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How Innovation and Improvement Ideas are Created for a Production System by a Kaizen Team: A Protocol Analysis

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Abstract. This paper presents a process model describing how a Kaizen team collectively creates innovation and improvement ideas for a production system and a protocol analysis approach based on the model. The process model captures the team-based creative problem solving practice as a process of updating a shared mental space comprising production system mental models (PSMMs) through exchanging utterances among the team members, where each utterance element characterizes an existing PSMM and/or creates a new PSMM. The paper also applies the proposed protocol analysis approach to an actual case, confirms its applicability and draws some insights into the process.

Keywords: Collective intelligence, continuous improvements, creative problem solving, innovation, mental models, mental space, protocol analysis

1 Introduction

The competitiveness of a production system has a dynamic nature and hence should be maintained through innovations and continuous improvements. How to accomplish them effectively is not simply a matter of choosing an optimal one from a given set of solutions, but is rather the matter of creating the solutions themselves as well as finding the concrete problems to solve. This means that introducing innovations and improvements to a production system should be regarded as another ill-defined creative problem solving process carried out somewhat tacitly by a cross-functional Kaizen team. Consequently, it is not clear how the process should be operated and managed, what kind of supports are possible and effective, etc. to enhance its productivity. Thus, a deeper understanding of the process is strongly demanded.

One may understand the creative problem solving process carried out by a Kaizen team as an idea generation process similar to a well-studied brainstorming session [1][2][3]. However, this view captures only a partial aspect of the process: The members of the Kaizen team not only generate and enumerate innovation and improvement ideas suitable for the target production system but also deepen and share the understanding on the production system as well as evaluate and elaborate the ideas.

Further, the three aspects of the process seem to be mutually coupled tightly together in a synergetic way. Hence, the possible synergy among the aspects should also be well understood to be capable of managing and supporting the process effectively, and it requires a process model suitable for studying the synergy. Thus, this paper proposes a new process model for describing how innovation and improvement ideas for a production system are being created through creative discussion among the members of a Kaizen team from all the three aspects.

Although it is usually not formally externalized during the discussion, the understanding (shared among the team members) on the target production system should form a certain mental model. Thus, the second aspect of the creative discussion can be captured as a kind of group model building [4][5]. However, the structure of the mental models created here seems to be more qualitative and vague than the system dynamics model, which is widely used in ordinal group model building sessions. Hence, an original model structure is developed for the proposed process model. Further, each innovation or improvement idea can be considered as corresponding to how the mental model representing the current status of the production system should be changed. Thus, the process model captures the first and the third aspects of the creative discussion as actions of introducing new mental models and evaluating and refining existing mental models.

Accordingly, the proposed process model treats the team-based creative problem solving process as a sequence of updating a set of mental models of the target production system shared by the team members through exchanging utterances among them. Further, it utilizes a protocol analysis technique [6][7][8] in order to follow the process based on the utterances. In addition, the applicability and utility of the proposed process model and accompanying protocol analysis approach are also confirmed by actually capturing an example practice of discussing how to improve a two-stage assembly cell by them. The analysis reveals some interesting characteristics of the team-based creative problem solving process.

In the remainder of the paper, section 2 presents the proposed process model of the team-based creative problem solving process, and section 3 applies the proposed model to a case and draws some relevant insights into the process. Finally, section 4 concludes the paper.

2 Process Model of Team-Based Creative Problem Solving

2.1 Mental Space and Mental Models

In the situation considered here, a Kaizen team is in charge of conducting innovations and continuous improvements for a production system. The Kaizen team is assumed to be properly motivated and cross-functional having different background knowledge. At least some of the members are familiar with the current status of the target production system.

The process model to be proposed below formally conceptualizes the creative discussion among the team members for collectively creating innovation and improvement ideas for the production system. It outlines the discussion as a process

of producing some output, like a manufacturing process. However, what the discussion process produces is not visible unfortunately. In the case of a manufacturing process, the subject is a visible raw material, part or subassembly, and what transform it are some operations like machining, assembling, etc. Analogically, in the case of the discussion process, an invisible concept on the target production system can be regarded as the subject, and interactions, such as exchanging utterances, among the team members can be deemed as transforming operations. Hence, the key is how to envision the invisible subject and how they are transformed through the discussion process.

