	0	0	0,25	0	0	0	0	0,13
B 2	0	0	0	0	0	0	0	0	0,00
C 1	0	0	0	0	0	0	0	0	0,00
D 1	0,5	0	0	-0,25	0,25	0	0	0	0,00
ni3 =	1,5							EG3 =	0,08
								W G3 =	0,21
G 4		A 1	A 2	A 3	B 1	B 2	C 1	D 1	E Gi4
	Assignment	0	0	0,5	0,5	0	0	0	
A 1	0	0	0	0	0	0	0	0	0,00
A 2	0	0	0	0	0	0	0	0	0,00
A 3	0,5	0	0	0	0,25	0	0	0	0,13
B 1	0,5	0	0	0,25	0	0	0	0	0,13
B 2	0	0	0	0	0	0	0	0	0,00
C 1	0	0	0	0	0	0	0	0	0,00
D 1	0	0	0	0	0	0	0	0	0,00
n i4 =	1							EG4 =	0,25
								W G4 =	0,14

Each E_{Gik} value (right column) are calculated as the sum of its immediate horizontal values divided into '$n_{ik}-1$'. Then, each E_{Gk} value is calculated as the sum of all its respective E_{Gik} values and dividing them into 'n_{ik}'. Appendices B and C are calculated in the same way.

Appendix B

Partial calculations of the E_{Gk} coefficients of the proposed optimal combination of employees for their assignment to the four groups/projects.

G1	Assignment	A1	A2	A3	B1	B2	C1	D1	EGi1
		0	1	0	1	0	1	0	
A1	0	0	0	0	0	0	0	0	0,00
A2	1	0	0	0	0	0	1	0	0,50
A3	0	0	0	0	0	0	0	0	0,00
B1	1	0	1	0	0	0	0	0	0,50
B2	0	0	0	0	0	0	0	0	0,00
C1	1	0	1	0	1	0	0	0	1,00
D1	0	0	0	0	0	0	0	0	0,00
ni1 =	3							**EG1 =**	**0,67**
								WG1 =	**0,43**

G2	Assignment	A1	A2	A3	B1	B2	C1	D1	EGi2
		1	0	0	0	0	0	0,5	
A1	1	0	0	0	0	0	0	0	0,00
A2	0	0	0	0	0	0	0	0	0,00
A3	0	0	0	0	0	0	0	0	0,00
B1	0	0	0	0	0	0	0	0	0,00
B2	0	0	0	0	0	0	0	0	0,00
C1	0	0	0	0	0	0	0	0	0,00
D1	0,5	0	0	0	0	0	0	0	0,00
ni2 =	1,5							**EG2 =**	**0,00**
								WG2 =	**0,21**

G3	Assignment	A1	A2	A3	B1	B2	C1	D1	EGi3
		0	0	0,5	0	0,5	0	0,5	
A1	0	0	0	0	0	0	0	0	0,00
A2	0	0	0	0	0	0	0	0	0,00
A3	0,5	0	0	0	0	-0,25	0	-0,25	-0,25
B1	0	0	0	0	0	0	0	0	0,00
B2	0,5	0	0	0,25	0	0	0	0,25	0,25
C1	0	0	0	0	0	0	0	0	0,00
D1	0,5	0	0	-0,25	0	0,25	0	0	0,00
ni3 =	1,5							**EG3 =**	**0,00**
								WG3 =	**0,21**

G4	Assignment	A1	A2	A3	B1	B2	C1	D1	EGi4
		0	0	0,5	0	0,5	0	0	
A1	0	0	0	0	0	0	0	0	0,00
A2	0	0	0	0	0	0	0	0	0,00
A3	0,5	0	0	0	0	-0,25	0	0	-0,13
B1	0	0	0	0	0	0	0	0	0,00
B2	0,5	0	0	0,25	0	0	0	0	0,13
C1	0	0	0	0	0	0	0	0	0,00
D1	0	0	0	0	0	0	0	0	0,00
ni4 =	1							**EG4 =**	**0,00**
								WG4 =	**0,14**

Appendix C

Partial calculations of the E_{Gk} coefficients of the proposed poor combination of employees for their assignment to the four groups/projects.

