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A Review of Mathematical Equations to Assign Individual Marks from a Team Mark

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BACKGROUND

Team-based learning is an integral part of engineering education today. Development of team skills is now a part of the curriculum at universities as employers demand these skills on graduates. Higher education institutions enforce academic staff to teach, practise and assess team skills, and at the same time, they ask academic staff to supply individual marks and/or grades. Allocating individual marks from a team mark is a very complex and sensitive task that may adversely affect both individual and team performance. A number of both qualitative and quantitative methods are available to address this issue. Quantitative mathematical methods are favoured over qualitative subjective methods as they are more straightforward to explain to the students and they may help minimise conflicts between assessors and students.

PURPOSE

This study presents a review of commonly used mathematical equations to allocate individual marks from a team mark. Quantitative analytical equations are favoured over qualitative subjective methods because they are more straightforward to explain to the students and if explained to the students in advance, they may help minimise conflicts between assessors and students. Some of these analytical equations focus primarily on the assessment of the quality of teamwork product (product assessment) while the others put greater emphasis on the assessment of teamwork performance (process assessment). The remaining equations try to strike a balance between product assessment and process assessment. The primary purpose of this study is to discuss the qualitative aspects of quantitative equations.

DESIGN/METHOD

This study simulates a set of scenarios of team marks and individual contributions that collectively cover all possible teamwork assessment environments. The available analytical equations are then applied to each case to examine their relative merits with respect to a set of evaluation criteria with exhaustive graphical plots.

RESULTS

Although each analytical equations discussed and analysed in this study has its own merits for a particular application scenario, the recent methods such as *knee formula* in SPARK^{PLUS} and *cap formula*, are relatively better in terms of a number of evaluation criteria such as fairness, teamwork attitude, balance between process and product assessments etc. In addition to having all favourable properties of *knee formula*, *cap formula* explicitly considers the quality of teamwork (i.e., team mark) while allocating individual marks. *Cap formula* may, however, be difficult to explain to the students due to relatively complex mathematical equations involved.

CONCLUSIONS

Not all existing analytical equations that allocate individual marks from a team mark have similar characteristics. Recent methods, *knee formula* and *cap formula*, are advantageous in terms of a number of evaluation criteria and are recommended to apply in practice. However, it is important to examine these equations with respect to enhancing students' learning achievements rather than the students and academic staff's preferences.

KEYWORDS

Teamwork assessment, team mark, individual mark, analytical equations

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Introduction

Team-based learning is an integral part of engineering education today. Development of team skills is now a part of the curriculum at universities as employers demand these skills on graduates. Higher education institutions enforce academic staff to teach, practise and assess team skills, and at the same time, they ask academic staff to supply individual marks and/or grades. Potential benefits from and problems of learning in teams are discussed in a number of existing literature (e.g., Hansen 2006, Li 2001, Lejk et al. 1996 etc.). The most cited problem of allocating a team mark to all individuals is that it is often not a fair reflection of an individual's effort (Conway et al., 1993). To encourage teamwork, it is essential that students feel confident that they will be rewarded fairly for their contributions and that any 'free-riders' or "social-loafers" or 'passengers" will not benefit unduly from the efforts of others. Hence, to develop a proper functioning learning team that produces quality outcomes, each members of the team is required to be accountable for their individual efforts as well as team efforts. A good distribution of marks in a unit or course is also sometimes required by university administration for benchmarking and comparison purposes. Powell (2004) examines that team project assessors tend to mark a little on a low side compared with the results from classical individual examinations and the results are more narrowly spread. Hence, there is a need for a balance between a 'good' and a 'fair' distribution of individual marks and a teamwork exercise.

However, allocating different individual marks from a team mark is a very complex (Johnston and Miles, 2004) and sensitive task that may adversely affect both individual and team performances. A number of both qualitative and quantitative methods are available to address this issue. Quantitative analytical methods are favoured over qualitative subjective methods because they are more straightforward to explain to the students and if explained to the students in advance, they may help minimise conflicts between assessors and students. This study compares existing analytical methods, which are used to allocate individual marks from a team mark. The readers of this article are requested to note that this study does not cover other important aspects of team learning such as team formation, selection of learning environment, assessment design and feedback system. This study examines the issue of allocating individual marks from a team mark when both the team mark (obtained from assessing the teamwork product) and individual contributions (derived from co-assessment or self-assessment or peer-assessment or combination of these assessment techniques for process assessment) are known.

