

# Analysis and Classification of Karakuri Technologies for Reinforcement of Their Visibility, Improvement and Transferability: An Attempt for Enhancing Lean Management

Hiroshi Katayama<sup>1</sup>, Kenta Sawa<sup>2</sup>, Reakook Hwang<sup>3</sup>,  
Norio Ishiwatari<sup>4</sup> and Nobuyuki Hayashi<sup>4</sup>

<sup>1</sup>Faculty of Science and Engineering, Waseda University, Tokyo, Japan

<sup>2</sup>Department of Industrial and Management Systems Engineering,  
School of Creative Science and Engineering, Waseda University, Tokyo, Japan

<sup>3</sup>Samsung Economic Research Institute, Seoul, Korea

<sup>4</sup>Sankyu Inc., Tokyo, Japan, Japan

**Abstract**--Karakuri technology, a member technology of lean management, is a unique method that aims to contribute environmental and labour issues by utilizing natural physical phenomena and related useful elemental mechanisms. Recent years, their developed works and application tend to become black box-like due to maniac development as well as technology advancement. Recognizing this situation, this paper proposes to utilize a template procedure for effective analysis and improvement of this technology for successful knowledge transfer among experts and beginners. Also, aiming to extract useful information on further development and improvement, it analyses the relations among various elements of this technology by statistical quantification model. An example application is also given for demonstrating relevance of obtained information.

## I. INTRODUCTION

Lean Management is well-known strategic management method and concept born in Japan[17] and globally propagated by US experts[18]. This management system consists of various module technologies and tools[10][11][14] with durable concept that enables to transfer it among industries and nations. All of these intend to contribute organizational performance and amount of evidence are accumulated in many companies, which are operating under this scheme. Within the module technologies, Karakuri technology is a Japan unique method, which aims to utilize natural physical phenomena, such as gravity force, wind, electromagnetic power etc. and elemental mechanisms, such as lever, link (force transmission), pulley mechanisms etc[16]. Distinctive merit of this technology is enabling environment friendly operations, *i.e.* energy-saving, work-load mitigation, operational simplification etc. and number of useful case works have been developed and/or under-developing by many professionals as well as researchers.

However, it tends to be quite sophisticated and complicated these years due to maniac development and technology advancement. Eventually, it became black-box like technology even for expert production engineers and most of young generation engineers have been isolated from it. To recover such hopeless situation, it is urgent to provide a comprehensive system to develop and improve this technology for the people who will succeed this asset. Based

on this understanding, this paper aims to clarify structural elements and the way to construct Karakuri contrivances through analysis of various cases offered by industry-side. This approach and information being organized might contribute knowledge transfer of this technology among manufacturing engineers and managers.

To perform effective analysis, relations among attributes of each Karakuri case, namely the objectives, its functions provided, utilized essential mechanisms and elementary contributors (natural phenomena, law in physics etc.) are intended to categorize and useful information for its reinforcement, *e.g.* what kind of elementary contributors are chartered for successful construction of specific essential mechanism, is anticipated to extract in terms of proximity data among aforementioned attributes. This analysis is performed based on the template procedure proposed in our past research[8]. Especially, for the latter proximity issue, a statistical quantification model[1] with its extension[12] is considered to apply. Then, some application example will be developed as case study for validation of our proposal.

Contents of this paper include outline of the template procedure, some introductory explanation on Karakuri cases that have been collected from companies keen on this technology[4], example applications for analysis of their mechanisms and finally, demonstration of revised mechanism for further improvement of operational performance. All of these might contribute successful knowledge transfer on the related technology among experts and beginners.

## II. BACKGROUND OF THIS STUDY

In this section, situation surrounding Karakuri technology including various efforts by industries and past research, is summarized. Distinctive activity that must be mentioned is Karakuri Exhibition[4][5][6] managed by Japan Institute of Plant Maintenance (JIPM), which was launched in 1993. This event has been held every year in Tokyo and Nagoya alternatively and, before the launch of this event, long-term, deep and substantial experience have been accumulated among driving industries such as car assemblers and parts suppliers[3][9][13][15].

Looking at academic research contributions, there are very

few numbers of papers on this subject. Therefore, international conference is a quite important vehicle in the meaning of knowledge sharing and transfer especially on this subject. One typical contribution in the past is on proposal of template procedure for Karakuri analysis[8], which aim to provide a weapon for easy understanding of essential mechanisms of Karakuri cases developed by experts. This template consists of 15 critical attribute issues which must be described in the specific format sheet through investigation. Specification of this template is given below.

1. Title of Improvement Project: Automatic Return of Trays (Example)
2. Company Name: Company A (Example)
3. Nickname of the Case: B (Example)
4. Objective Operation: Parts Transportation and Automatic Return Operation of Trays (Example)
5. Feature: Variety of Parts Shape and Weight, Automatic Transportation of Heavy Parts (Example)
6. Overall Structure of Karakuri Contrivance: (Example)  
 Fig. 1 and 2 illustrate overview of the equipment and essential structure of Karakuri mechanism which are provided by the company and drawn by our laboratory respectively.
7. State Definition of Karakuri Contrivance: (Example)  
 Table 1 is for the definition of the elements and their states of Karakuri mechanism.