Fauconnier [9][10] introduced a schema called *mental space* for visualizing the subject of verbal communication. In order to utilize the aforementioned analogy, the process model proposed here applies this schema and captures the team-based creative problem solving process as a sequence of updating a shared mental space through utterances. The contents of the mental space considered here are limited to those related to the production practice conducted in the target production system, and are called production system mental models (PSMMs). PSMMs can be stated as inter-subjective concepts on the target production system. The PSMMs that appear in the team-based creative problem solving process can be classified into the following two classes:

Real PSMMs: Each of them is a concept regarding the production practice actually conducted or experienced in the target production system.

Imaginary PSMMs: Each of them is a concept made by changing a part of another PSMM. It is a candidate concept of how the target production system should be innovated or improved.

2.2 Characteristics of Production System Mental Models

The mental space shared by the team members contains several PSMMs as described later and each of them is characterized by a number of attributes and the relationships among them. The attributes and relationships can be qualitative and abstract. For enabling a posteriori analysis on the scope of discussion, the attributes of a PSMM are classified into the following three layers:

Objective Layer (OL): This layer includes observable facts in the PSMM.

Subjective Layer (SL): This layer contains unobservable feelings, thoughts and mental tasks of the operators in the PSMM.

Judgmental Layer (JL): This layer gathers interpretations or evaluations on the PSMM of the Kaizen team members.

Further, since the practice of creative problem solving is composed of problem finding and solving activities, the attributes are also distinguished into the following two categories:

Problem-Related (PR): An attribute in this category is related to a problematic situation in the target production system.

Solution-Related (SR): An attribute in this category is concerned with a solution to a problematic situation in the system.

Most attributes of a PSMM are not stand-alone but are related to one another. During the creative discussion process, the team members can elaborate a PSMM not only by adding a new attribute to it but also introducing a new relationship among its attributes. Here, the possible relationships among the attributes of a PSMM are first classified into directional, hierarchical and non-directional: Directional relationships include those from a cause to its effect, from a premise to its consequence, from a reason to its evaluation or interpretation, from a problem to its solution, etc. Hierarchical relationships appear between an abstract characteristic and its detailed features. Whereas, a pair of analogically mapped characteristics or alternative solutions are connected by a non-directional relationship. Then, the relationships can be deemed as corresponding to the following knowledge handling actions:

Ordinal inference: This action is represented in the proposed model by adding a new directional relationship.

Generalization/Specialization: A new hierarchical relationship appears when this action is taken.

Analogical-mapping/Alternative-seeking: Taking this action corresponds to introducing a non-directional relationship.

2.3 State Transitions through Utterances

In the proposed process model, the process of creating innovation and improvement ideas for the target production system through creative discussion among the team members is captured as follows: First, it starts with the initial mental space, called State 0, where there is only an empty real PSMM. Then, as shown in Figure 1, the state is being updated step by step by utterances exchanged among the members. For example, a new attribute is added to an existing PSMM; a pair of attributes are connected by a relationship; a new PSMM is introduced, etc. The PSMMs are numbered in the order of appearance to the mental space.

Since the shared mental space itself is not visible, it must be *reverse-engineered* from the recorded utterances exchanged during the creative discussion. The proposed approach applies a protocol analysis technique for this purpose: After irrelevant parts are screened out from the utterances, they are sorted out into meaningful elements. Then, each utterance element is encoded in terms of on which PSMM it is talking about and what attribute and relationships it adds to the PSMM, as described in the next section.