Existing Methods

Existing methods to allocate individual marks by adjusting a team mark using an individual team member's contribution to a teamwork include (i) distributing the pool of marks by adding differentials (Race, 2001), (ii) adding a mark to or subtracting a mark from team mark based on an individual contribution, which is determined using the process assessment (Lejk et al., 1996 and Conway et al., 1993) and (iii) multiplying team mark by a factor derived from an individual's contribution to the teamwork (Goldfinch, 1994, Conway et al., 1993; Johnston and Miles, 2004, Willey and Gardner, 2009; Nepal, 2011). The last method is the most widely used in practice as it is straightforward to calculate individual contribution factor (*ICF*) using co-assessment, peer-assessment, self-assessment or a combination of two or more of these assessment methods. Equation (1) is a mathematical expression of this method.

$$IM = TM \times f(ICF) \tag{1}$$

where *IM* is the mark awarded to an individual team member, *TM* is the team mark and *f(ICF)* is a multiplying factor as a function of *ICF*. A generalised equation for calculating *ICF* is given in equation (2).

$$ICF = \frac{Individual\ contribution\ (\%)}{Average\ contribution\ (\%)} = \frac{Individual\ contribution\ (\%)}{\left(\frac{100}{n}\right)} \quad (2)$$

where n is the number of members in a team. For example, if an individual team member's contribution is 30% in a team of five members, his or her *ICF*= 30/(100/5)= 30/20=1.50. Co-assessment, peer-assessment, self-assessment or a combination of two or more of these teamwork evaluation surveys can be used to derive individual contributions. Goldfinch and Raeside (1990) used two part peer assessment scores and combined them using weights to calculate a single score (i.e., *ICF*). Goldfinch (1994) revised this approach and suggested some modifications which is similar to Conway et al. (1993). Willey and Gardner (2009) discussed SPA factor derived from self- and peer-assessment ratings. Kilic and Cakan (2006), Zhang et al. (2008) and Lew et al. (2010) evaluated the reliability and examined the variations of *ICF*. This study neither attempts to address the issue of the reliability and the variability of *ICF* nor does it intend to devise a method to improve it. Instead, it aims to evaluate existing analytical methods that use a multiplying factor as a function of *ICF* to allocate individual marks from a team mark. In this study, we formulate the existing methods using consistent mathematical equations and evaluate these methods using exhaustive graphical plots based on a set of evaluation criteria.

The existing analytical methods differ on specifying the functional form of *f(ICF)* as summarised in the following equations:

Method 1: $$f(ICF) = 1 \quad (3)$$

Method 2: $$f(ICF) = ICF \quad (4)$$

Method 2.1: $$f(ICF) = \begin{cases} ICF & for\ \ ICF \le 1 \\ 1 & for\ \ ICF > 1 \end{cases} \quad (5)$$

Method 3: $$f(ICF) = \sqrt{ICF} \quad (6)$$

Method 3.1: $$f(ICF) = \begin{cases} ICF & for\ ICF \le 1 \\ \sqrt{ICF} & for\ ICF > 1 \end{cases} \quad (7)$$

Method 4: $$f(ICF) = \frac{ICF}{ICF_{max}} \quad (8)$$

Method 5: $$f(ICF) = \begin{cases} ICF & for & [ICF \le 1] & (a) \\ ICF - \frac{(1-ICF)^2}{2\alpha\left(1-\frac{TM}{100}\right)} & for & \left[1 < ICF < 1 + \frac{\alpha}{2}\left(1 - \frac{TM}{100}\right)\right] & (b) \\ 1 + \frac{\alpha}{2}\left(1 - \frac{TM}{100}\right) & for & \left[ICF \ge 1 + \frac{\alpha}{2}\left(1 - \frac{TM}{100}\right)\right] & (c) \end{cases} \quad (9)$$

where,

ICF = individual contribution factor;

ICF_{max} = maximum individual contribution factor within a team;

TM = team mark; and

α = cap factor ($0 \le \alpha \le \infty$).

Method 1 in equation (3) allocates individual marks equal to the team mark. This is the simplest path, easy to manage and is worth considering if it is primarily the product of the team learning which is to be assessed, and not the processes leading up to this team product. Although this method is simple and is widely used at academic institutions, it is not considered to be 'fair' as it neither penalises free riders nor rewards additional contributions.

Method 2 in equation (4) allocates individual marks proportional to the individual contributions. Although this method is considered 'fair' and widely suggested in existing literature, it has at least three issues. First, the individual marks allocated are not always contained within a generally accepted upper limit, i.e., 100%. Second, the team mark is not always reflected in the mark awarded to an individual team member. For example, a team member who contributes significantly higher than the average contribution may receive substantially high individual mark even for a very low team mark. Hence, this method is biased towards the process assessment (i.e., individual contribution) and does not align with the principle of criterion-referenced assessment system (Biggs and Tang, 2007). Third, the method does not provide check-and-balance for an individualistic behaviour in team learning environment. A team member may aggressively takeover all teamwork activities to benefit himself or herself. A variant of this method (Method 2.1) that allocates individual marks equal to the team mark for an average and above-average contributions and proportionally lower individual marks for below average contributions addresses the first and the third issues but introduces a new issue: no reward for additional contributions.

