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Predicting Technical Communication in Global Product Development Projects Related Change Propagation

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Abstract: Technical communication is a key feature in Global Product Development (GPD) project to coordinate geographically distributed change management process due to a new functionality requirement or technology. Design Structure Matrix (DSM) and Multi-Domain Matrix (MDM) models are effective approaches for predicting technical communication and change propagation, optimizing GPD organization, and reducing change complexity. This paper presents the involvement degree matrix with the notion of gain factors among distributed teams to explore the factors influencing communication frequency in GPD. Further, this paper proposes a method to measure the combined change likelihood matrix based on numerical change propagation paths order, which extends previous change propagation algorithms. Finally, an industrial example is provided to illustrate the proposed models of predicting technical communication related to product's change. Results provide an integrated managerial insight to reflect how change propagation can impact the technical communication among team's organization.

Keywords: global product development (GPD), project management, technical communication, change propagation, design structure matrix (DSM), multi-domain matrix (MDM)

1 Introduction

Global products continually evolve through frequent complex process changes (i.e. redesign). Managing this process across global PD team's coordination barriers become more complex because of the technical communication exchange challenges to reduce the development cost effort within a GPD team organization (Yang et al., 2015). This may lead the project managers and the engineering managers to identify the GPD team organization associated with redesign process (Sosa, 2008). The Design Structure Matrix (DSM) and Multi-Domain Matrix (MDM) (Eppinger and Browning, 2012) are a powerful structural method to model the numerical effects of potential change propagation between components in a complex product, and predict the amount of redesign effort for future changes. Global PD organization is likely to be symmetric (i.e., an actor requires information while the other one provides information) and is typically determined by the directionality of components dependencies. In this paper, we extend previous models proposed by Hamraz et al. (2013) to measure the numerical change propagation in process redesign, and models proposed by Bonjour et al. (2010) and Sosa et al. (2008) to predict technical communication derived from change propagation in GPD project organization. We contribute a systematic method for predicting technical communication in GPD organization using MDM (Section 2). The paper presents a new involvement degree of PD teams in process design related to the factors influencing technical communication. The paper illustrates new numerical DSMs to evaluate the combined change likelihood for multiple potential change propagation order (Section 3). In Section 4, an industrial example is used to verify the proposed model. We conclude the paper in Section 5.

2 Technical communication of GPD teams related to product change using DSM/MDM

Change propagation analysis has been based on the view that the design change of one component can propagate through the interdependence relationships, requiring redesigns of many other components until all components can work together to perform the intended function (Clarkson et al. 2004; Hamraz et al. 2013; Maier et al. 2014).

The likelihood of change (i.e., the probability) can help designers adjust components and interfaces to manage product modularity and evolution. Still other analyses have used DSMs as the basis for calculating various metrics, especially pertaining to modularity (e.g., Chiriac et al., 2011; Sarkar et al., 2013). Researchers also built DSM models of project risks to show the relationships among components and determine the second-order risks emerging from risk interactions (e.g., Fang and Marle, 2012; Marle et al., 2013). Because the implications of design or engineering changes reach across the product, process, and organizational domains, several have used MDM models to investigate change propagation in various industries (e.g., Koh et al., 2012; Mikaelian et al., 2012; Pasqual and De Weck, 2012). Rich MDM models have provided a basis for capturing and storing system-level knowledge about products, design tasks, design organizations, etc. (Tang et al., 2010) and for identifying organizational core competencies (Bonjour and Micaëlli, 2010).

The predicted technical communication in the reorganized GPD organization determines the pair of teams that could potentially handle indirect changes if one component is redesign in the product (Sosa et al., 2008； Bonjour et al., 2010).

