Innovative Solution through Bifocal Thinking: A Case Study of Tacit Knowledge Creation to Optimize Contradictory Performances between Designs and Production Engineering

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Abstract--**This paper examines knowledge creation through transfer of contradictory viewpoints between designs & production engineering (PE) to achieve quick turn activities from design of products to volume productions with significant upgrade of contradictory performances. Through activities of prototyping for design review, the firm finds problems in future volume productions and transfers contradictory viewpoints of designs & PE in the form of suggestions to design team of customers and subsidiary plants of the firm in overseas. The recipients lead incomplete solutions through knowledge sharing in the initial stage and gradually generate bifocal viewpoints through acquisition of the contradictory viewpoints in contexts of suggestions from the firm in the process of application for their own activities. The innovative solutions can be generated by tacit knowledge creation through bifocal thinking to optimize contradictory performances between designs & PE.**

I. INTRODUCTION

In recent years, electronics industries are facing rapid progress of diversified global market and firms have to share development of products and volume productions with different organizations such as inter-firm subsidiary plants in overseas and/or electronics manufacturing service (EMS) firms for the outsourcing [1]. Under such environment, the firms have difficulties to lead optimal solutions for contradictory performances of design & production engineering between organizations. For instance, design activities for ultimate miniaturization with cost reduction affect negative impact for performances of production engineering such as productivity and quality. Firms need to resolve these problems so that they can achieve significant increment of both performances in technology transfer through quick turn activities from development of new products to volume productions. Dyer and Nobeoka [2] indicate that the organizational capability to maintain advantages for productivity and quality can be led by a knowledge sharing network in production process through multi-lateral transfer of tacit knowledge such as know-how among the core firm and suppliers as the results of a case study of automotive firm. Yassine and Braha [3] provide the way for matrix of design structure for complex concurrent engineering to lead shorter development times. Smith and Eppiger [4] describe a model of concurrent engineering to decide between serial and parallel schedule of multiple tasks in two-stage design process to reduce the overall development time. These studies have provided useful insights about process to reduce overall lead times from development of new products to volume productions. However, the indication for the process of knowledge creation to reduce the lead times through timely optimizations of contradictory performances between design and production engineering has not been provided. Segawa & Ikawa [5] indicated the co-activation process of tacit knowledge through a case study of a US-based EMS firm (hereafter called firm "A"). The firm "A" established a unique support system for the design of new products under collaboration with its customers with the transfer of technologies to its overseas subsidiary manufacturing plants for volume productions and succeeds quick turn activities from designs to volume productions with significant upgrade for contradictory performances between designs & production engineering. The purpose of this paper is to examine how knowledge recipients apply tacit knowledge of the knowledge provider for their activities and lead knowledge creation to optimize contradictory performances between designs & production engineering through a case study of the firm "A". Results of this study will provide one of the key aspects for firms who execute outsourcing activities to be successful in globalized operation.

II. THEORETICAL BACKGROUND

A. Review of literatures

Henderson and Clark [6] indicate that the architectural knowledge is embedded in the organizational routine and difficult to destroy. Therefore, the architectural innovation is generated by learning of new knowledge through interactions with different kind of organizations and people with different skills. Nonaka and Takeuchi [7] indicate that the knowledge creation is made by the process of conversion of tacit to explicit knowledge and successive explicit to tacit knowledge circle. Tacit knowledge is able to be transferred from a firm to the other party across organizational boundaries by mutual understanding and trust through experience sharing [8]. Cook and Brown [9] indicate that knowledge is the tool of knowing as actions and categorized four forms such as individual/group and tacit/explicit. New knowledge and new ways of knowing are generated by the interaction between knowledge and knowing as a source of organizational innovation through epistemic practice that is described as coordinated activities of individuals and groups in their real works per organizational contexts. Polanyi [10] explains tacit knowledge using an example that a player of chess gradually acquires tacit knowledge of an expert through repetitive practice of the procedure which the expert did in the game. Nonaka, Toyama, and Hirata [11] describe tacit knowledge as

the distinction between know-how in relation to skills for actions and viewpoints in relation to skills for thinking. Miyazaki and Ueno [12] describe that viewpoints led by experiences are described as the proximal term of tacit knowledge and can be traced from the information to specify viewpoints in the distal term in phenomenal aspects which the viewpoints are applied for actions. Spender [13] indicates the distinction between explicit & implicit knowledge which is defined as preconscious knowledge. Mezirow [14] defines critical reflection as negations of premises on which people's beliefs have been built, and explains that reflection in the context of problem solving commonly focuses procedures or methods but reflection on premises involves critical review of distorted presuppositions.