Critical issues for creating this table are to identify composed elements of Karakuri and to define the possible states of each element.

Then, we can move to the next step, investigation of state transition of each element, by using analysis sheet (See Table 2). This sheet consists of all the other issues from “8. Elementary Operations” down to “15. Other Merits” and analyser, watching video, have to fill the related spaces in the sheet carefully.

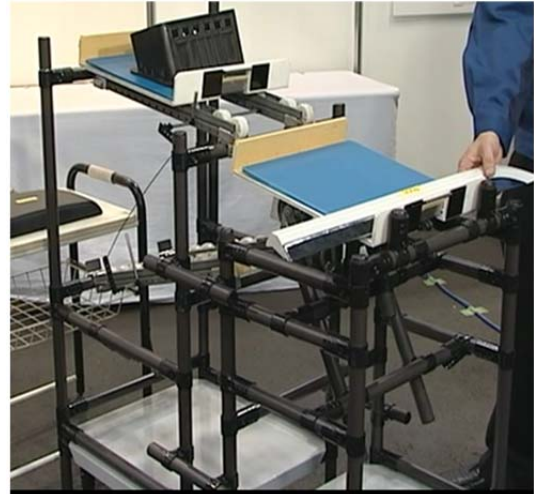


Fig. 1. Overview of the Equipment (Example) [7]

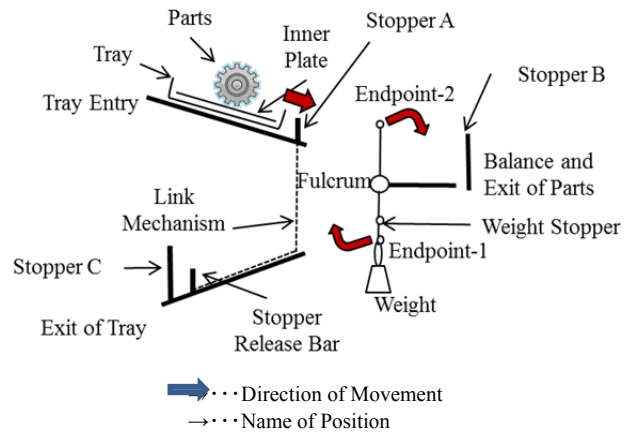


Fig. 2. Structure of the Karakuri Contrivance[7]

TABLE 1. DEFINITION TABLE OF ELEMENTS AND THEIR STATES OF KARAKURI MECHANISM[7][8] (FOCUS ON THE ELEMENTS THAT TAKE SIGNIFICANT STATE CHANGE)

Elements	Functions	States (Code No.: Description of Status)	Way of State Transition/Mechanism
Tray A	-Work Holding -Work Transportation	0: Initial state (Before parts entry)	Gravity Force and Implemented Mechanisms
		1: Tray with parts is at the entry point	
		2: Tray with parts is at the exit point	
		3: Empty tray is at the exit point	
		4: Empty tray is at the tray return point	
....	....	....	....
Balance	-Tray Holding -Tray Transportation	0: Initial state (Vacancy)	Mechanism of Stopper B and Weight Slide Mechanism
		1: Tray with parts is loaded	
		2: Tray without parts is loaded	
Weight of Balance	-Deceleration of tray supply by buffer mechanism -Acceleration of tray forwarding by inclination mechanism	0: Initial state (Located at the endpoint-1)	Gravity Force
		1: Located at the point of weight stopper	

TABLE 2. ANALYSIS SHEET OF KARAKURI STATE TRANSITION [7][8]

Sequence No.	8. Elementary Operations	9. State and Transition of State	10. State Description (After Transition)	11. Sequence of Karakuri Operation	12. Elementary Mechanisms	13. Functions	14. Provided Value	15. Other Merits
I	Initial State Setting	State 0 Tray A: 0 Tray B: 0 Stopper A: 0 Stopper release bar: 0 Balance: 0 Weight of balance: 0		—	—	—	—	—
III	Tray A and B with parts are loaded	State 0 → State 1 ⊙Tray A: 0→1 ⊙Tray B: 0→1 ⊙Balance: 0→1 ⊙Weight of balance: 0→1 Stopper A: 0 Stopper release bar: 0		①Tray A with parts and Tray B with parts are settled at entry and exit respectively. ②When Tray B is loaded on the Balance, it inclines to Endpoint-2 ③Weight moves to the position at Weight Stopper	<b>-Balance Mechanism</b> <b>-Weight Sliding Mechanism</b>	<b>-Setup Function (by Setting Tray A and B with Parts)</b> <b>-Position Fixing Function (by Stopper A and B)</b>	-Labour -saving Setup - Position Fixation by one action	Capable for various items to transport (Shape, Weight)

III RESEARCH PROCEDURE

Understanding the above procedure, following 5 steps is performed to attain the purpose of this research.