Fig. 1 shows the steps of predicting technical communication in GPD organization related to the possibility of change propagation between components in the product DSM (*P_DSM*) (i.e., the estimation of the combined likelihood of change in *P_DSM*) and the involvement degree of a team in the redesign of one component (i.e. $ID(I,i)$).The predicted organization DSM (*O_DSM*) estimates the potential technical communication interactions that would need to coordinate changes in component (i.e., how to reorganize GPD teams if component C_i is redesigned?).Thus, the technical communication of GPD teams related to product change can be calculated by equation 1.

$$O_{DSM\,(I,J)} = \sum_{i=1}^{n} ID(I,i) \times \sum_{j=1,j\neq i}^{n} \left(ID(J,j) \times \left(CL(i,j) + CL(j,i) \right) \right) \quad (1)$$

For the GPD projects, not only the time zone difference but also the dependency relationship between activities will impact the communication efficiency between globally distributed teams. The typical dependency relationship between activities can usually be divided into sequential activities and coupled activities (Eppinger and Browning, 2012). Therefore, the overlapping process can lead to increased synchronous communication. We assume that the synchronous communication between the teams can be negligible if no overlapping exists. In GPD, overlapped coupled activities involve strong communication frequency with more synchronous communication, which is a major driver of project cost and schedule overruns. So, there is a two-way communication between teams performing coupled activities. We present the concept of the team's *Gain Factor* (in the synchronous situation (i.e., GF_S) and the asynchronous situation (i.e., GF_A)) which is defined as the potential gain degree of the team involved in the PD process to emphasize communication in the environment of GPD project. The *communication dependency strength* (*CDS*) between teams related to the redesign process is as follows:

$$CDS(I,J) = PSC(I,J) \times GF_S(I,J) + PAC(I,J) \times GF_A(I,J) \quad (2)$$

$$GF_S(I,J) = \lambda_1 \cdot \lambda_2 \cdot \frac{\ln(\alpha \times T_{OV}(i,j) \times DSWR(i,j) + 1)}{N_I(I) + N_I(J)} \quad (3)$$

$$GF_A(I,J) = \gamma \cdot \frac{\ln(\beta \times DAWR(i,j) + 1)}{N_I(I) + N_I(J)} \quad (4)$$

The *proportion of synchronous communication* (*PSC*) and the *proportion of asynchronous communication* (*PAC*) are the ratio of synchronous and asynchronous communication frequency to the total required communication frequency respectively, and $PAC(I,J)=1-PSC(I,J)$. $N_I(I)$ (or $N_I(J)$) represents the number of individuals in the team *I* (or team *J*) performing activity *i* (or activity *j*). Since larger sizes of the team have fewer opportunities to participate in discussions than team members from smaller teams (Bardhan et al. 2012), so $N_I(I)$ and $N_I(J)$ is the inverse function of GF_S and GF_A (Equations (3) and (4)).

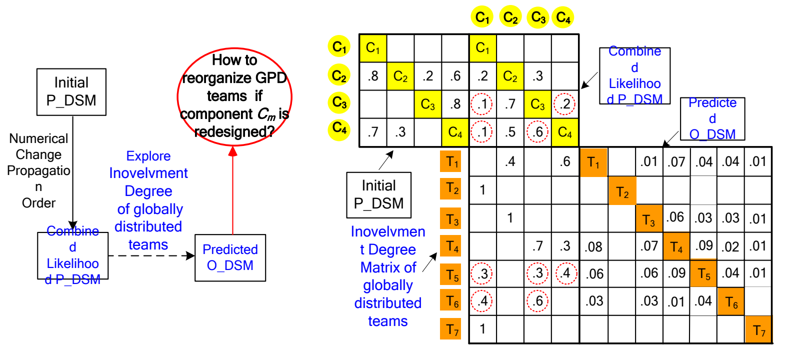

Figure 1. Steps of predicting technical communication of GPD teams related to product change

λ_1 represents the value of different overlapped situation (λ_1=0.5 for the overlapped sequential activities and λ_1=1 for the overlapped coupled activities). λ_2 represents the organization's IT facility for increasing communication of overlapped work in geographically distributed environments. α represents the capability for reducing misunderstanding and communication uncertainty related to spatial distance. *B* indicates the level of importance and emergency of information exchange between teams during shifting working hours. γ represents the IT that can be used by a team's individuals during shifting hours to facilitate asynchronous information exchange. *DSWR* is the *Daily Synchronous Working Ratio* between team's activities as the ratio of *DSWH* to the total working hour of a location's activities (i.e., *WH*(*I*) and *WH*(*J*)).

$$DSWR(i,j) = \frac{DSWH(i,j)}{WH(I) + WH(J) - DSWH(i,j)} \quad (5)$$

DSWH refers to the time of synchronous communication during the workday between teams responsible for overlapped activities.