G1		A1	A2	A3	B1	B2	C1	D1	E_{Gi1}
	Assignment	0	0	1	0	1	1	0	
A1	0	0	0	0	0	0	0	0	0,00
A2	0	0	0	0	0	0	0	0	0,00
A3	1	0	0	0	0	-1	-1	0	-1,00
B1	0	0	0	0	0	0	0	0	0,00
B2	1	0	0	1	0	0	1	0	1,00
C1	1	0	0	-1	0	0	0	0	-0,50
D1	0	0	0	0	0	0	0	0	0,00
ni1 =	3							E_{G1} =	-0,17
								W_{G1} =	0,43

G2		A1	A2	A3	B1	B2	C1	D1	E_{Gi2}
	Assignment	1	0	0	0	0	0	0,5	
A1	1	0	0	0	0	0	0	0	0,00
A2	0	0	0	0	0	0	0	0	0,00
A3	0	0	0	0	0	0	0	0	0,00
B1	0	0	0	0	0	0	0	0	0,00
B2	0	0	0	0	0	0	0	0	0,00
C1	0	0	0	0	0	0	0	0	0,00
D1	0,5	0	0	0	0	0	0	0	0,00
ni2 =	1,5							E_{G2} =	0,00
								W_{G2} =	0,21

G3		A1	A2	A3	B1	B2	C1	D1	E_{Gi3}
	Assignment	0	0,5	0	0,5	0	0	0,5	
A1	0	0	0	0	0	0	0	0	0,00
A2	0,5	0	0	0	0	0	0	0,25	0,13
A3	0	0	0	0	0	0	0	0	0,00
B1	0,5	0	0,25	0	0	0	0	0	0,13
B2	0	0	0	0	0	0	0	0	0,00
C1	0	0	0	0	0	0	0	0	0,00
D1	0,5	0	-0,25	0	0,25	0	0	0	0,00
ni3 =	1,5							E_{G3} =	0,17
								W_{G3} =	0,21

G4		A1	A2	A3	B1	B2	C1	D1	E_{Gi4}
	Assignment	0	0,5	0	0,5	0	0	0	
A1	0	0	0	0	0	0	0	0	0,00
A2	0,5	0	0	0	0	0	0	0	0,00
A3	0	0	0	0	0	0	0	0	0,00
B1	0,5	0	0,25	0	0	0	0	0	0,13
B2	0	0	0	0	0	0	0	0	0,00
C1	0	0	0	0	0	0	0	0	0,00
D1	0	0	0	0	0	0	0	0	0,00
ni4 =	1							E_{G4} =	0,13
								W_{G4} =	0,14

References

Aldefer, C.P., 1987. An intergroup perspective on group dynamics. In: Lorsch, J.W. (Ed.), Handbook of organizational behavior. Prentice-Hall, Englewood Cliffs. NJ, pp. 190–222.

Andrews, M.C., Kacmar, K.M., Blakely, G.L., Bucklew, N.S., 2008. Group cohesion as an enhancement to the justice—affective commitment relationship. Group & Organization Management 33 (6), 736–755.

Asquin, A., Garel, G., Picq, T., 2009. When project-based management causes distress at work. International Journal of Project Management 28 (2), 166–172.

Baiden, B.K., Price, A.D.F., 2011. The effect of integration on project delivery team effectiveness. International Journal of Project Management 29 (2), 129–136.

Beal, D.J., Cohen, R., Burke, M.J., McLendon, C.L., 2003. Cohesion and performance in groups: a meta-analytic clarification of construct relation. Journal of Applied Psychology 88, 989–1004.

Bezanilla, J.M., Miranda, A., 2008. Validez del método sociométrico. Alternativas en psicología. Segunda época, Año XIII, Número 19.

Campion, M.A., Medsker, G.J., Higgs, A.C., 1993. Relations between work group characteristics and effectiveness: implications for designing effective work groups. Personnel Psychology 46, 823–847.

Cartwright, D., 1968. The nature of group cohesiveness, In: Cartwright, D., Zander, A. (Eds.), Group Dynamics: Research and Theory, 3rd ed. Tavistock Publications, London U.K, pp. 91–109.

Chansler, P.A., Swamidass, P.M., Cammann, C., 2003. Self-Managing Work Teams. An empirical study of Group Cohesiveness in ”Natural Work

Groups" at a Harley-Davidson Motor Company Plant. Small Group Research 34 (1), 101–120.

Chen, S.J., Lin, L., 2004. Modelling team member characteristics for the formation of a multifunctional team in concurrent engineering. IEEE Transactions on Engineering Management 51, 111–124.

Chiocchio, F., Beaulieu, G., Boudrias, J.B., Rousseau, V., Aubé, C., Morin, E.M., 2010. The Project Involvement Index, psychological distress, and psychological well-being: Comparing workers from projectized and non-projectized organizations. International Journal of Project Management 28 (3), 201–211.

Dean, B.V., Denzler, D.R., Watkins, J.J., 1992. Multiproject staff scheduling with variable resource constraints. IEEE Transactions on Engineering Management 39, 59–72.

Dwivedula, R., Bredillet, C.N., 2010. Profiling work motivation of project workers. International Journal of Project Management 28 (2), 158–165.

Eisenberg, J., 2007. Group Cohesiveness. In: Baumeister, R.F., Vohs, K.D. (Eds.), Encyclopaedia of Social Psychology. Sage, Thousand Oaks, CA, pp. 386–388.

