Degree of collaboration Measurement in Face to Face and Computer Mediated Collaboration in Design

Wadhah Amer Hatem, Alan Kwan & Samiaah M. H. Al-Tmeemy
Baquba Technical Institute
Email:wadhah7@yahoo.com

Abstract: Collaboration is something which in concept is well understood but the determination of a metric which can be used to assess the degree of collaboration is something which is far more challenging. This paper studies how collaboration works during the design process for mature design and compares the differences between two methods of achieving collaboration, namely: face to face (FTF) and computer mediated communication (CMC). The results show that the number of exchanges was the best indicator of the degree of collaboration for this work and this degree in CMC higher than FTF.

1. Introduction

Degree of collaboration represents the amount of interaction between team members to achieve an enhanced shared understanding and enable all team members to fully participate and accomplish the mission. The degree of collaboration for any team depends on several key factors such as emotional interaction, cooperation comprehension, shared vocabulary and inter-personal interaction (Van & Fridqvist, 2006). The degree of collaboration is one of the most important variables which should be considered during an evaluation of team performance because this reflects on the efficiency of the team when working towards its final goal. This applies whether the team uses FTF or CMC (Kaushik et al., 2000). Collaboration is an important factor to the success of any team mission; therefore there have been various attempts to find metrics to determine the collaboration level between participants within a team (Barratt & Oliver, 2001). Measuring collaboration level assists with the identification of the shortcomings of a given collaboration and helps to find the possible initiatives to remedy them. The measurement of collaboration levels also helps people to determine the benchmark for the current collaboration level and compare it with any new collaboration performance in the future (Simatupang & Sridharan, 2004).

In spite of the collaboration being widely studied in many different fields, the work has not produced any standard, agreed method for the calculation of the degree of collaboration. Simatupang & Sridharan (2005) have developed a collaboration index that computes the collaboration level in a supply chain relationship. Their index depends on three factors, these being decision synchronicity which refers to joint decision making in planning such as future planning, market demand, etc, operational contexts such as shipping products and refilling products in the stores, etc, amount of information sharing and incentive alignment which refers to the degree to which chain members share costs, risks and benefits. The collaboration index is basically the mean of scores for the three factors as evaluated for each participant in the team as shown in the Fig. 1, they used Likert scales (1-5) (Likert, 1932) to assess the degree of collaboration for each member. A high score in this index means this member has high level of supply chain collaboration. The collaboration index measure has been adopted in some organisations, but the method appears to be very subjective and depends on the personal assessment and is therefore not very reliable. Semar (2005) studied the degree of collaboration between student team members working, using management software. He claimed the degree of collaboration depends on four components:

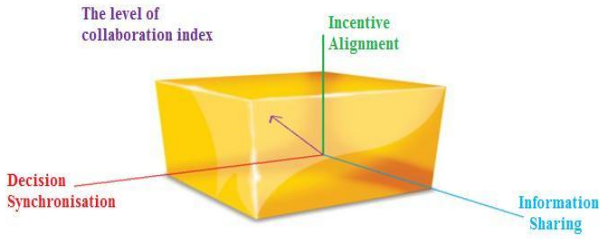

Figure 1: The concept of the collaboration index (Simatupang & Sridharan, 2005)

1. "Synthesis", which concerns the degree of agreement in a team and is evaluated with a "voting tool" on the summary decisions of the team in a discussion.
2. "Independence", which concerns the team's ability to work without the instructor, and is evaluated by number of occasions, the instructor interjects with corrective information/instructions in the team discussion.
3. "Interaction", which concerns the flow of discussion, and is evaluated by the number of "stand-alone" comments, i.e. comments made by a participant which are not then responded to by other participants.
4. "Participation", which concerns equal sharing in the discussion, and is evaluated by the total deviation of the number of comments made by participants, from the ideal split (i.e. all participants in a team making exactly the same number of comments).