Because the redesign process of component *m* may involve more than one team, the original *relative communication dependency strength* ($RCDS_O$) of teams *I* compared to the *CDS* of all the involved teams in *m* can be obtained as follows:

$$RCDS_O(I,m) = \sum_{J=1}^{N_T} CDS(I,J)_m \quad (6)$$

where N_T is the size of teams. In order to obtain a normalized $RCDS(I,m)$, the value of $RCDS_O(I,m)$ is divided by the maximum. The involvement degree ($ID(I,m)$) is defined as the ratio of $RCDS(I,m)$ to its entire *RCDS* in the redesign process of all involved components.

3 Combined change likelihood of different change propagation path

Managing change propagation effectively is necessary not only to understand the state of the design and the connectivity between the product's parts but also how design changes could propagate into the organizational structure and the impact of technical communication among the teams involved.

First-Order (Direct) Change Propagation

The initial product DSM indicates the direct effect of change design between components *n* and *m* is the *single likelihood* of first-order change propagation ($SL^{(1)}$).

$$SL^{(1)}(m,n) = DSM(m,n) \quad (7)$$

Second-Order (Indirect) Change Propagation

The $SL^{(2)}$ resulted from the indirect impact of a design change of component *n* on component *m* through an intermediate component *p* (i.e.,$C_n \rightarrow C_p \rightarrow C_m$) (see Fig. 2(a)is:

$$SL^{(2)}(m,n) = \sum_{p=1}^{N_C} SL^{(2)}(m,n) = \sum_{p=1}^{N_C} DSM(p,n) \times DSM(m,p) \quad (8)$$

where $p \epsilon \{1,2,\ldots,N_C\}$, $m \neq n$, $n \neq p$, $m \neq p$.

Third-Order (Indirect) Change Propagation

The $SL^{(3)}$ resulted from the indirect impact of design change of component *n* on *m* through two intermediate components *p* and *q* (i.e.,$C_n \rightarrow C_p \rightarrow C_q \rightarrow C_m$) be calculated without cyclic path (see Fig.2(b)):

$$SL_{p,q}^{(3)}(m,n) = DSM(p,n) \times DSM(p,q) \times DSM(m,q) \quad (9)$$

where $q \epsilon \{1,2,\ldots,N_C\}$.For the situation of the change propagation with cyclic path (see Fig. 2(c)), the $SL^{(3)}$ would also allow a loop for the second component which involves higher coordination costs between redesign teams (Sosa et al., 2013):

$$SL_{p}^{(3)}(m,n) = DSM(m,n) \times DSM(p,m) \times DSM(m,p) \quad (10)$$

The $SL^{(3)}$ from *n* to*m* through all possible intermediate components is:

$$SL^{(3)}(m,n) = \sum_{p=1}^{N_C} \sum_{q=1}^{N_C} SL_{p,q}^{(3)}(m,n) + \sum_{p=1}^{N_C} SL_{p}^{(3)}(m,n) \quad (11)$$

Combined Change Likelihood

The combined change likelihood (i.e., $CL(m,n)$) (see Fig.2(d))refers to the integrated change probability in the design of component *n* leading to a design change in component *m* through all potential change propagation path *z*.

$$CL(m,n) = SL^{(1)}(m,n) \cup SL^{(2)}(m,n) = 1 - \prod_{z=1}^{3}(1 - SL^{(z)}(m,n) \quad (12)$$