STEP 1: Collection of Karakuri cases → 23 Karakuri cases are obtained in collaboration with JIPM headquarters and 15 of them are adopted for further analysis.

STEP 2: Definition of Karakuri elements and their structure → Feature of Karakuri technology is summarized by case attributes such as (1) Purpose, (2) Functions, (3) Karakuri mechanisms and (4) Elementary phenomena/mechanisms. Structural relations between specific attributes are established for detail analysis, i.e. Bill of Function (BOF) between purpose and functions, Bill of Karakuri Mechanisms (BOK) between function and Karakuri mechanisms and Bill of Elementary

Phenomena/Mechanisms (BOP) between Karakuri mechanism and elementary phenomena/mechanisms.

STEP 3: Extraction of relevant Karakuri elements from cases and their classification → Based on the outcome of Step 2, relevant elements of Karakuri cases are classified in to 4 categories.

STEP 4: Relation analysis among elements by statistical quantification model → Quantification Model III[1][2] and its extended version are adopted, where the formulation of the latter is given.

STEP 5: Summary of the results → Outcomes obtained from Step 3 and 4 are summarized in terms of the proximity data among elements belonging to adjacent level of categories.

STEP 6: Improvement of Karakuri contrivance → A Karakuri case is selected and examine its improvement by utilizing proximity data identified in Step 4.

IV. ANALYSIS OF KARAKURI MECHANISMS: CASE STUDIES (STEP 2 AND 3)

Suppressing detail description on Step 1 due to intellectual property issues, this section start from Step 2. Fig. 3 illustrates the hierarchical relation of BOF, BOK and BOP. Table 3 and 4 summarize the attribute members of each category with the code number of the Karakuri case that each element comes from.

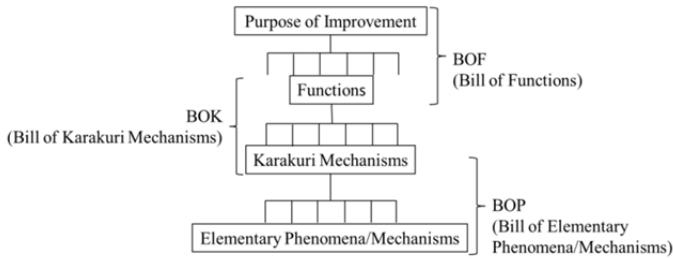


Fig. 3. Bill structure of Improvement by Karakuri Mechanisms

TABLE 3. SET OF IMPROVEMENT PURPOSES

Purpose of Improvement	Cases	
	Code No.	Objective Operations
Improvement of Work Efficiency	1	Stacking
	2	Turn-rounding
	3	Return Operation
	4	Cutting
Work Automatization	5	Work Rotation
	6	Pallet Supply/Return Operation
	7	Pallet Stacking/Return Operation
Work-load Reduction	8	Transportation
	9	Lifting by Equipment /Transportation
	10	Manual Lifting/Transportation
Working-hour Reduction	11	Seal Removing Operation
	12	Residual Removing Operation
	13	Screw Bolt Setting
Fixed Quantity Picking	14	Screw Picking
Scatter Prevention	15	Sand Manipulation Work

TABLE 4. SET OF FUNCTIONS

Functions	Code No.
Labour Power-saving	1,2,3,5,6,7,8,13
Output Amplification	9,10
Support of Transportation	1,3,5,6,7,8
Support of Rotation Movement	2,4,5,11
Change of Direction	2,5,13,14
Change of Power Direction	6,7,9,10,12,15
Power Generation	4,6
Control of Movement	5,14
Position Fixation	2,4,6,9,10
Termination of Movement	5,7,8,11,12,13
Release of Restraint	2,4,6,9,10
Switching	2,4,11
Power Transmission	1,2,3,4,6,7,8,9,10,12
Avoidance of Defect (Fuguai)	2,6
Movement Termination	4,6

TABLE 5. SET OF KARAKURI MECHANISMS

Karakuri Mechanisms	Code No.
Seesaw Mechanism	1,5,7,14
Balance Mechanism	6,9,10
Rotation Mechanism	2,4,5
Stopper Mechanism	5,6,7,8,11,12,15
Lock-up/Release Mechanism	2,4,6,9,10
Clutch Mechanism	2,4,11
Link Mechanism	1,2,3,4,6,7,8,9,10,12
Pokayoke Mechanism	2,6
Slide Mechanism	1,3,5,6,7,8
Pulley Mechanism	6,9,10
Magnet Mechanism	14

TABLE 6. SET OF ELEMENTARY PHENOMENA/MECHANISMS

Elementary Phenomena/Mechanisms	Code No.
Gravity Force	1,5,6,7,9,10,14
Lever Mechanism	1,5,7,14
Weight-shift Mechanism	1,5,6,7,9,10
Friction	1,3,5,6,7,8
Cam Mechanism	2,4,5,6,7,8,9,10,11,12,15
Spring Mechanism	2,4,11
Roller Mechanism	1,2,3,4,5,6,7,8,9,10
Magnetic Force	14

Hereafter, some of the typical examples of Karakuri mechanisms are explained for better understanding.