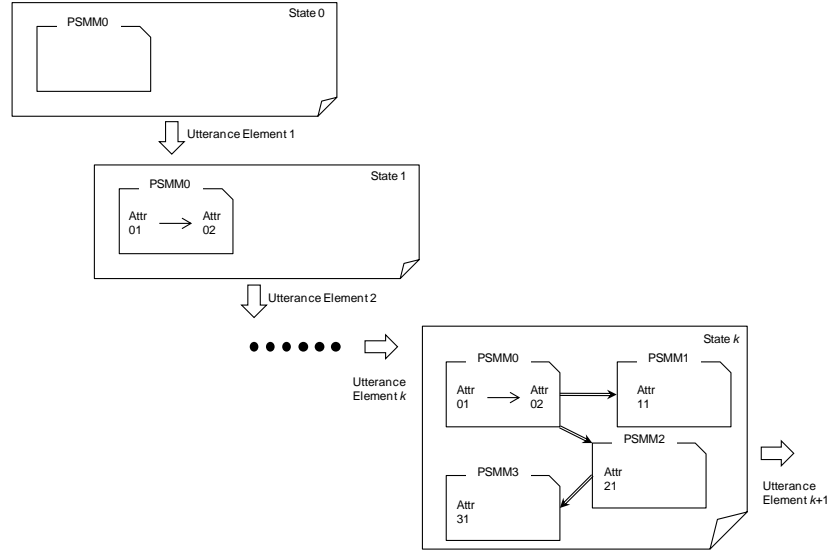


Fig. 1. Overview of proposed state transition model.

3 Case Study

3.1 Case Overview

A two-stage assembly cell for a product (a lego block car) is used as an example production system, and four university students are engaged in the experiment. The experiment is composed of some production sessions and discussion sessions. In a production session, two of the participants actually experience operating the cell and produce 16 products, and the other two members observe the operation as analysts. The assignment of the roles to the participants is determined by the participants themselves. In the following discussion session, which is about one hour long, they discuss how to enhance the production rate of the assembly cell. The innovation and improvement ideas created in the discussion session are actually introduced into the cell, and then the next production session is started. The fee paid to the participants is set proportional to the highest production rate of the production sessions performed in the experiment, and which is announced to them before starting the first production session. It is left up to the participants how to organize the discussion session. However, the number of ideas introduced to the cell after each discussion session is limited up to three, so that they would concentrate on refining ideas rather than simply enumerating simple ones. The discussion sessions are video and voice recorded.

3.2 Encoding Discussion Sessions

The transcript of the utterances exchanged in the first and the second discussion sessions is analyzed according to the proposed state transition model. All the utterances are first extracted from the recorded data and those which are judged not directly related to the creative problem solving practice are screened out. If a certain statement is repeated, only the original one appearing first is included in the analysis and the rests are omitted. The remaining utterances are then divided into elements so that each of them should have a separate meaning. Finally, each utterance element is encoded in terms of the attribute, relation and PSMM introduced in the previous section, respectively.

Table 1 shows a part of the result. For example, the attribute added by utterance element 1 is classified as a problem-related one of PSMM0 in the judgmental layer, and that added by utterance element 2 is encoded as a problem-related one of the same PSMM but in the objective layer. Further, it is considered that the second element introduced a directional relationship from the second to the first attribute and thus functioned as an ordinal inference.

Table 1. Example utterance elements and their codes (translated from Japanese).

| ID | Utterance element | Attribute | Relation | PSMM |
|----|--|-----------|-----------------------|------|
| 1 | The assembly operation in cell 1 is more difficult than that in cell 2. | JL-PR | | 0 |
| 2 | The idle time of operator 2 is almost as long as his working time in each cycle. | OL-PR | Directional (2, 1) | 0 |
| 3 | Inserting operation of operator 1 is sometimes imperfect. | OL-PR | | 0 |
| 4 | There are moments when an operator changes the holding angle of a part. | OL-PR | | 0 |
| 5 | What about making it possible to insert the part without changing its holding angle? | OL-SR | Directional (4, 5) | 1 |
| 6 | There are more parts to be inserted in cell 1 than cell 2. | OL-PR | Directional (6, 1) | 0 |

It is observed during the analysis that the participants themselves sometimes become confused on which PSMM they are currently talking about. Because of this, encoding is most difficult in terms of PSMM. If this analysis can be made online, visualizing the result and feeding it back to the participants will help them prevent themselves from getting lost and stay aware of where they are.