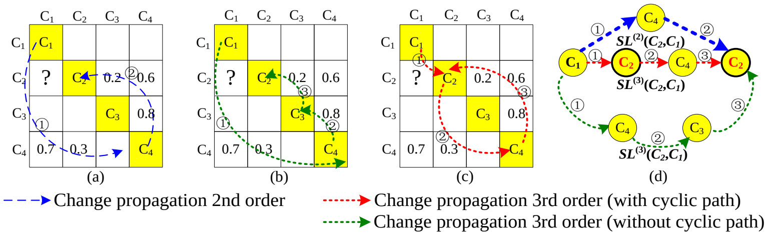

Figure 2. An example of the first, second and third order change propagation

4 Illustrative Example

An industrial example, Wrapper Revamping redesign project or Paradise Food Industry managed by the Italian Cavanna Packaging Group is used. The Wrapper Revamping redesign project is a globally distributed to meet customers' requirements. The technical teams executing the process of the redesign are distributed in four locations across Southern Europe and Northern America: two Italian plants located at Prato Sesia and Turino, two American plants located in Allendale and Duluth. The Involvement Degree Matrix is shown in Fig. 4. We developed the program using Matlab 15 software. The parameters in equations (3) and (4) are evaluated according to the project manager's knowledge and experience.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A		.42						.58										
B				.52					.40				.04		.04			
C	.54								.46									
D						.82		.09			.05		.04					
E		.26	.31									.42						
F			.26				.44									.18	.12	
G				.24						.53				.23				
H					.68								.32					
I	.15									.12								.73
J																		
K						.25								.75				
L		.04						.27	.68				.01					
M				.66	.17							.10			.07			
N																1		
O			.51								.49							
P	.63																.37	
Q							.37						.32			.31		
R				1														
S																	1	
T			.78										.22					
U						.20				.51								.29
V					.40							.60						
W						.55				.18						.27		

Prato Sesia | Allendale | Duluth | Turino

(b)

Figure 4.Involvement Degree Matrix

The original likelihood DSM is elicited from the chief designers, sales managers, and project managers. The combined likelihood is the resulted change propagation after three paths order. $SL^{(1)}(m,n)$ and $CL(m,n)$ are shown in Fig. 5(a) and (b) respectively.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sealing Wheel	1	1	.3		.6											.4			
Zero5 Wrapper	2	.5	2									.7	.7			.3			
Differential Box	3		.8	3			.8	.5									.5		
Servo Motor	4	.5	.8		4					.8									
Dwell Gear Box	5			.8		5												.5	.3
Conveyor	6			.3			6												
Lane Reducer	7		.8	.1				7		.5								.9	
Electrical Panel	8								8										
Screen HMI	9	.4		.3	.1					9									
Row Preparation	10							.6			10			.6					
Buffer Fifo	11	.1										11							
Stream In Feed	12												12						
SBF Loader	13								.8					13					
Crimper Jaws	14			.5						.4			.2		14	.3			.6
Loading System	15	.7														15			
Stacking Device	16			.8								.1					16		
Pull-Nose Device	17					.7												17	
Transfert Unit	18										.4								18

(a) $SL^{(1)}(m,n)$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	.55		.63					.48		.55	.07			.93			
2	.63	2		.72					.69		.48	.60			.98			
3			3															
4	.76	.98		4					.87		.78	.85			.85			
5					5													
6	.62	.46		.54		6					.93	.26			.45			
7	.25	.32		.29			7		.65						.87			
8								8										
9	.85	.83		.91					9		.93	.89			.88			
10	.76			.91			.65	.93	.80	10			.76					
11	.62	.46		.15							11	.69			.25			
12	.42	.93		.31							.39	12			.49			
13								.33					13					
14	.76	.89	.93	.77			.74	.88	.78	.89			.86	14	.87			.84
15	.93	.49		.39					.93		.39	.37			15			
16	.31	.31	.56								.93	.62				16		
17					.83												17	
18							.43	.43	.02	.93			.21					18

(b) $CL(m,n)$

Prato Sesia Duluth Turino

Figure 5. Single and combined change likelihood DSMs

The development organization structure obtained by simulating change propagation is presented in Fig.6(a). We overlap the current organization DSM (i.e., $O\_DSM_C(I,J)$ (calculated by replacing $CL(m,n)$ with $SL^{(1)}(m,n)$ in Eq. (1)) with the predicted $O\_DSM(I,J)$(calculated by Eq. (1)), which is obtained by subtracting $O\_DSM(I,J)$ from $O\_DSM_C(I,J)$(i.e., Δ $O\_DSM(I,J)$). We can present a comparison matrix M whose element $M(I,J)$ can be defined as follows: $M(I,J) = 1 \ If \ \Delta O\_DSM(I,J) = O\_DSM(I,J)$; $M(I,J) = 2 \ If \ \Delta O\_DSM(I,J) = O\_DSM_O(I,J$; $M(I,J) = 3 \ If \ \Delta O\_DSM(I,J) = \alpha_{\in\Re}$. We define the co-affiliation matrix which refers to a couple of teams commonly involve in the redesign of certain components (Field et al., 2006). By overlapping the co-affiliation matrix with the preliminary comparison matrix we can identify truly predicted (unattended) interactions between teams. We introduce the notion of *Team Performance Index* (*TPI*), which refers to a team's performance to align their pattern of technical communication with their pattern of change in design components. *TPI* ranks the teams involved to reorganize the overall organization DSM (see Fig. 7(b) and (c)).