- The first example is Seesaw mechanism. Fig. 4 illustrates how it works and is utilized. This case is given from one of the main car assembly factories of company X. This mechanism provides automatic turn operation of the work when it is set on the Karakuri-equipped particular tray. Sequence of the movement is like this. Put the work on the tray → Tray inclines to left-side → Tray start to turn left till 90 degrees due to shift of the center of gravity → Then, pick-up operation become easier than before as the position of work changed (See also Fig. 5).

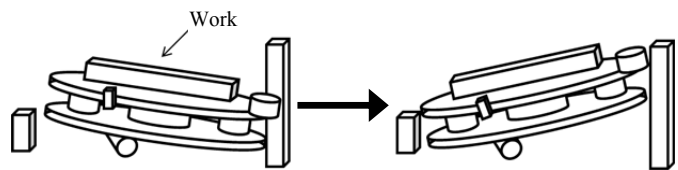


Fig. 4. Example of Seesaw Mechanism (Case of position change of work)

- The second example is Stopper mechanism. Fig. 5, which shows the subsequent movement of Fig. 4, illustrates how it works and is utilized. This mechanism provides automatic stoppage of the movement and sequence is like this. (Continued from first example) → Tray start to turn left till 90 degree due to shift of the center of gravity → When tray reaches 90 degree of turn, turn terminates immediately as two stopper A and B equipped in this Karakuri make collision.

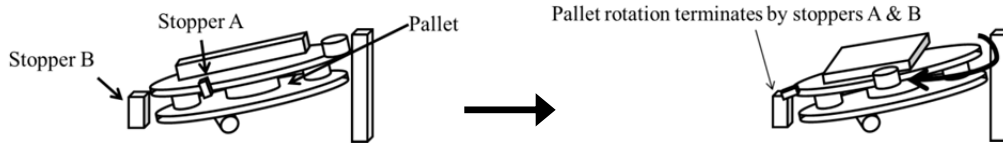


Fig. 5. Example of Stopper Mechanism (Case of position change of work)

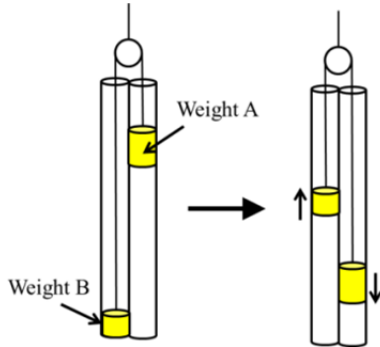


Fig. 6. Example of Pulley Mechanism (Case of vertical movement of weights)

Lock is released → Weight A start comes down and weight B comes up due to the former is heavier than the latter, of which operation is enabled by opposite force directions that equipped pulley actuates.

Table 7 is summary of entire BOF-concerned information obtained through examination of data.

Where, each column and row represents functions and purpose respectively and each figure represent observed frequency of the related combination.

Table 8 is summary of entire BOK-concerned information, where each column and row represents Karakuri mechanisms and functions respectively. Also, Table 9 is summary of entire BOP-concerned information, where column and row represents elementary phenomena/mechanisms and Karakuri mechanisms respectively.

- The third example is Pulley mechanism. Fig. 6 illustrates how it works and is utilized. This mechanism provides automatic vertical movement and sequence is like this.

TABLE 7. BOF (BILL OF FUNCTIONS)

Purpose of Improvement	Case Operations	Functions														
		Labour Power-saving	Output Amplification	Support of Transportation	Support of Rotation Movement	Change of Direction	Change of Power Direction	Power Generation	Control of Movement	Position Fixation	Termination of Movement	Release of Restraint	Switching	Power Transmission	Avoidance of Defect (Fugate)	Movement Termination
Improvement of Work Efficiency	Stacking	1	0	1	0	0	0	0	0	0	1	0	0	0	1	1
	Turn-rounding	1	0	0	1	0	0	0	0	1	0	1	0	0	1	0
	Return Operation	1	0	1	0	1	1	0	0	1	0	1	0	1	0	0
	Cutting	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1
Work Automatization	Work Rotation	1	0	1	1	1	0	0	1	0	0	0	0	0	0	1
	Pallet Supply /Return Operation	1	1	1	0	0	1	1	1	1	0	1	0	1	1	1
	Pallet Stacking /Return Operation	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0
Work-load Reduction	Transportation	0	0	1	0	0	0	0	1	1	0	1	1	1	1	0
	Lifting by Equipment /Transportation	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0
	Manual Lifting /Transportation	0	1	1	0	0	1	0	0	1	0	1	0	0	0	0
Working-hour Reduction	Seal Removing Operation	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0
	Residual Removing Operation	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0
	Screw Bolt Setting	1	0	1	0	1	0	0	0	0	1	0	0	1	1	0
Fixed Quantity Picking	Screw Picking	1	0	1	0	0	0	0	0	0	1	0	0	0	1	0
Scatter Prevention	Sand Manipulation Work	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0