All four components have a normalised score, and the degree of collaboration as shown in Fig. 2 is defined as a 4x1 vector with entries being the four normalised scores, and is visualised as a quadrilateral on an *x-y* plot. The ideal collaboration is thus $[1\ 1\ 1\ 1]^T$ and is represented as a rhombus with vertices at 1 on each of the four axes.

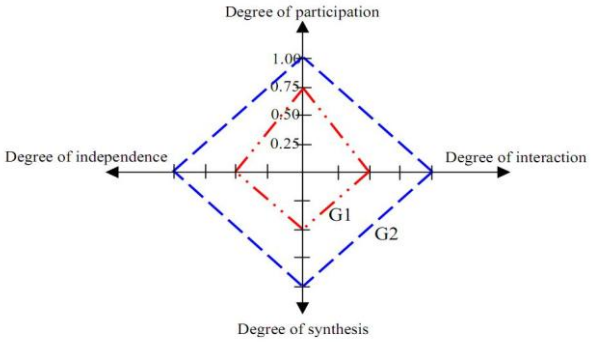

Figure 2: The concept of degree of collaboration (Semar, 2005)

This method has been developed for use with learning environment task which are very different to design task. Also, it is obvious that the role of the instructor in this method may negatively impact on the degree of collaboration. Due to the above particular shortcomings, and the fact that the tasks and subject matter in the present investigation were significantly different, this paper adopted another method for calculating the degree of collaboration, by resorting to experimentally determined metric quantities such as number of exchanges, number of words and time measurements.

2. Methodology

The aim of the research described in this paper is to assess the differences that occur

between people who undertake engineering tasks when FTF and people who do the same tasks when working remotely from once another using a network to support CMC. The programme of experiments to investigate this has therefore involved teams of two people who are assigned two tasks. One of these they are asked to perform FTF and the other using CMC. The order in which the tasks are performed is random to avoid any systematic bias in the results. For both the FTF and CMC tasks, the participants have to work using a 3D computer model of a building which has to be modified. So this is a task which involves a relatively mature design rather than conceptual design. The software used to support the work for both FTF and CMC is Autodesk Revit Architecture. None of the participants was familiar with Revit so before the tasks could be performed, all of them had to be trained. The training was identical for all the participants.

At the start of each task, the participants were given a sheet of instructions which describes the task to be performed. For each participant the tasks were different so, within each experiment, every participant had a different set of instructions. The instructions were carefully devised so that the tasks could not be carried out without assistance from the other participant. This approach enforces the need for collaboration and hence communication. For each experiment, there are 4 sections to the overall task which the participants are required to complete. Great care was taken before the experiments to ensure that the participants were given identical verbal and written instructions and that the participants were not told anything about the purpose of the experiments. Likewise when the experiments were over, they were instructed not to discuss what had occurred with anybody else to avoid "contamination "of potential future participants. The hardware used consists of a server coupled to two other computers, which are in separate rooms Fig (3). For the CMC, each participant works remotely using one of the computers. For the FTF, the participants sit together and use a single computer to make the required adjustments to the design. The participants position in relation to the computer was chosen randomly between them (i.e. they were given freedom in choosing their position) Fig. (4) so that which participant controlled the mouse was a matter to be settled between the two of them. In CMC the participants work on a single Revit model which is situated on the server. Each user can check out a copy of this central file and work on a local file which then has to be saved back to the central file Fig (5). Generally in all the experiments the position of the users still the same his place in FTF and CMC, in FTF User is sitting close and mostly use the computer is User1 and the opposite one is User2.In CMC, User1 still in his place and user2 move to other room to do the experiments.