B. Framework & Research question

Considering review of literatures described on above, the framework of this study is described as follows. Firstly, technologies are defined as technical skills and technology transfer is defined as transfer of technical skills. Expert engineers have superior skills which can be described as procedures, perspectives & benchmark of judgements in the form of manuals or suggestions. Therefore, procedures, perspectives & benchmark of judgements in the form of suggestions can be described as explicit knowledge. Know-how can be described as tacit knowledge in relation to skills for action and viewpoints can be described as tacit knowledge in relation to skills for thinking per the literature [11]. The literature [13] indicates that tacit knowledge has two stages which are unconscious stage with several viewpoints per various experiences and preconscious stage with a particular viewpoint led from various experiences through thinking. The explanation in the literature [10] indicates that tacit knowledge of the expert exists in context of the procedure (explicit knowledge) and can be transferred to the knowledge recipient together with explicit knowledge through the process which the knowledge recipient gradually acquires tacit knowledge of the expert in context of explicit knowledge through repetitive practice. The literature [6] indicates that the innovation is generated by learning of new knowledge through interaction with people who have different skills (viewpoints). The literature [14] indicates that solutions for problem solving can be found through critical review of presuppositions which has been built by people's beliefs.

Per review of literatures on above, we set-up following research questions and execute the case analysis of the process to lead the innovative solution to optimize contradictory performances from the aspect of knowledge creation in association with transfer & acquisition of the different viewpoint through interaction between designers & production engineers.

- *Research question-(1): How can innovative solutions to optimize contradictory performances between designs & production engineering be led through interaction of people with different viewpoints?*
- *Research question-(2): What is the condition to lead the innovative solutions?*

III. CASE STUDY

Per e-mail communication data & meeting minutes, the firm "A" succeeds to optimize contradictory performances between designs & PE and lead quick turn activities from development of new products to volume productions in deals with the customer "C-1" & "C-2" (hereafter called the designer "C-1" & "C-2") as following procedures. Designers need to achieve both ultimate miniaturization & multiple functions besides the cost reduction. These needs in the electrical design data of print circuit board assembly (PCBA) is given by designers to the firm "A". After the activities of prototyping, the firm "A" submits suggestions for design changes to designers and designers modify original designs and submit the re-design data to the firm "A". Both parties repeat the activities a few times in Japan so that designers can optimize over all performances of finished goods. After the completion of designs of PCBAs by designers, the firm "A" transfers technologies, together with suggestions to the subsidiary plant of the firm "A" in China (hereafter called China plant) for the volume production. More than seventy models have been developed by designers, and the firm "A" and designers could achieve time to the market for all new products without any trouble in quality & delivery even difficulties of the technology gradually increased for the development in every six months cycle. The fact indicates that activities of the firm "A" lead optimal solutions for designers & China plant. In other words, designers and China plant lead optimal solutions through application of skills of the firm "A" for their own activities. In order to lead answers for the research questions to optimize contradictory performances between designs & PE, two cases in deals with designers are selected and analysed as follows.

A. Case 1

The contradictory points are described as shown in table 1.

Designers request to place a large size IC under SD Card Connector (SDCC) to save space of placement of components on two sides of the print circuit board (PCB) for further miniaturization as shown in Fig. 1 at almost the same time. The firm "A" submits the proposal for design changes to designers, together with following suggestions. Yields of the large size IC are not so good and the visual inspection will be unable to execute if placement of the IC under SDCC is designed. In order to execute failure analysis and rework of the defective IC, SDCC is necessary to remove and the performances of production engineering such as productivity & quality will decrease with increment of cost in future volume productions. The other solution should be re-considered for the design of miniaturization.

TABLE 1 CONTRADICTORY POINTS OF CASE 1

Positive Point (Design)	Negative point (PE)
Placement of the large size IC under SD card connector (SDCC) can be achieved designs for both multiple functions & miniaturization by saving space for placement of more electric components on the print circuit board (PCB).	Defective ratio of the IC is high and SDCC is necessary to remove in order to execute failure analysis & rework of the large size IC, which generates serious impact for decrement of productivity & quality with extra cost.

(1) Case 1-1

Per the suggestion from the firm "A", the designer "C-1" changes the design to place discrete components such as transistors, diodes and passive components under SDCC instead of the large size IC, but the space saving is not enough.