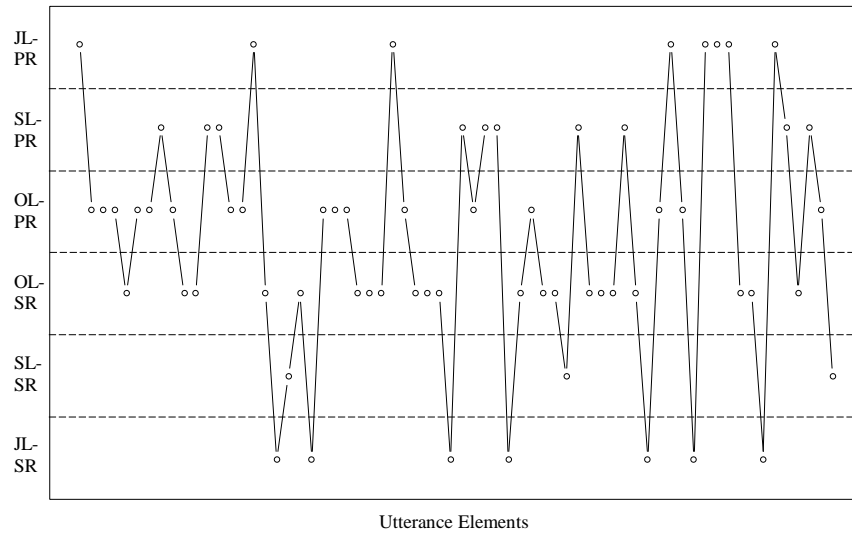


Fig. 2. Sequence of added attributes in discussion session 1.

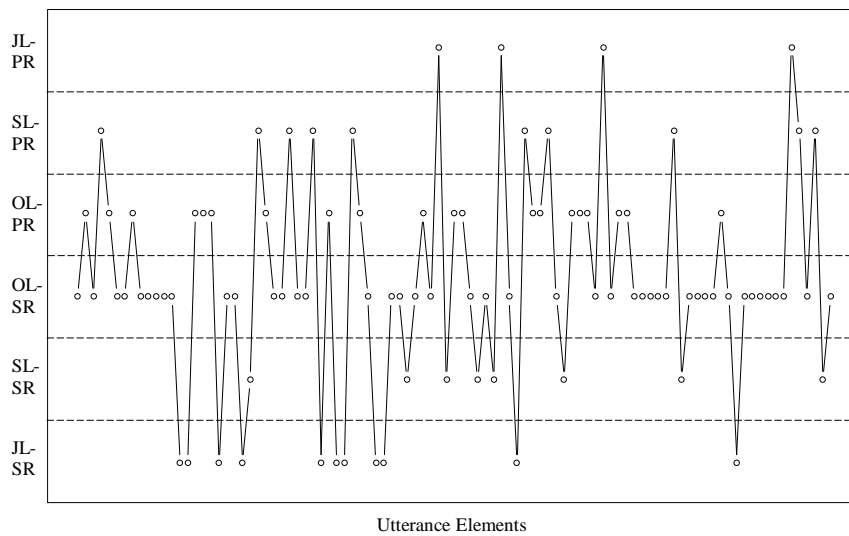


Fig. 3. Sequence of added attributes in discussion session 2.

3.3 Outline of Discussion Sessions

Figures 2 and 3 represent the sequence of added attributes in the first and second discussion sessions, respectively. Although repeated attributes are omitted, an

overview of how the scope of discussion changes along time can be obtained from the figures. What is interesting in the figures is that the scope does not always move from abstract (JL) to concrete (OL) and from problem (PR) to solution (SR) but it moves in the opposite direction almost equally frequently. Further, the distribution of attributes across the scopes does not seem to be stable over the whole discussion process. This implies that the discussion process is composed of several distinguishable phases.