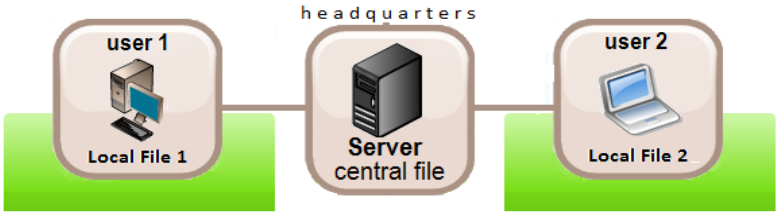

Figure 3: Hardware

Revit contains features which allow people to work simultaneously on the same model but not on the same parts of the model. The responsibility for different areas of the model (e.g. exterior walls, roof, plumbing, etc) are allocated to different people (in this case the two

participants) and if someone else wishes to modify something which impinges on an object which they do not own, then they have to request permission to do so. The tasks have been set up so that the work necessarily involves such requests. The models/designs which the users are required to work on are deliberately sub-standard so that the need for modification is relatively obvious.

For the CMC experiments, the communication between the participants is achieved using Skype for both audio and visual, the latter consisting of an image of the other participant on the top left of the screen. At no time do participants share a desktop so all communication about the task has to be verbal or using the chat facility in Skype. For both CMC and FTF the participants are videoed plus the full session including the complete computer interaction and audio is recorded. Once the experiments have been completed, the various data streams are joined together using Corel Video Studio 12.

The analysis of the results is undertaken by extracting from the transcript of the experiment measures such as the total of task and non-task related words, the total working time (i.e. time actually spent on the task), non-task related time, productivity, the number of exchanges (i.e. the number of times the discussion moved from one participant to the other) and the length of time when nobody spoke. Most of these measures were calculated for each individual and then aggregated where appropriate to obtain the team performance.

Figure 4: FTF

Figure 5: CMC

To demonstrate the differences in user behavior during FTF and CMC, Twenty experiments were conducted and each experiment consists of 2 participants. Each group has different tasks with similar concept, the task was not repeated in FTF and CMC so that the users do not become familiar with the tasks when conduct FTF because this might affect results reliability when conducting CMC. If the tasks were not completed during the 35 minutes, the participants were asked to cases working at the end of their allotted time. For the analysis time, each experiment lasting 35 minutes and divided into 7 time intervals of 5 minutes. The results of each experiment were fully studied and analyzed and finally the average of each result item was studied to compare the difference between FTF and CMC and give more validity for the result since that each average represents 20 experiments.

The analysis allows the comparison of the performance of individuals within each experiment plus a comparison of how each couple performed in comparison to the other groups. Most of the participants are PhD students at Cardiff University and they have experience in aspect of design and the construction industry. As the participants have varying levels of experience from expert to novice, this allows some interesting inferences to be drawn about how the various groups perform (see Table 1). The performance

comparison include:-

- The productivity of each team regarding to the completion of various activities. For calculating the productivity of the tasks (i.e. FTF and CMC) each contains four worksets and each workset has five items. Generally each workset is allocated 2.5 points and each item has 0.5 points so if a team finishes 5 items for each workset they receive 2.5 points and if the team finishes all the four workset it receives ten points
- The time spent on the task and non-task time (i.e. non-productive) for each group and individuals.
- The number of words for each team, this being an indication of the level interaction and also if one team member is more dominant. Likewise the number of non-task related words gives an indication of how effective and task focussed the participants were.
- The total number of exchanges (percentage of interaction) between users is a good indicator of the degree of collaboration.

Table 1: Type of team expert according to level of expertise

Expert Level	Acronym	Description
Expert-Expert	E-E	Both users have a high level of expertise in the design field (typically > 5 years post-Engineering graduation).
Expert-Junior expert	E-jE	One user has a high level of expertise, but the other has only a moderate level of expertise (typically an engineering graduate but with < 5 years of expertise).
Expert-Novice	E-N	One user has a high level of expertise but the other is a novice who is not an engineering graduate, and has not any expertise in construction or design.
Junior expert-Novice	jE-N	One of the users has moderate expertise but the other is a Novice.
Novice-Novice	N-N	Both users have no or very little expertise in construction or design.