(2) Case 1-2

After trial & error, the designer "C-1" is aware of the solution to stack two ICs for space saving and asks the firm "A" to examine potential problems in future productions from the viewpoint of PE. Per the suggestion from the firm "A", the designer "C-1" establishes the technology of Package on Package (POP[1]) as shown in Fig. 2. After that, the designer "C-1" applies the new technology for designs for other new products and can achieve significant space saving for miniaturization of products without any decrement of performances of production engineering which 4 or 6 pieces of large size ICs can be placed on half space of 2 or 3 pieces.

(Source: Presentation Material of the firm "A")

Front Side Back Side

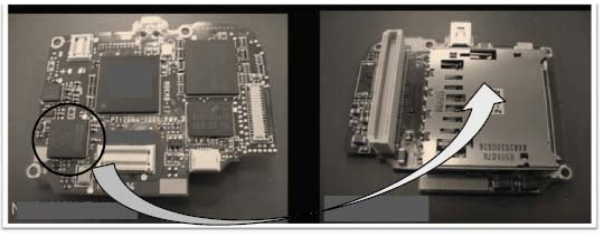

Fig.1 Request for Miniaturization of PCBA

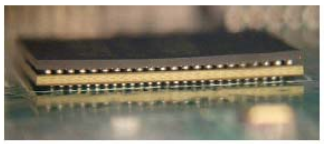

Fig.2 Package on Package

(3) Case 1-3

The designer "C-2" rejects the suggestion from the firm "A" and the firm "A" advises China plant to resolve problems in volume productions through review of the production process. China plant can finally find the solution to execute function test after the completion of placement of all components except SDCC and placement of SDCC is made for only good PCBAs after the function test at the final stage of the process. The designer "C-2" can achieve the original objective to save the space of 1 piece of the large size IC which is placed under SDCC without any negative impact for performances of PE through a new production process which is established by the frim "A" & China plant. However, the designer "C-2" is unable to find solutions for further miniaturization.

B. Case 2

The contradictory points are described as shown in table 2.

Designers requests to place a new IC on flexible PCB for upgrade of the design performance, but heat resistance of the IC is 180 degree C at almost the same time. The firm "A" informs designers of following suggestions. Normal melt solder at 240 degree C is unable to use considering the heat resistance of the IC but low melt solder at 180 degree C is necessary to use for the placement. However, the low melt solder has severe characteristics such as harder & fragiler than the normal one. Structures of the IC are fine pitch & pin (lead less) type and the flexible PCB has characteristic to bend. Due to characteristics of the solder, IC & PCB, the risk of solder defects caused by crack increases in future volume productions at China plant and/or at designers' final assembly lines.

Designers understand the suggestions from the firm "A" and accept to share the risk. The firm "A" advises China plant that the problem is unable to resolve from the viewpoint of the accuracy of placement of the IC but it can be resolved by adjustment of fixtures in the production process of solder printing. China plant can find a solution to adjust thickness of the stencil which is related to volume & strength of solder. The stencil is a fixture for screen printing of solder paste and made by thin metal with fine holes. The solder paste is

TABLE 2 CONTRADICTORY POINTS OF CASE 2

Positive Point (Design)	Negative Point (PE)
Achievement of designs for both increment of performances & miniaturization by placement of fine pitch & lead less type large size IC with characteristics of heat resistance @ 180 degree C on the flexible PCB.	Increment of risk for solder defects caused by crack between the large size IC and bendable flexible PCB due to characteristics of low melt solder @ 180 degree C such as harder & fragiler than normal melt solder @ 240 degree C.

[1] Package on Package is now popular technology, but the customer "C-1" established at very early stage.

printed on PCB through fine hole of the stencil. Thicker thickness of the stencil increases volume & strength of the solder. However, too much increment of the volume of solder generates negative impact for solder defects for the fine pitch IC. China plant can finally find an optimal thickness of the stencil and succeeds to avoid the risk and improves the productivity.

IV. ANALYSIS

Case analysis of interaction between the firm "A" besides China plant (hereafter called the production engineer) and designers can be described as follows.