Method 3 in equation (6), original formula used in SPARK system (Willey and Gardner, 2009) allocates an individual mark equal to the team mark for an average contribution, lower but more than proportional individual marks for below-average contributions and higher but diminishing individual marks for above-average contributions. Although this method discourages individualistic behaviour to some extent, it does not fully control it as a team member continues to receive additional rewards (even more than 100% in some cases) albeit at a diminishing rate. In addition, the method allocates higher than the 'fair share' for below average contributions. A variant of this method, Method 3.1 in equation (7), popularly known as *knee formula* in SPARK^{PLUS} as discussed in Willey and Gardner (2009) allocates an individual mark equal to the team mark for an average contribution, proportionally lower individual marks for below-average contributions and higher but at a diminishing individual marks for above-average contributions. This method addresses only the last issue discussed for Method 3.

Method 4 in equation (8) allocates an individual mark equal to team mark for the highest contribution and proportionally lower individual marks for other contributions. Although Nepal (2011) reported that a significant proportion of students preferred this method, it assigns individual marks on a low side compared with other methods. It depends heavily on the highest contribution and an individualistic team member may become aggressive to penalise teammates.

Method 5 in equation (9) is a *cap formula* (Nepal, 2011) that allocates an individual mark equal to the team mark for an average contribution, proportionally lower individual marks for below-average contributions, higher but diminishing and subsequently capped individual marks for above-average contributions. This is the only method that systematically incorporates product assessment, i.e. team mark, to develop individual contribution factor (i.e., *ICF*), using a cap factor ($0 \leq \alpha \leq \infty$). The cap factor ($\alpha$) equal to infinity ($\infty$) means that the individual marks are proportional to the individual contributions which is exactly same as Method 2. The cap factor (α) equal to zero (0) means that individual marks are equal to the team mark for an average and above-average contributions which is exactly same as Method 2.1. Nepal (2011) suggested the cap factor (α) to be less or equal to 2.0 to discourage individualism in a team learning environment and to contain all individual marks within generally acceptable upper limit (i.e., 100%). For practical purposes, the cap factor (α) can be chosen in such a way that a team member who contributes more than an average receives some additional rewards (e.g., higher grade, higher GPA etc.). Although this method by far is the best and does not require additional data to be collected, the mathematical equations used are somewhat complex and it may be difficult to sell the idea to students. However, graphical plots and spread-sheet can easily be developed to apply in practice.

Graphical Plots

For the purpose of comparative review, the existing equations discussed in previous section are plotted graphically that collectively cover all possible combinations of team marks and individual contributions. If all team members contribute equally (a perfect example of teamwork), it is the team mark each member receive. Variations from this ideal case, however, do exist in actual team learning environments. The team mark may vary from 0% (a team of student produced an outcome of the lowest possible standard) to 100% (a team of students produced a perfect product). Similarly, individual contributions may vary from as low as 0% (an individual did not contribute to a teamwork product at all, a free-rider) to as high as 100% (a team member completed all team activities by himself or herself, an individualistic team member). In some situations, these extreme cases are easier to deal with. For example, it is not unfair to assign 0% marks for all team members if the product they produce is of 0% quality irrespective of their individual contributions. Similarly, if a team member does not contribute (individual contribution = 0%), he or she receives 0% mark irrespective of the team mark. In other cases, it is very difficult to consistently distribute individual marks from a team mark.

Figures 1 to 4 show the plots of the distributions of individual marks for a range of team mark and individual contributions.