TABLE 8. BOK (BILL OF KARAKURI MECHANISMS)

Functions	Karakuri Mechanisms										
	Seesaw Mechanism	Balance Mechanism	Rotation Mechanism	Stopper Mechanism	Lock-up/Release Mechanism	Clutch Mechanism	Link Mechanism	Pokayoke Mechanism	Slide Mechanism	Pulley Mechanism	Magnet Mechanism
Labour Power-saving	3	0	3	1	0	3	4	0	4	0	1
Output Amplification	1	0	0	0	0	0	1	0	0	1	0
Support of Transportation	3	0	3	0	0	0	4	0	5	0	0
Support of Rotation Movement	0	0	3	0	0	1	0	0	0	0	0
Change of Direction	1	0	1	0	0	1	0	0	1	0	0
Change of Power Direction	0	0	0	0	0	0	0	0	0	3	0
Power Generation	0	1	1	0	0	0	0	0	0	0	0
Control of Movement	0	0	0	3	2	0	0	0	0	0	0
Position Fixation	0	0	0	0	6	0	0	0	0	0	0
Termination of Movement	0	0	0	5	0	0	0	0	0	0	1
Release of Restraint	0	0	0	0	6	0	0	0	0	0	0
Switching	0	0	0	0	0	3	0	0	0	0	0
Power Transmission	0	0	0	0	0	0	8	0	0	0	0
Avoidance of Defect (Fuguai)	1	0	0	1	2	0	0	4	0	0	0
Movement Termination	0	0	0	3	0	0	0	0	0	0	0

TABLE 9. BOP (BILL OF ELEMENTARY PHENOMENA/MECHANISMS)

Karakuri Mechanisms	Elementary Phenomena/Mechanisms							
	Gravity Force	Lever Mechanism	Weight-shift Mechanism	Friction	Cam Mechanism	Spring Mechanism	Roller Mechanism	Magnetic Force
Seesaw Mechanism	6	3	3	0	0	0	0	0
Balance Mechanism	1	1	1	1	0	0	0	0
Rotation Mechanism	3	0	1	3	0	0	3	0
Stopper Mechanism	0	0	0	3	5	0	0	1
Lock-up/Release Mechanism	0	0	0	0	6	0	0	0
Clutch Mechanism	1	0	0	0	6	1	0	0
Link Mechanism	0	2	0	0	10	2	0	0
Pokayoke Mechanism	1	0	0	0	4	0	0	0
Slide Mechanism	3	0	0	0	3	0	5	0
Pulley Mechanism	2	0	0	3	1	0	3	0
Magnet Mechanism	0	0	0	0	0	0	0	1

V. ANALYSIS BY QUANTIFICATION MODEL III AND ITS EXTENSION (STEP 4 AND 5)

In this section, way of statistical quantification analysis, including extended Quantification Model III[1][2], and obtained results with summary are described. Hereafter, description is focused on BOP-concerned issue as this part is the kernel of our research.

A. BOP-concerned Analysis by Quantification Model III

As mathematical system of Quantification Model III, which assigns numerical figures to qualitative items such as seesaw mechanism, a member of Karakuri mechanism, to identify mutual difference among members in the same category on the logically formulated platform, and its software package is enough popular among Japanese

scientists who use statistical method, obtained outcomes are directly presented in Table 10, 11, 12. All of these data is typical output from this analytical model. Utilized input data is of Table 9, but frequency is degenerated to zero or one, depending on whether frequency is zero or others. This data manipulation must be performed as logic of this model supposes this data format.

TABLE 10. EIGENVALUES AND CORRELATION COEFFICIENTS OBTAINED BY QUANTIFICATION MODEL III

Eigenvalue No.	Eigenvalue	Correlation Coefficient
1	0.677	0.823
2	0.468	0.684

TABLE 11. EIGENVECTORS IDENTIFIED FOR SAMPLE ITEMS, WHICH IS MEMBERS OF KARAKURI MECHANISM IN THIS CASE

No.	Karakuri Mechanisms	Eigenvector for eigenvalue No. 1	Eigenvector for eigenvalue No. 2
1	Seesaw Mechanism	-0.53	-0.66
2	Balance Mechanism	-0.347	-0.713
3	Rotation Mechanism	-0.274	-0.803
4	Stopper Mechanism	1.297	0.014
5	Lock-up/Release Mechanism	0.028	1.131
6	Clutch Mechanism	-0.287	1.063
7	Link Mechanism	-0.348	1.055
8	Pokayoke Mechanism	-0.196	0.463
9	Slide Mechanism	-0.235	0.114
10	Pulley Mechanism	-0.126	-0.133
11	Magnet Mechanism	3.661	-0.216