1) Case 1-1
   The production engineer (PE) provides the proposal of design changes for the designer per the contrary suggestion of problems in future volume productions from the viewpoint of PE. The designer accepts and follows the suggestion from PE. The designer proceeds re-design without any contrivance and led the incomplete solution. Namely, the incomplete solution is led when the designer accepts the suggestion from PE and executes the re-design without any contrivance.
2) Case 1-2
   The designer continues to consider problem solving per the contradictory suggestion of PE and can find a discontinuous solution using the technology of PoP as the breakthrough solution beyond the original objective without any negative impact for performances of production engineering. Namely, the discontinuous solution is led when the designer accepts the suggestion from PE and executes the re-design through deep thinking for the contrivance.
3) Case 1-3
   The designer rejects the suggestion from PE who contrives the solution. The designer can achieve the original objective which is to save the space for 1 piece of the large size IC without any negative impact for performances of production engineering through the contrivance that is made by PE. However, it is an incomplete solution for the designer in comparison to the result of the case 1-2 on above. Namely, the incomplete solution is led when the designer rejects the suggestion from PE who contrives the solution.
4) Case 2
   PE provides the suggestion of problems in future volume productions from the viewpoint of PE, and the designer accepts to share the risk. After that, PE contrives the solution. As the results of problem solving by PE, the designer can achieve the original objective to upgrade the design performance without any negative impact for performances of production engineering. Namely, the incremental solution is led when the designer accepts the suggestion from PE who contrives the solution.
5) The case 1 & 2 on above do not indicate what will happen if PE does not provide the suggestion for the designer or nobody contrives per the suggestion from PE, but it can be described that there is potential risk that both parties will have serious troubles in quality & productivity with extra cost for problem solving & re-designs after the volume production if the suggestion for problems in future volume productions is not given by PE or nobody contrives per the suggestion from PE.

Per the case analysis as described above, process to lead solutions can be described as shown in Fig. 3.

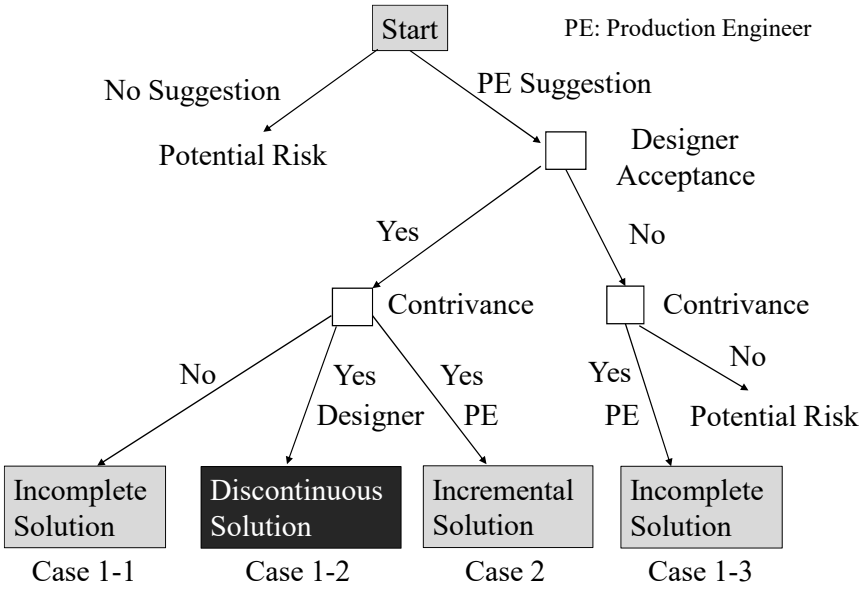

Fig. 3 Process to lead Solution

The case analysis on above indicates that the innovative solution is led through interaction in the case 1-2 which is deals between the designer "C-1" and PE. Interviews with managers of the engineering section of the designer "C-1" (the customer "C-1") & PE (the firm "A") were conducted, which indicate the following interviewee explanations about comment for suggestions of PE, circumstances to find the discontinuous solution (PoP) in the case 1-2 on above and the skills of PE.

- Interviewee-1[2]: Through the prototyping in PE per our design data, PE examine & adjust positions for placement of electric components so that they can verify the ideal positions from aspects of quality & productivity. After that, we receive the proposal of design changes to tune potential problems in the volume production from PE. We can be aware of unknown factors by the suggestions and tune overall designs. We consider that it's wonderful capabilities to be gained through experiences which we have never seen in other firms, and it is great advantages for PE.
- Interviewee-2[3]: We couldn't give up because the activity is absolutely necessary to achieve unique designs for differentiation of the product and finally found the solution of PoP to add more memory chips.
- Interviewee-3[4]: We (PE) have the skill to review both designs & production engineering per experiences when we used to work for the US-based IT firm[5] in Japan.