Table 2. Number of attributes added in each scope.

| | JL-PR | SL-PR | OL-PR | OL-SR | SL-SR | JL-SR |
|-----------|-------|-------|-------|-------|-------|-------|
| Session 1 | 8 | 10 | 17 | 21 | 3 | 7 |
| Session 2 | 4 | 10 | 20 | 44 | 8 | 11 |
| Total | 12 | 20 | 37 | 65 | 11 | 18 |

Table 2 shows the number of attributes added to each scope during the sessions. It is noticed that the distribution is quite similar between sessions 1 and 2. For example, many attributes are located in the objective layer (OL) in both sessions. It suggests that this layer is used as the main field of elaborating problems and solutions. Further, there are more solution-related attributes than problem-related ones in the objective layer (OL), but the opposite is true in the subjective layer (SL). This interesting feature suggests that objective solutions tends to bring about subjective side effects in one's mind and vice versa.

Table 3. Frequencies of scope changes in discussion session 1.

| | JL-PR | SL-PR | OL-PR | OL-SR | SL-SR | JL-SR |
|-------|-------|-------|-------|-------|-------|-------|
| JL-PR | 2 | 1 | 3 | 2 | | |
| SL-PR | | 2 | 4 | 3 | | 1 |
| OL-PR | 2 | 2 | 6 | 5 | 1 | 1 |
| OL-SR | 1 | 3 | 2 | 9 | 1 | 5 |
| SL-SR | | 1 | | 1 | | |
| JL-SR | 2 | 1 | 2 | 1 | 1 | |

Table 4. Frequencies of scope changes in discussion session 2.

| | JL-PR | SL-PR | OL-PR | OL-SR | SL-SR | JL-SR |
|-------|-------|-------|-------|-------|-------|-------|
| JL-PR | | 1 | | 2 | 1 | |
| SL-PR | | | 4 | 3 | 2 | 1 |
| OL-PR | | 1 | 7 | 10 | | 2 |
| OL-SR | 3 | 5 | 5 | 21 | 4 | 5 |
| SL-SR | 1 | 1 | 2 | 4 | | |
| JL-SR | | 2 | 2 | 3 | 1 | 3 |

Tables 3 and 4 show the frequencies of scope changes in sessions 1 and 2, respectively. The focus of discussion moved from a scope corresponding to the row to

the next one corresponding to the column. The distributions shown in the tables are also similar to each other. Further, as conjectured above, the focus moved frequently within the objective layer (OL) as well as from/to the problem-related scope in the subjective layer (SL-PR). It is also noticed that the focus sometimes moved from the solution-related scope in the objective layer (OL-SR) to the solution-related one in the judgmental layer (JL-SR) and then to various ones. This suggests that a judgment of a member given to a concrete solution functions as a watershed of the discussion flow.