TABLE 12. EIGENVECTORS IDENTIFIED FOR ITEMS/CATEGORIES, WHICH IS MEMBERS OF ELEMENTARY PHENOMENA/MECHANISMS IN THIS CASE

No.	Elementary Phenomena/Mechanisms	Eigenvector for eigenvalue No. 1	Eigenvector for eigenvalue No. 2
1	Gravity Force	-0.346	-0.14
2	Lever Mechanism	-0.496	-0.155
3	Weight-shift Mechanism	-0.466	-1.06
4	Friction	0.167	-0.598
5	Cam Mechanism	0.023	0.774
6	Spring Mechanism	-0.386	1.548
7	Roller Mechanism	-0.257	-0.401
8	Magnetic Force	3.012	-0.148

Table 13 summarizes Euclidean distance among quantified score of seesaw mechanism and that of elementary phenomena/mechanisms, which is created from above 3 Tables. This data appropriately express the proximity between seesaw mechanism and each elementary phenomenon/mechanism. Therefore, it can be notice that how each elementary phenomenon/mechanism is useful for constructing seesaw mechanism.

For example, roller, weight-shift, gravity and lever mechanisms are suggested very useful and/or often used.

TABLE 13. EUCLIDEAN DISTANCE TABLE BETWEEN SEESAW MECHANISM AND EACH ELEMENTARY PHENOMENON/MECHANISM

Elementary Phenomena/Mechanisms	Euclidean Distance from The Score of Seesaw Mechanism
Gravity Force	0.552
Lever Mechanism	0.506
Weight-shift Mechanism	0.405
Friction	0.700
Cam Mechanism	1.537
Spring Mechanism	2.213
Roller Mechanism	0.376
Magnetic Force	3.579

*B. Formulation of Extended Quantification Model III for BOP-concerned Analysis*

As mentioned above, it seems quite pitiful to degenerate important data by converting frequency data to zero-one because of violated input specification. In this sub-section, revised formulation enabling to accept frequency data is

given.

Objective function

$$\max S_{xy} = \sum_{m=1}^n \sum_{t=1}^s w_{mt} x_m y_t \tag{1}$$

Subject to

$$\sum_{m=1}^n \sum_{t=1}^s w_{mt} x_m^2 = \sum_{m=1}^n \sum_{t=1}^s w_{mt} y_t^2 = 1 \tag{2}$$

$$\bar{x} = \bar{y} = 0 \tag{3}$$

From the above formulation represented by (1), (2) and (3), can be (4) is obtained.

$$\sum_{m=1}^n \left\{ \frac{1}{\sqrt{\sum_{i=1}^s w_{qi}}} \sum_{j=1}^s \left( \frac{w_{qj}}{\sum_{l=1}^n w_{lj}} \times \frac{w_{mj}}{\sqrt{\sum_{t=1}^s w_{mt}}} \right) \right\} a_m = \lambda^2 a_q \quad q \in \{1, \dots, n\} \tag{4}$$

This formula is recognized as (5), a typical eigenvalue problem.

$$A \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_m \\ \vdots \\ a_n \end{bmatrix} = \lambda^2 \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_q \\ \vdots \\ a_n \end{bmatrix} \quad (5)$$

Then, tackling with this problem solving, we can obtain new numerical scores reflecting important frequency data.

<Symbols>

$m, l, q$	: Item-category code numbers ( $m, l, q = 0, \dots, n$ )
$t, i, j$	: Sample code numbers ( $t, i, j = 0, \dots, S$ )
$w_{mt}$	: Frequency data of utilization of each item-category, which is regarded as elementary phenomena/mechanisms in the BOP case
$x_m$	: Quantified data to each item-category
$y_t$	: Quantified data to each sample
$S_{xy}$	: Sum of squared deviation
$\lambda^2$	: Eigenvalue
$a_m$	: Eigenvector
$A$	: Coefficient matrix of $a_m$ ( $n \times n$ matrix)

C. BOP-concerned Analysis by Extended Quantification Model III

The same analysis as sub-section 1 is performed and Table 14, 15, 16 are obtained.

TABLE 14. EIGENVALUES AND CORRELATION COEFFICIENTS OBTAINED BY EXTENDED QUANTIFICATION MODEL III

Eigenvalue No.	Eigenvalue	Correlation Coefficient
1	0.642	0.801
2	0.551	0.742

Also, Table 17 is created that summarizes Euclidean distance among quantified score of seesaw mechanism and that of elementary phenomena/mechanisms. Here, Fig. 7, drawn by the data in Table 17, is useful for better understanding on the proximity of all the elementary phenomena/mechanisms. Again, gravity, lever and weight-shift mechanisms are suggested quite useful for construct seesaw mechanism as these are close to seesaw score.