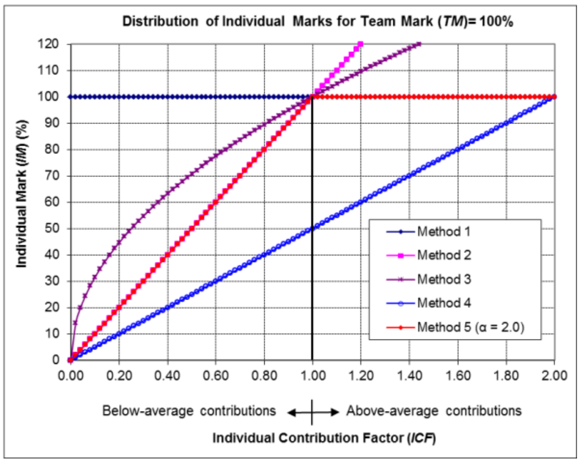

Figure 1: Distribution of *IM* for *TM* = 100%

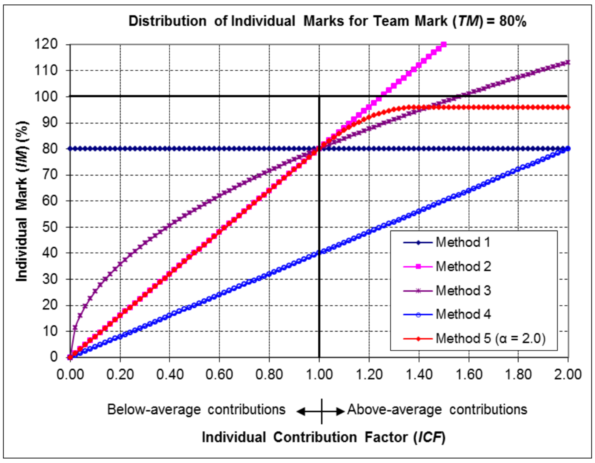

Figure 2: Distribution of *IM* for *TM* = 80%

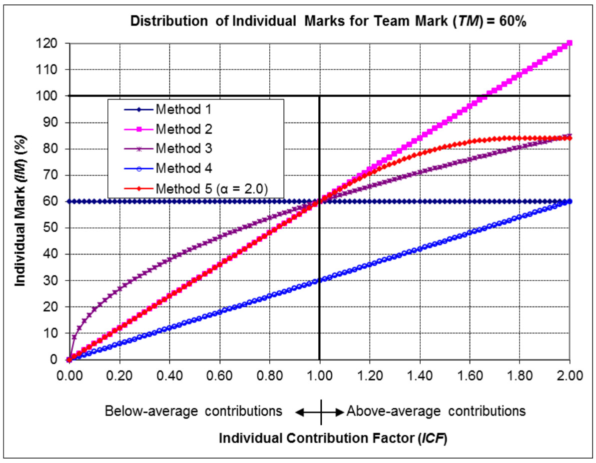

Figure 3: Distribution of *IM* for *TM* = 60%

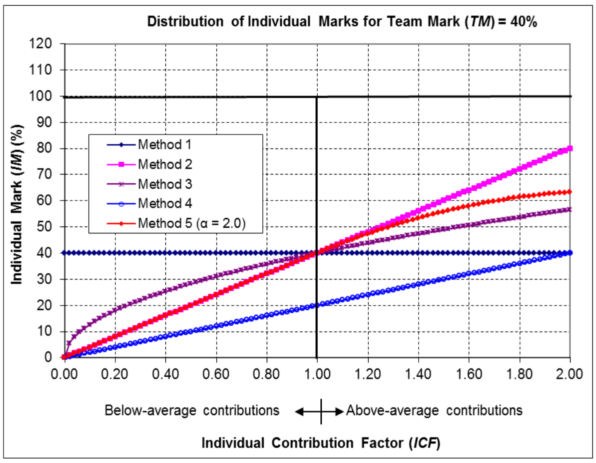

Figure 4: Distribution of *IM* for *TM* = 40%

It is interesting to see all methods but Method 4 allocate individual marks equal to team mark for average contribution (*ICF* = 1.00). They differ only on the amount of rewards for above-average contributions (*ICF* > 1.00) and on the amount of penalty for below-average contributions (*ICF* < 1.00). It may be easier to justify proportionally lower individual marks for below average contributions (all methods but Method 3), it is often difficult to justify proportionally higher individual marks for above-average contributions (Method 2) as it encourages individualistic behaviour and team spirit may be lost. Trade-offs between Method 1 and Method 2 may achieve a balanced objectives- fair share, penalties for below-average contributions and rewards for above average contributions. Method 3 (*knee formula*) and Method 5 (*cap formula*) provide a balance. In addition to having all favourable properties of *knee formula*, *cap formula* explicitly considers the quality of teamwork while developing individual contribution (i.e., *ICF*). *Cap formula* may, however, be difficult to explain to the students due to relatively complex mathematical equations involved. Method 4 allocates individual mark equal to team mark for the highest contribution and severely penalises other contributions. It is not recommended to use in practice as it may develop conflicts among team members that may adversely affect team learning.

Concluding Remarks

This study compares existing mathematical equations to allocate individual marks from a team mark. Quantitative analytical equations are favoured over qualitative subjective methods because they are more straightforward to explain to the students and if explained to the students in advance, they may help minimise conflicts between assessors and students. It simulates a set of scenarios of team marks and individual contributions that collectively cover all possible teamwork assessment. The available analytical methods are then applied to each case to examine their relative merits with respect to a set of evaluation criteria with exhaustive graphical plots. Although each analytical method discussed and analysed in this study has its own merits for a particular application scenario, the recent methods such as *knee formula* and *cap formula*, are relatively better in terms of a number of evaluation criteria such as fairness, teamwork attitude, balance between process and product assessments etc. In addition to having all favourable properties of *knee formula*, *cap formula* explicitly considers the quality of teamwork while allocating individual marks. *Cap formula* may, however, be difficult to explain to the students due to relatively complex mathematical equations involved. However, it is important to examine these equations with respect to enhancing students' learning achievements rather than the students and academic staff's preferences.

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