3. Results and Discussion.

There are many indicators that can provide a good measure for collaboration. In this paper four indicators have been studied for the degree of collaboration as shown below. These include:-

- The number of exchanges which shows the amount of interaction and participation in the speech; a high number of exchanges shows a good degree of collaboration between the participants.
- Differences in individual productivities, as a ratio of the total team productivity is also regarded as an indicator for the degree of collaboration. It is argued that where there is good collaboration, then each team member would account for half the productivity of the team (i.e. zero difference in individual productivities), and hence a ratio close to zero would be an indication of good degree of collaboration between the users.
- Differences in the word count between the two users, out of the total number of words. This is regarded as another indicator of the degree of collaboration, which is similar to the differences in individual productivity. If each user speaks half of the total number of words, this indicates that there is not a domineering partner.
- Differences in the working time between the two users, out of the total working time of the team, is also regarded as an indicator for the degree of collaboration. If

each user accounts for half the team's working time, then both users are collaborating and working equally, and thus a low ratio would be an indicator of a good degree of collaboration.

3.1 Number of Exchanges

It is clear that, at one extreme, if there is no collaboration between the users in a team, then no communication at all can be expected, or there is monologue from the dominant user, with the other user taking no part at all, both resulting in a zero number of exchanges. In contrast, if there is genuine collaboration, then a high number of exchanges can be expected. However, it is recognised that there must be an upper limit beyond which each speech transaction would be so fragmented so as to be of no or little use. The number of exchanges for FTF and CMC for each of the 20 teams of users is presented in Fig. 6. Here, it can be seen that for 16 of the 20 experiments, the number of exchange is higher for CMC than for FTF. These results in an overall average of 145 exchanges for FTF compared to 155 for CMC. Hence, there is a good indication of a higher degree of collaboration in CMC.
Figure 6 is also plotted with teams of similar expertise being grouped together. It is notable that the teams with the higher expertise have a greater number of exchanges. Furthermore, it is the teams with uneven expertise pairings such as Expert-Novice and Junior expert-Novice that consistently have a higher number of exchanges in CMC than in FTF. To a lesser extent, this is also true for the teams classified as Expert-Junior expert, even though the size of the difference is less.