TABLE 15. EIGENVECTORS IDENTIFIED FOR SAMPLE ITEMS,

No.	Karakuri Mechanisms	Eigenvector for eigenvalue No. 1	Eigenvector for eigenvalue No. 2
1	Seesaw Mechanism	-0.422006	-0.016619
2	Balance Mechanism	-0.345899	0.052188
3	Rotation Mechanism	-0.387007	0.128930
4	Stopper Mechanism	0.401493	0.001437
5	Lock-up/Release Mechanism	0.774801	-0.413795
6	Clutch Mechanism	0.550575	-0.337601
7	Link Mechanism	0.565846	-0.345635
8	Pokayoke Mechanism	0.514603	-0.328356
9	Slide Mechanism	-0.111838	-0.055037
10	Pulley Mechanism	-0.236500	0.092928
11	Magnet Mechanism	0.404718	1.216028

TABLE 16. EIGENVECTORS IDENTIFIED FOR ITEMS/CATEGORIES,

No.	Elementary Phenomena/Mechanisms	Eigenvector for eigenvalue No. 1	Eigenvector for eigenvalue No. 2
1	Gravity Force	-0.421555	0.009942
2	Lever Mechanism	-0.156278	-0.088329
3	Weight-shift Mechanism	-0.352966	0.019114
4	Friction	-0.177664	0.214178
5	Cam Mechanism	0.620729	-0.307060
6	Spring Mechanism	0.225909	-0.171742
7	Roller Mechanism	-0.316622	0.088420
8	Magnetic Force	0.324238	0.902365



TABLE 17. EUCLIDEAN DISTANCE TABLE BETWEEN SEESAW MECHANISM AND EACH ELEMENTARY PHENOMENON/MECHANISM

Elementary Phenomena/Mechanisms	Euclid Distance from The Score of Seesaw Mechanism
Gravity Force	0.0266
Lever Mechanism	0.2752
Weight-shift Mechanism	0.0777
Friction	0.3361
Cam Mechanism	1.0824
Spring Mechanism	0.6662
Roller Mechanism	0.1488
Magnetic Force	1.1838

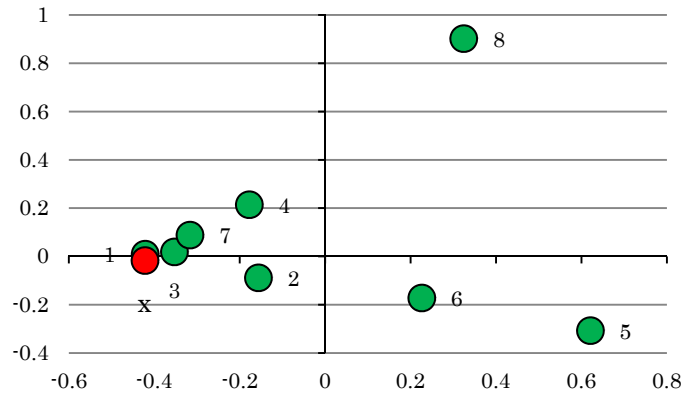


Fig. 7. Location of seesaw mechanism and each elementary phenomenon/mechanism on the 2-dimensional Euclidean space

*D. Comparison Analysis of the Result from Quantification Model III and that of Extended Version*

To compare the obtained scores from different mathematical analyses, it is necessary to set up common platform space and normalize data from both models to this domain. 2-dimensional metric space with seesaw mechanism as origin and proper scale of axes is established and data is

converted to this domain. Table 18 summarizes the result of this operation for the data from original Quantification Model III and Table 19 is that of Extended Quantification Model III. Then, Fig. 8 illustrates how positions of the same item-categories are different, where white and dark spots are the data from Original Model and Extended Model respectively.

TABLE 18. NORMALIZED EIGENVECTORS (QUANTIFICATION MODEL III)

No.	Elementary Phenomena/Mechanisms	Eigenvector for eigenvalue No. 1	Eigenvector for eigenvalue No. 2
1	Gravity Force	0.051948	0.199387
2	Lever Mechanism	0.009599	0.193635
3	Weight-shift Mechanism	0.018069	-0.153374
4	Friction	0.196781	0.023773
5	Cam Mechanism	0.156126	0.549847
6	Spring Mechanism	0.040655	0.846626
7	Roller Mechanism	0.077075	0.099310
8	Magnetic Force	1	0.196319
	Seesaw Mechanism	0	0

TABLE 19. NORMALIZED EIGENVECTORS (EXTENDED QUANTIFICATION MODEL III)

No.	Elementary Phenomena/Mechanisms	Eigenvector for eigenvalue No. 1	Eigenvector for eigenvalue No. 2
1	Gravity Force	0.000433	0.021962
2	Lever Mechanism	0.254838	-0.059292
3	Weight-shift Mechanism	0.066210	0.029546
4	Friction	0.234328	0.190833
5	Cam Mechanism	1	-0.240148
6	Spring Mechanism	0.621361	-0.128261
7	Roller Mechanism	0.101065	0.086851
8	Magnetic Force	0.715660	0.759852
	Seesaw Mechanism	0	0