The interviews indicate that the innovative solution is led through the interaction between PE who can review both designs & production engineering and designer who has empathy & respect for suggestions & skills of PE besides strong desire to achieve unique designs for differentiation of the product.

The literature [10] indicates that tacit knowledge can be traced from the information to specify the viewpoint which is applied for actions. Per the aspect, we analyze the interaction between the designer & PE in the case 1-2 as follows. The designer submits the design objective to PE in the form of design data and PE proposes design changes with the negative suggestion of potential problems in future volume productions through the activities of prototyping which performances of productivity & quality will decrease if the large size IC with higher risk of failure is assembled under the large size connector as shown in Table 1. In the suggestion of PE, there are four factors which the layout design to assemble the IC under the connector where is a blind area of PCB for operators at shop floors, visual inspection, rework & replacement of failure ICs and higher failure rate of the IC. The suggestion indicates that PE connects four factors with potential problems and leads a viewpoint[6] which "performances of productivity & quality will decrease if the layout design to assemble components with higher risk of failure is made on a blind area of PCB for operators at shop floors". The viewpoint is not indicated in the suggestion of PE but it exists in context of the suggestion.

On the other hand, the designer accepts the negative suggestion from PE and finds solution to stack two ICs instead of placement under the large size connector. The action indicates that the designer acquires the negative viewpoint of PE with the designer's own interpretation as new knowledge in context of the suggestion and leads the solution through thinking from both the negative & positive viewpoints per empirical knowledge of the designer to achieve the design objective. For example, the negative viewpoint of PE can be described as a positive viewpoint for the designer to find solution that "performances of productivity & quality will not decrease unless the layout design to assemble components with higher risk of failure is made on a blind area of PCB for operators at shop floors".

V. DISCUSSIONS

Considering the case analysis as described on above, the process to lead the innovative solution to optimize contradictory performances can be described as follows. The designer makes design data (explicit knowledge) per the objective (explicit knowledge) & the designer's own empirical knowledge (unconscious tacit knowledge). The objective is transferred to PE in the form of design data and PE leads a negative viewpoint (preconscious tacit knowledge) from PE's own empirical knowledge (unconscious tacit knowledge) through critical review which PE connects several factors in results of prototyping with potential risk in future volume productions. The viewpoint of PE is transferred to the designer in the form of the suggestion (explicit knowledge) which indicates potential problems in future productions. The designer is aware of the negative viewpoint of PE with designer's own interpretation as new knowledge in context of the suggestion through thinking with empathy and newly leads the positive viewpoint (preconscious tacit knowledge) to achieve the design objective from the designer's own empirical knowledge (unconscious tacit knowledge). The innovative solution to optimize contradictory performances can be led by bifocal thinking per the negative & positive viewpoints through the process of tacit knowledge creation as described on above in the interaction between PE who can review both designs & production engineering and the designer who has empathy &

[2] Manager, Engineering Section of the customer "C-1", interviewed by author, the place of dinner, Nov. 20, 2009.

[3] Manager, Design Section of the customer "C-1" per the meeting minutes on Feb. 7, 2012.

[4] General Manager, New Product Introduction Facility of the firm "A", interview by author, the meeting room of the office, Nov.26, 2009.

[5] The firm "A" acquired the US-based IT firm in Japan and twenty five engineers were transferred to the firm "A" in Oct., 2001.

[6] PE manager of the firm "A" mentioned that he didn't remember that well but the viewpoint was common sense by the phone call on Apr. 4, 2016.

respect for suggestions & skills of PE besides strong desire to achieve unique designs for differentiation of the product.

Considering the case analysis as discussed above, comparisons with similar & conflict literatures are as follows. The literature [6] indicates that the innovation is generated by learning of new knowledge through interaction with different kind of organizations that have different skills and the literature [8] indicates that trust through experience sharing is important for organizational tacit knowledge transfer. We show similar results that innovative solution can be led through the interaction between people with different viewpoints and empathy is important for organizational tacit knowledge transfer. The literature [7] indicates that knowledge creation is made by the process of conversion of tacit to explicit knowledge and successive explicit to tacit knowledge circle and the literature [6] does not indicate the process to lead the innovation. However, we show a process & conditions to lead the innovative solution to optimize contradictory performances through knowledge creation without conversion of tacit to explicit knowledge per a similar process to the explanation in the literature [10] which tacit knowledge of an expert can be transferred to the knowledge recipient together with explicit knowledge such as the procedure and the knowledge recipient can acquire tacit knowledge of an expert in context of the procedure through repetitive practice.