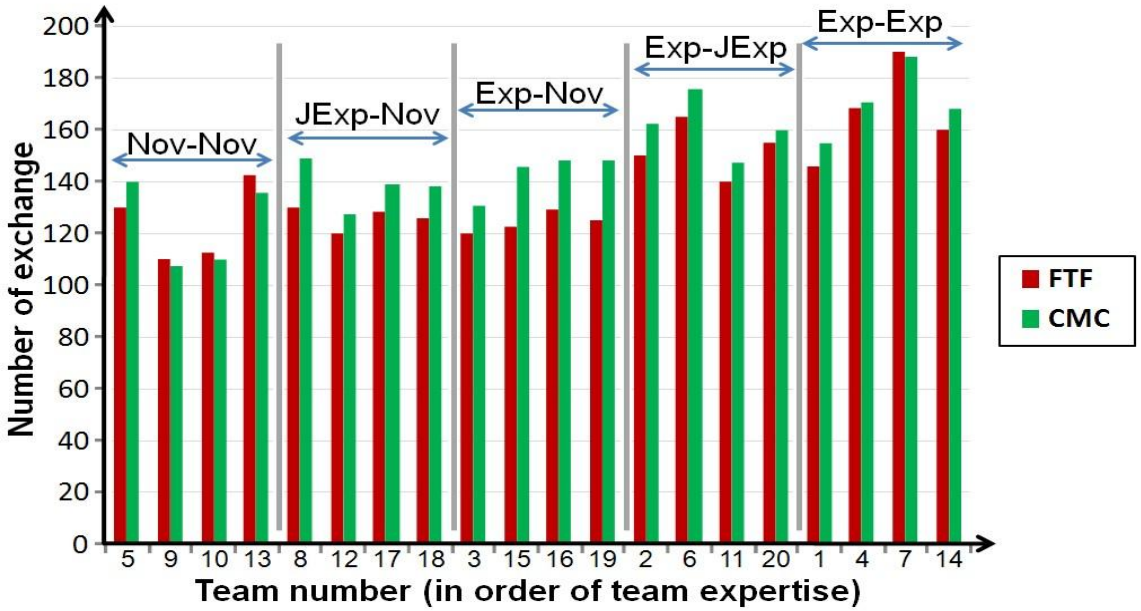

Figure 6: The number of exchanges for FTF and CMC

However, when the data is re-examined according to team-expertise (see Fig. 7), there is little change in productivity for the Expert-Expert teams, despite a variation in the number of exchanges from 152 to 196. It is an observed trend that the Expert-Expert teams are relatively uninfluenced by the varying factors (including the number of exchanges) and continue to produce high productivity regardless. However, once these four teams are

removed from the calculation, there is evidently an even stronger correlation between productivity and the number of exchanges, as seen by a tighter banding of the remaining data around a best-fit straight line.

3.2 Individual Productivity Compared to Team Productivity

The second indicator chosen for the degree of collaboration is the difference between the productivity of the two individuals in a team, here expressed as a percentage ***P*** = | (User1 productivity-User2 productivity)| *100 % / (Team productivity). It is argued that when a team is collaborating effectively, then each member would contribute well to the productivity of the team, and thus the difference between the individual productivity would be low. Table 2 gives this percentage value for all 20 teams in FTF and CMC. The results show that ***P*** in CMC is lower than in FTF in 75% of the total experiments. Again this suggests that the degree of collaboration for CMC is better than for FTF.

Table 2: Percentage difference ***P*** between the individual productivity in FTF and CMC

Team Number	***P* for FTF (%)**	***P* for CMC (%)**	**Team Number**	***P* for FTF (%)**	***P* for CMC (%)**
1	14.70	17.60	11	24.00	12.00
2	31.00	15.30	12	14.00	11.55
3	37.56	10.00	13	6.00	7.75
4	5.00	2.00	14	4.00	0.00
5	9.80	6.00	15	27.50	13.00
6	25.80	0.00	16	19.60	11.00
7	1.00	0.00	17	14.00	7.00
8	20.00	10.00	18	15.00	7.75
9	22.11	30.00	19	21.88	9.00
10	18.75	23.90	20	10.00	20.00
Mean average				**17.09**	**10.73**

Table 3 illustrates an interesting point relating to the differences in the ***P*** averages in FTF and CMC for each type of teams. For example, the team type Expert-Expert consists of teams 1, 4, 7 and 14, and the average ***P*** for these teams is 6.18 and 4.90, for FTF and CMC respectively, i.e. only a small difference of 1.28.

Table 3shows the same differences in averages of ***P*** values for the other team types. It is clear that the difference values for team types Expert-Expert and Novice-Novice are significantly less than with other types of teams (with pairings of unequal expertise). Clearly, where the team is homogenous as regards to the expertise, the differences in ***P*** are low when compared with the other teams with different expertise levels. This finding in Table 3 is consistent with the results in Figure 6, which shows that the differences in the number of exchanges between FTF and CMC in teams with users of the same expertise level is also less than with the other types of team.

Table 3: Differences in averages of ***P*** values in individual productivity for teams in FTF and CMC

Team type	***P* for FTF (%)**	***P* for CMC (%)**	**Difference**
Expert-Expert	6.18	4.90	1.28
Expert-Junior expert	22.70	11.83	10.87
Expert-Novice	26.64	10.75	15.89
Junior expert-Novice	15.75	9.08	6.67
Novice-Novice	14.17	16.92	2.75

3. 3 Individual Word Count Compared to Team Word Count

The third indicator for the degree of collaboration between team members is the ratio of the difference between the numbers of words spoken by the individuals in a team to the total word count of the team; this indicates the equality of participation of each member within the team. The amount of this participation depends on the nature and type of user which mainly relates to the user's behaviour when achieving the task. The equitable distribution of the speech between the users gives a clear indication about the collaboration degree between users during the experiment. If this percentage is very small, it indicates good collaboration. This percentage has been calculated as W = | (User1 word count-User2 word count)| *100 % / (Team word count).