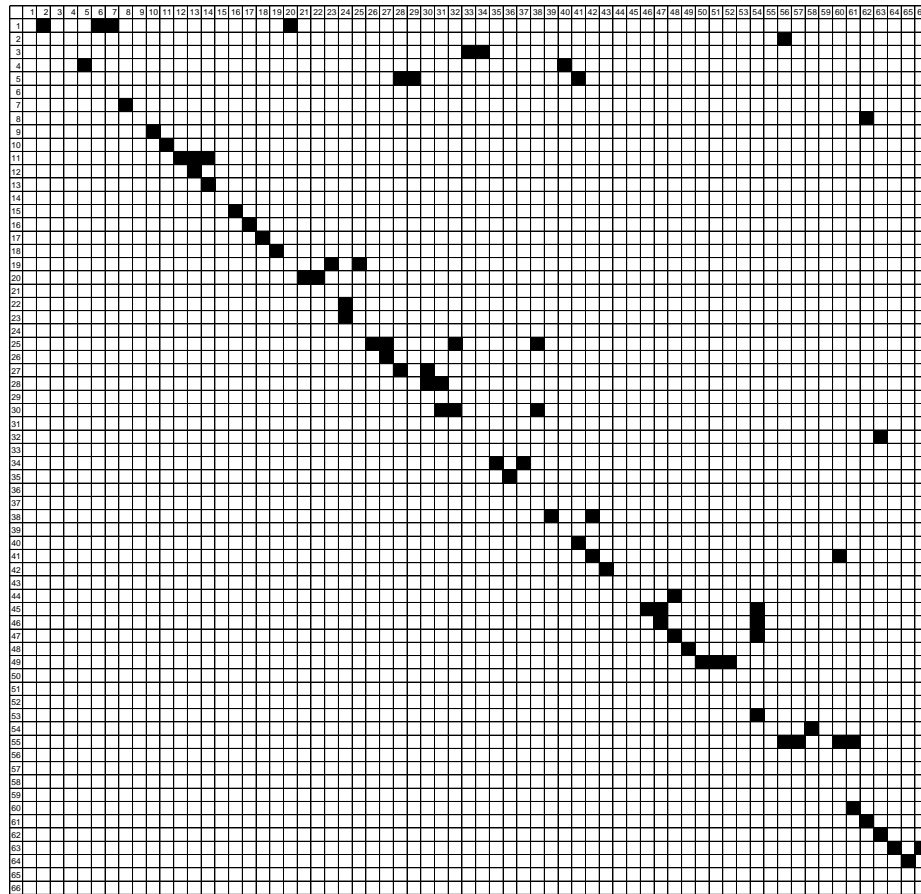


Fig. 4. Pairs of attributes for which relationships are given in discussion session 1.

Figures 4 and 5 visualize the upper triangular matrices showing between which attributes relationships are given in sessions 1 and 2, respectively. Each blacked out box represents that one of the relationships defined earlier is introduced between the attributes corresponding to the row and the column. The distributions of the black boxes in the figures are even surprisingly similar to each other. That is, there are many local clusters along the diagonal line as well as some plots away from the line, which represent occasional relationships between attributes far away from each other.

Those attributes to which relationships are introduced even from far downstream may be regarded as functioning as the main topics of discussion.

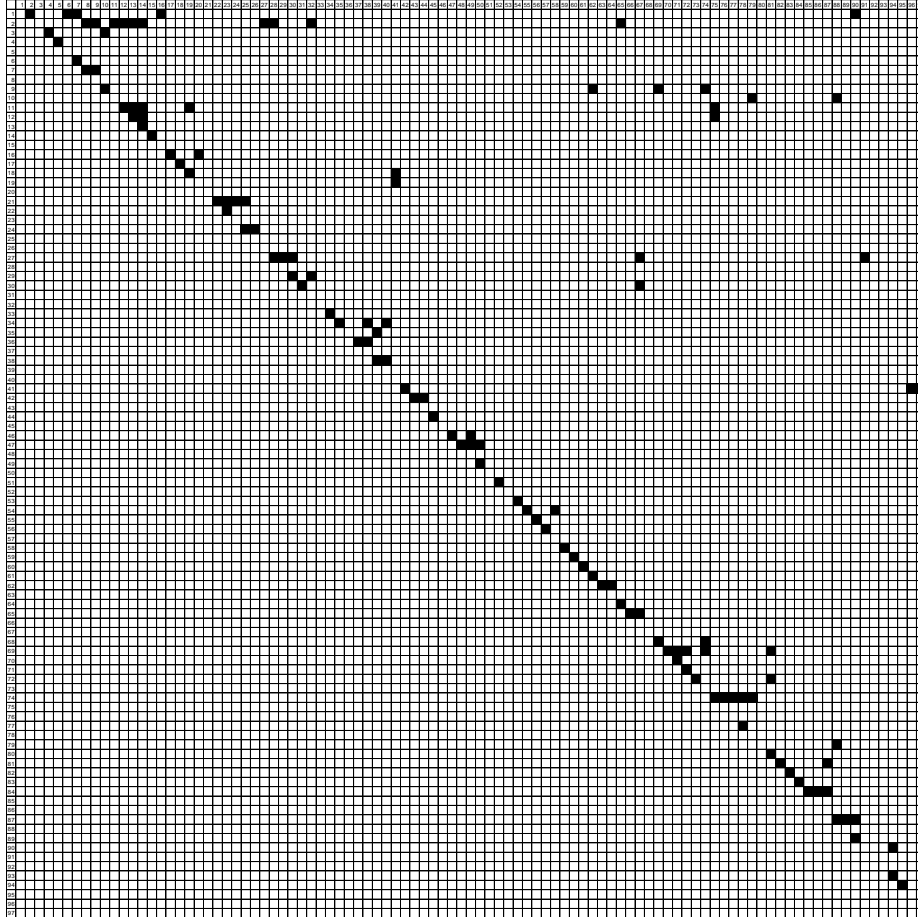


Fig. 5. Pairs of attributes for which relationships are given in discussion session 2.