Per the case analysis as discussed above, the answers for the research questions can be described as follows.

- *Research question-(1): How can innovative solutions to optimize contradictory performances between designs & production engineering be led through interaction of people with different viewpoints?*

  The Designer makes design data per the objective & the designer's own empirical knowledge and the objective is transferred to PE in the form of design data. PE connects several factors in results of prototyping with potential problems in future volume productions and leads the negative viewpoint from PE's own empirical knowledge through critical review. The negative viewpoint of PE is transferred to the designer in the form of the suggestion. The designer is aware of the negative viewpoint of PE with the designer's own interpretation as new knowledge in context of the suggestion through thinking with empathy and newly leads a positive viewpoint to achieve the design objective from the designer's own empirical knowledge. The innovative solution to optimize contradictory performances can be led by bifocal thinking per the negative & positive viewpoints through the process of tacit knowledge creation as described on above.
- *Research question-(2): What is the condition to lead the innovative solutions?*

  The innovative solution is led when the interaction is made between the production engineer who can review both designs & production engineering and the designer who has empathy & respect for suggestions & skills of PE besides strong desire to achieve unique designs for differentiation of products.

VI. CONCLUSION

Based on the findings of this study, a process to lead the innovative solution to optimize contradictory performances is proposed as in Fig.4.

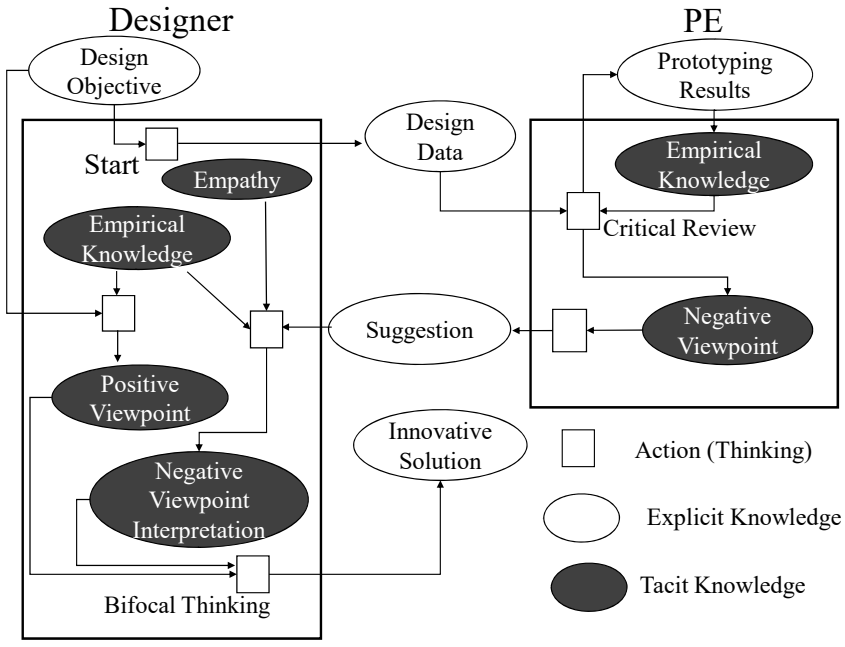

Fig. 4 Innovative Solution through Bifocal Thinking

While firms develop new products in the same location & organization, the knowledge creation with tacit knowledge transfer through face to face interactions can be effective measures. However, in recent years, firms have to share the activities with different organizations to achieve efficient globalized operation. We show a process that the negative viewpoint (tacit knowledge) of the production engineer (PE) can be transferred to the designer in the form of the suggestion (explicit) and the designer newly leads a positive viewpoint from the designer's own empirical knowledge through awareness of the negative viewpoint of PE with the designer's own interpretation in context of the suggestion of PE. The innovative solution to optimize contradictory performances can be led by interaction between PE & the designer who has both contradictory viewpoints to find solution through the process of tacit knowledge creation as described on above. Namely, bifocal thinking through tacit knowledge creation drives quick turn activities from designs to volume productions with significant upgrade for contradictory performances between designs & production engineering and it is one of the key aspects for firms who execute outsourcing activities to be successful in globalized operation.

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