Table 4 presents the W value for the 20 experiments in FTF and CMC. The results illustrate that the W value in CMC is less than FTF in 80% of cases and is equal in 20% of the total experiments. These percentages indicate that the degree of collaboration in CMC is better than in FTF and the users work more freely, with the speech between them being evenly distributed.

Table 4: Percentage difference W between the individual number of word in FTF and CMC

Team Number	W for FTF (%)	W for CMC (%)	Team Number	W for FTF (%)	W for CMC (%)
1	6.00	2.00	11	28.00	11.65
2	26.33	2.00	12	6.00	2.00
3	35.78	17.60	13	6.00	6.00
4	0.00	0.00	14	4.48	2.00
5	8.00	8.00	15	21.80	13.90
6	23.77	15.55	16	24.00	12.00
7	2.44	0.00	17	10.45	6.38
8	21.80	2.35	18	12.00	6.00
9	30.00	30.00	19	14.00	5.75
10	10.45	5.75	20	30.00	11.90
Mean average				**16.01**	**8.13**

Table 5 illustrates the differences in averages in the W values which have been calculated for each team type in FTF and CMC. Again, W values for team type Expert-Expert and Novice-Novice are less than the other team types with unequal expertise pairing. Clearly, these results are consistent with those in Fig. 6 and Section 3.2.

Table 5: Differences in averages of W values in individual number of words for teams in FTF and CMC

Team type	W for FTF (%)	W for CMC (%)	Difference
Expert-Expert	3.23	1.00	2.23
Expert-Junior expert	27.03	10.28	16.75
Expert-Novice	23.90	12.32	11.58
Junior expert-Novice	12.56	4.19	8.37
Novice-Novice	13.62	12.44	1.18

3. 4 Individual Working Time Compared to Team Working Time

The fourth indicator for the degree of collaboration is the ratio of difference between the working times of the two individuals in a team to the total working time of the team, which is previously defined as the time spent by each user to complete his/her task. Consequently, this time has been exploited evenly between the users; this means that the

degree of collaboration between them is good. However, if one user spent all the time achieving the team's productivity, it indicates that there is no collaboration between the team members and one user was dominant in the task productivity.

The percentage of individual working time can be expressed as $\boldsymbol{T}$ = | (Working time spent by User1-Working time spent by User2)| x100 % / (Team working time). If this percentage is close to zero this indicates there is good collaboration because of the working time is divided equally between the two users, but if this percentage achieves a high score, the degree of collaboration is not good.

Table 6 illustrates the $\boldsymbol{T}$ value for 20 experiments in FTF and CMC. Here, it is obvious that this value in CMC is less than for FTF in 75% of the total experiments. These results are exactly consistent with the $\boldsymbol{P}$ value in the percentage of individual productivity; this means there is a strong relationship between the individual productivity of any user with the working time for one particular user.

Table 6: Percentage difference $\boldsymbol{T}$ between the individual working time in FTF and CMC

Team Number	***T* for FTF (%)**	***T* for CMC (%)**	**Team Number**	***T* for FTF (%)**	***T* for CMC (%)**
1	2.40	4.20	11	32.85	4.00
2	31.80	3.40	12	3.80	0.00
3	52.00	11.32	13	5.25	6.00
4	1.00	0.00	14	2.00	1.45
5	7.50	6.25	15	23.00	15.00
6	32.00	16.00	16	18.75	10.15
7	4.00	1.00	17	8.50	7.00
8	18.50	4.70	18	7.15	5.00
9	20.00	30.00	19	15.38	10.60
10	6.87	10.00	20	18.15	25.20
Mean average				**15.55**	**8.57**

Table 7 shows differences in averages of $\boldsymbol{T}$ values in individual working time for each team type in FTF and CMC. It is evident that the differences in the averages for the $\boldsymbol{T}$ values for team type Expert-Expert and team type Novice-Novice are less than for the other team types. These results are also consistent with the previous results in Figure 6 and Sections 3.2 and 3.3.