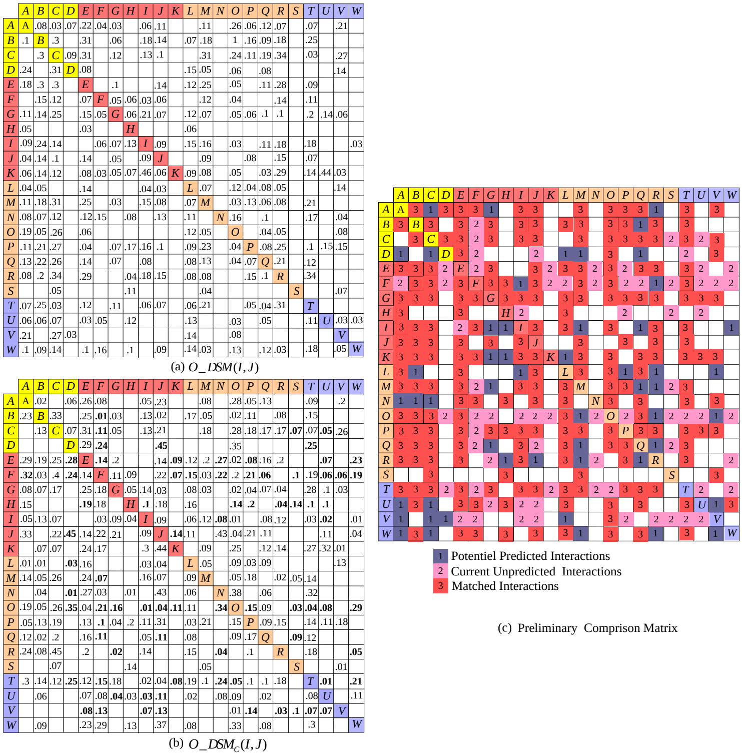

Figure 6. Preliminary comparison analysis

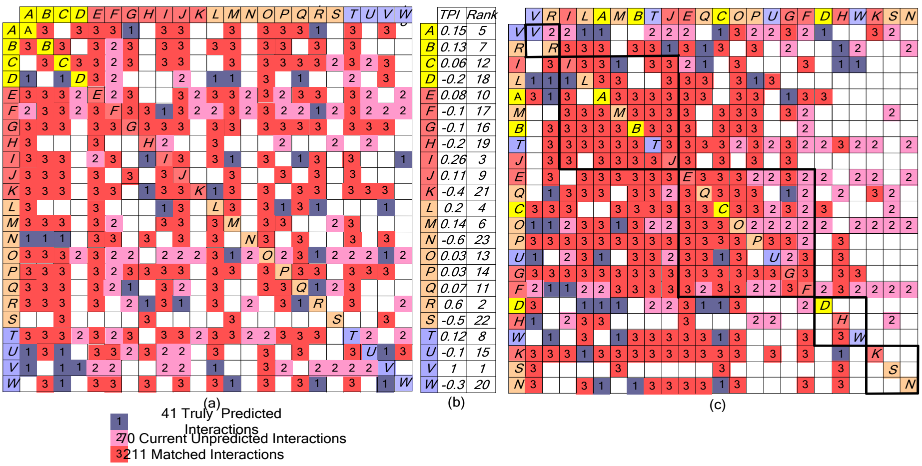

Figure 7. Optimized organization DSM

5 Conclusion

A systematic method for predicting technical communication between geographically dispersed teams related product change in GPD projects has been presented in this paper.

We argue that not only the time zone difference (i.e. downstream activities located at eastern or western time zone compared to upstream activities) but also the dependency relationship between activities (i.e. *overlapped sequential activities* and *overlapped coupled activities*) impacts the communication efficiency between globally distributed teams. In practice, the project manager can utilize our models to predict the potential team organization distributed across geographical boundaries if changes occur in the product architecture.

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