Ferrin, D.L., Bligh, M.C., Kohles, J.C., 2007. Can i trust you to trust me? Group & Organization Management 32 (4), 465–499.

Fitzpatrick, E.L., Askin, R.G., 2005. Forming effective worker teams with multi-functional skill requirements. Journal of Computers & Industrial Engineering. 48, 593–608.

Gordon, J.R., Mondy, R.W., Sharplin, A., Premeaux, S.R., 1990. Management and Organizational Behavior. Allyn and Bacon, Boston, MA.

Guzzo, R.A., Shea, G.P., 1992. Group performance and intergroup relations in organizations, In: Dunnette, M.D., Hough, L.M. (Eds.), Handbook of Industrial and Organizational Psychology, 3rd ed. Consulting Psycologists Press, Palo Alto, CA, pp. 269–313.

Hackman, J.R., 1987. The design of work teams. In: Lorsch, J.W. (Ed.), Handbook of organizational behavior. Prentice-Hall, Englewood Cliffs. NJ, pp. 67–102.

Hadj-Hamou, K., Caillaud, E., 2004. Cooperative design: A framework for a competency-based approach. 5th International Conference on Integrated Design and Manufacturing in Mechanical Engineering, IDMME'04, University of Bath.

Hendriks, M., Voeten, B., Kroep, L., 1999. Human resource allocation in a multi-project R&D environment: resource capacity allocation and project portfolio planning in practice. International Journal of Project Management 17, 181–188.

Hlaoittinun, O., Bonjour, E., Dulmet, M., 2007. A team building approach for competency development. IEEE International Conference on Industrial Engineering and Engineering Management. Singapur. doi:10.1109/IEEM.2007.4419343.

Hoegl, M., Gemuenden, H.G., 2001. Teamwork quality and the success of Innovative Projects: a theoretical concept and empirical evidence. Organization Science 12, 435–449.

Hollenbeck, J.H., Scott, D., Guzzo, R., 2004. Bridging the Gap between I/O research and HR practice: improving team composition, team training and task design. Human Resource Management 43, 353–366.

Huemann, M., Keegan, A., Turner, J.R., 2007. Human resource management in the project-oriented company: a review. International Journal of Project Management 25 (3), 315–323.

Jones, D., 2001. Sociometry in team and organisation development. British Journal of Psychodrama and Sociodrama. 16, 1.

Laslo, Z., Goldberg, A.I., 2008. Resource allocation under uncertainty in a multi-project matrix environment: is organizational conflict inevitable? International Journal of Project Management 26 (8), 773–788.

Maurer, I., 2010. How to build trust in inter-organizational projects: the impact of project staffing and project rewards on the formation of trust, knowledge acquisition and product innovation. International Journal of Project Management 28 (7), 629–637.

Moreno, J.L., 1941. Foundations of Sociometry: an Introduction. Sociometry 4 (1), 15–35.

Moreno, J.L., 1961. Fundamentos de la Sociometría. Paidós, Buenos Aires.

Morse, L.C., McIntosh, J.O., Whitehouse, G.E., 1996. Using combinations of heuristics to schedule activities of constrained multiple resource projects. Project Management Journal 1996 (1), 34–40.

Patanakul, P., Milosevic, D., 2009. The effectiveness in managing a group of multiple projects: factors of influence and measurement criteria. International Journal of Project Management 27 (3), 216–233.

Piper, W., Marrache, M., Lacroix, R., Richardson, A., Jones, B., 1983. Cohesion as a basic bond in groups. Human Relations. 36, 93–108.

Tong, T.K.L., Tam, C.M., 2003. Fuzzy optimisation of labour allocation by genetic algorithms. Engineering, Construction and Architectural Management 10 (2), 146–155.

Tsai, H.T., Moskowitz, H., Lee, L.H., 2003. Human resource selection for software development projects using Taguchi's parameter design. European Journal of Operational Research 151, 167–180.

Tseng, T.L., Huang, C.C., Chu, H.W., Gung, R.R., 2004. Novel approach to multi-functional project team formation. International Journal of Project Management 22, 147–159.

Turner, R., Huemann, M., Keegan, A., 2008. Human resource management in the project-oriented organization: employee well-being and ethical treatment. International Journal of Project Management 26 (5), 577–585.

Wiendieck, G., 1992. Teamarbeit. In: Frese, Erich (Ed.), Handwoerterbuch der Organisation. C.E. Poeschel Verlag, Stuttgart, Germany.

Wu, Y.K., 2007. On the manpower allocation within matrix organization: a fuzzy linear programming approach. European Journal of Operational Research 183 (1), 384–393.

Zakarian, A., Kusiak, A., 1999. Forming teams: an analytical approach. IIE Transactions 31, 85–97.

Zwikael, O., Unger-Aviram, E., 2010. HRM in project groups: the effect of project duration on team development effectiveness. International Journal of Project Management 28 (5), 413–421.