Table 7: Differences in averages of $\boldsymbol{T}$ values in individual working time for teams in FTF and CMC

Team type	***T* for FTF (%)**	***T* for CMC (%)**	**Difference**
Expert-Expert	2.35	1.67	0.68
Expert-Junior expert	28.70	12.15	16.55
Expert-Novice	27.29	11.77	15.52
Junior expert-Novice	9.49	4.18	5.31
Novice-Novice	9.90	13.07	3.17

4. The Principle Indicator for Collaboration

The productivity for any team is the main objective of the collaboration process in this work. A good degree of collaboration is therefore expected to result in high productivity. It is necessary to have a specific measure of the degree of collaboration, so that its effect on, for example, productivity can then be assessed. Four different indicators have been

postulated above, and it is necessary to assess which of these four is the best indicator. It is thus useful to separately examine the relationship between each indictor with team productivity.

Figure 7 gives the relationship between team productivity and number of exchanges, where there is a strong positive correlation between them for both FTF and CMC (correlation factor = 0.8826 and 0.8602 respectively). Similarly, team productivity was plotted with the other three indicators (i.e. P, W & T) to obtain the correlation factor. Table 8 shows these correlation factors for all degree of collaboration indicators.

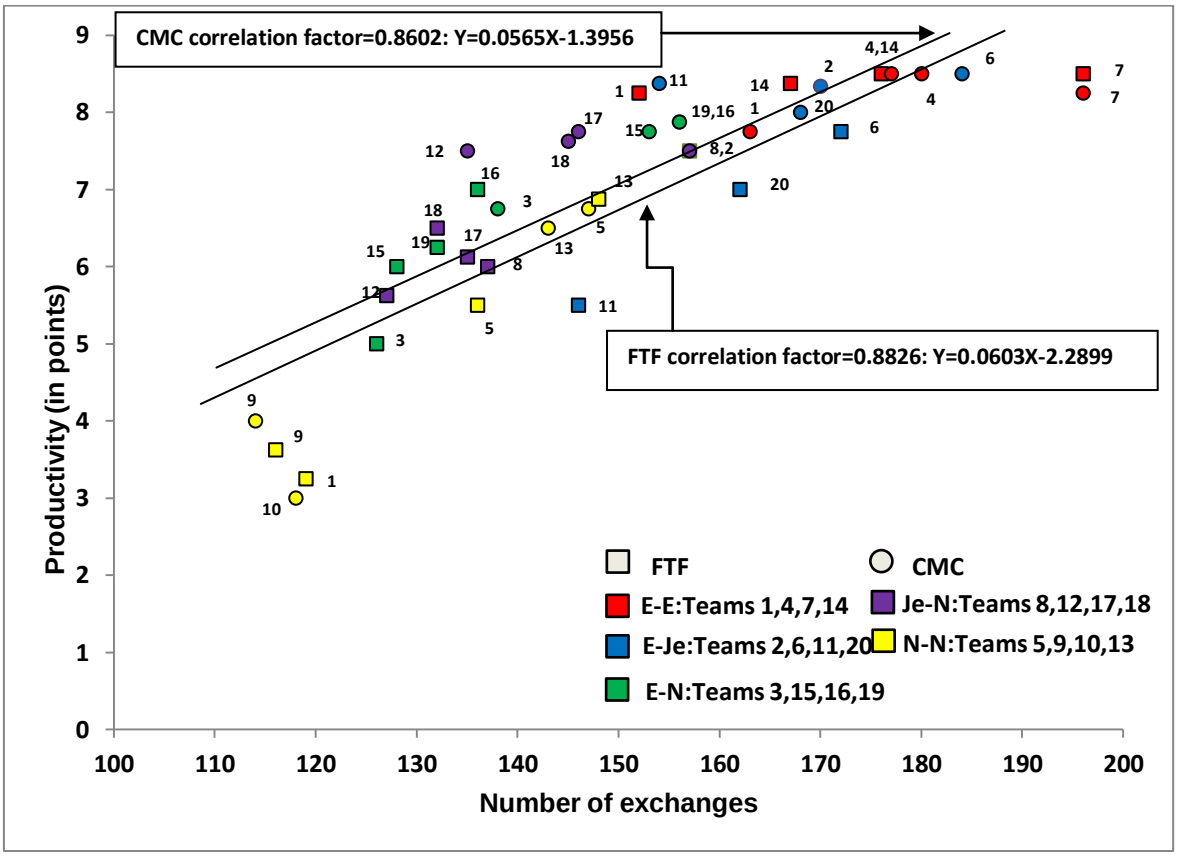

Figure 7: Percentage of individual productivity and team productivity in FTF and CMC

Table 8: Correlation factors for four indicators of collaboration degree with team productivity in FTF and CMC

Correlation factors	Number of exchanges	Percentage of individual productivity (*P*)	Percentage of individual number of words (*W*)	Percentage of individual working time(*T*)
In FTF	0.8826	-0.4467	-0.4569	-0.4276
In CMC	0.8602	-0.4109	-0.2619	-0.2619

It is noted that the four indicators are different quantities; one is a summation number, and the other three percentages. The correlation factors have been deliberately calculated according to the ranked data (as opposed to raw data) in each case, which normalises the data and makes it dimensionless, and thus allow direct comparison between the four indicators. Table 8 shows the correlation factor for all four indicators in FTF and CMC, it

is clear that the number of exchanges has much the better correlation factor with team productivity when compared to all the other indicators, by two to three times. The number of exchanges is clearly the best indicator of degree of collaboration, and therefore it is the only indicator used for degree of collaboration in the rest of the current work.