3.4 Knowledge Handling Actions

This subsection studies the knowledge handling actions taken in the discussion sessions. Table 5 sorts out the frequencies of the ordinal inference actions, that is, the directional relationships introduced in the sessions. Each of them derives an attribute in the scope corresponding to the column from another in the scope corresponding to the row. The table shows that this action is quite frequently taken between various scopes, which are not only from problem to solution but also within problem, within solution and even from solution to problem.

Table 5. Frequencies of ordinal inference actions.

| | JL-PR | SL-PR | OL-PR | OL-SR | SL-SR | JL-SR |
|-------|-------|-------|-------|-------|-------|-------|
| JL-PR | | | | 7 | | 1 |
| SL-PR | 1 | 2 | 2 | 8 | | |
| OL-PR | 8 | 9 | 7 | 12 | 1 | 4 |
| OL-SR | 3 | 9 | 13 | 4 | 8 | 7 |
| SL-SR | | | | 1 | | 1 |
| JL-SR | | | 1 | 1 | | 2 |

Table 6 summarizes the frequencies of the generalization/specialization actions, that is, the hierarchical relationships defined in the sessions. Each of them connects an abstract characteristic in the scope corresponding to the row and its detailed feature in the scope corresponding to the column. It is observed in the table that this action is also frequently taken and, in most cases, the detailed feature lies in the objective layer (OL). This action is usually used within problem or within solution but between problem and solution.

Table 6. Frequencies of generalization/specialization actions.

| | JL-PR | SL-PR | OL-PR | OL-SR | SL-SR | JL-SR |
|-------|-------|-------|-------|-------|-------|-------|
| JL-PR | 3 | | | | 1 | |
| SL-PR | | 1 | | | | |
| OL-PR | | | 3 | | | 1 |
| OL-SR | | | | 33 | | |
| SL-SR | | | | | | |
| JL-SR | | | | 14 | 1 | 1 |

Table 7 shows the frequencies of the analogical-mapping/alternative-seeking actions, that is, the non-directional relationships mentioned in the sessions. Each of them bridges between a pair of attributes in the scopes corresponding to the row and column. Since the relationship is non-directional, the table is a lower triangular matrix. The table shows that this action is frequently taken and it is mostly within solution. It implies that this action is an effective vehicle for exploring the solution space. It is further observed that this action can be used not very often but also within problem and even between problem and solution.

Table 7. Frequencies of analogical-mapping/alternative-seeking actions.

| | JL-PR | SL-PR | OL-PR | OL-SR | SL-SR | JL-SR |
|-------|-------|-------|-------|-------|-------|-------|
| JL-PR | | | | | | |
| SL-PR | | 1 | | | | |
| OL-PR | | 1 | 3 | | | |
| OL-SR | | | 1 | 22 | | |
| SL-SR | 1 | 2 | | 1 | | |
| JL-SR | 1 | | | 2 | | 1 |

4 Conclusions

This paper proposed a state transition model for analyzing how a Kaizen team collectively creates innovation and improvement ideas for a production system, and captured actual sessions of creative discussion according to the process model. The analysis shows that the team-based creative problem solving practice is not a simple unidirectional process from abstract to concrete and from problem to solution. It is also observed that knowledge handling actions, such as ordinal inference, generalization, specialization, analogical-mapping, alternative-seeking, are frequently used in the process.

A future research direction is to reveal standard features of the team-based creative problem solving process by conducting more case studies. Further, it is also an interesting challenge to develop the proposed process model into a systematic tool for supporting the discussion process of creating innovation and improvement ideas for a production system. Possible directions of this include cognitive support by using the model as a computerized minute, automatic proposition of potentially effective knowledge handling actions, creativity support by combining the process model with TRIZ [11], etc.

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