5. Conclusion

This paper examined the term degree of collaboration in FTF and CMC to establish the best indicator for this term. This came about because of the difficulty in finding a real scale to measure the degree of interaction and collaboration for team members when achieving a task. There are four main indicators for the degree of collaboration: the number of exchanges is the key factor and others are secondary factors, such as the percentages of individual productivities, individual number of word count and working time.

The difference between the number of exchanges in FTF and CMC for the Expert-Expert and the Novice-Novice categories is less than the differences for other types, such as the Expert-Novice, Junior expert-Novice and the Expert-Junior expert (i.e. the difference between FTF and CMC in teams have the same user expertise less than the teams have users in different level of expertise). The ***P*** values for individual productivities , ***W*** values for individual number of words count and ***T*** values for individual working time in CMC is less than the ***P, W*** and ***T*** values in FTF. This means that CMC has a better degree of collaboration than FTF.

References

Van, L. J. P. & Fridqvist, S., 2006. An information model for collaboration in the construction industry. *Computers in Industry*, Vol. 57, pp. 809-816.

Kaushik, R., David, P., Kline, S. & Oaks, D., 2000. Social presence effect: A study of CMC versus FTF in collaboration fiction project. In: Proceeding of the 5th Annual International Workshop, Universidad Fernando Pessoa, 9-11 October Porto, Portugal, pp. 1-28.

Barratt, M. & Oliveira, A., 2001. Exploring the experiences of collaborative planning initiatives. *International Journal of Physical Distribution & Logistics Management*, Vol. 31(4), pp. 266-289.

Simatupang, T. M. & Sridharan, R., 2004. A benchmarking scheme for supply chain collaboration. *Benchmarking: An International Journal*, Vol. 11 (1), pp. 9-30.

Simatupang, T. M., & Sridharan, R. 2005. The collaboration index: A measure for supply chain collaboration. *International Journal of Physical Distribution & Logistic Management*, Vol. 35(1), pp. 44-62.

Likert, R., 1932. A technique for the measurement of attitudes. *Archives of Psychology*, Vol. 140(1), pp. 44-53.

Semar. W., 2005. Development of benchmark system for analyzing collaborative group performance as part of an educational online knowledge management system. In: Proceedings of International Conference on Information and Knowledge Engineering (IKE'05). Las Vegas, 20-23 June: CSREA Press, P. 53-59.