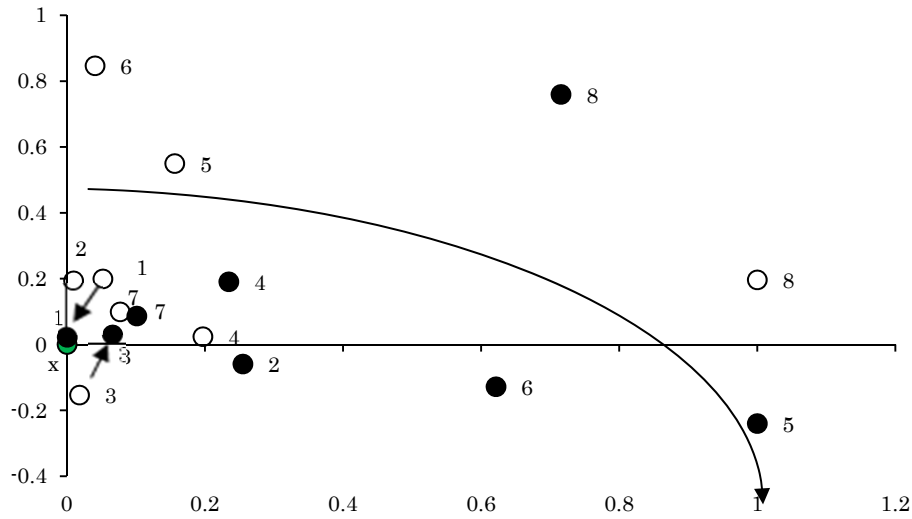


Fig. 8. Difference of the positions derived from two quantification models

In addition, preference or proximity of each elementary phenomenon/mechanism to seesaw mechanism is evaluated for both data and summarized

in Table 20. Applying the same analysis to other Karakuri Mechanisms, we finally obtained Table 21.

TABLE 20. COMPARISON ON DISTANCE DATA OF EACH ELEMENTARY PHENOMENON/MECHANISM TO SEESAW MECHANISM

Elementary Phenomena/Mechanisms	Euclid Distance from The Score of Seesaw Mechanism (Conventional Quantification Model III)	Preference	Euclid Distance from The Score of Seesaw Mechanism (Weighted Quantification Model III)
Gravity Force	0.206043	∩	0.021967
Lever Mechanism	0.193873	-	0.261645
Weight-shift Mechanism	0.154435	∪	0.072503
Friction	0.198212	∩	0.302203
Cam Mechanism	0.571583	∩	1.028431
Spring Mechanism	0.847601	-	0.634461
Roller Mechanism	0.125710	-	0.133256
Magnetic Force	1.019088	-	1.043812

TABLE 21. SUMMARY OF BOP-CONCERNED RESULT

Karakuri Mechanisms	Elementary Phenomena/Mechanisms							
	Gravity Force	Lever Mechanism	Weight-shift Mechanism	Friction	Cam Mechanism	Spring Mechanism	Roller Mechanism	Magnetic Force
Seesaw Mechanism	○	□	○	△	×	△	□	×
Balance Mechanism	□	□	○	□	×	△	○	×
Rotation Mechanism	□	△	□	□	×	△	□	×
Stopper Mechanism	△	△	△	△	△	□	△	△
Lock-up/Release Mechanism	×	×	×	×	□	△	×	×
Clutch Mechanism	×	△	△	△	○	△	△	×
Link Mechanism	×	△	×	△	○	△	△	×
Pokayoke Mechanism	×	△	△	△	□	△	△	×
Slide Mechanism	△	○	□	□	△	△	□	×
Pulley Mechanism	□	□	□	□	△	△	□	△
Magnet Mechanism	×	×	×	×	×	×	×	△

Where, the symbols in table 21 are defined as follows.

○:  $0 \leq x \leq 0.07$  □:  $0.07 < x \leq 0.31$  △:  $0.31 < x \leq 0.69$  ×:  $0.69 < x \leq 1$

x: Normalized value of quantified scores of each model

This sort of knowledge can be very useful for managing Karakuri development and improvement projects effectively. Some consideration on this matter is given in the next section.

### VI. IMPROVEMENT OF KARAKURI CONTRIVANCE (STEP 6)

In this section, taking an example Karakuri mechanism developed and offered by a company, improvement consideration is introduced based on the obtained result in the previous section. This Karakuri case is for heavy parts/products handling operation with support of lift equipment. Problem of current Karakuri contrivance is utilizing air-cylinder for energy source, therefore, the system rely on extra facility cost.

Following is the operation sequence of current system.

- ①: Parts and/or products settled on the dolly, which is on the rail, is raised vertically by lifter and, simultaneously, rail on the seesaw inclines right-side by the energy of air-cylinder (Fig. 9).
- ②: Then, dolly moves to right-side automatically by its own weight (Fig. 10).
- ③: Dolly stops at the prefixed position, parts/products is removed from dolly and stacked (Fig. 11).
- ④: Then, rail inclines left-side by the energy of air-cylinder, where amount of energy must be necessary as rail is heavy (Fig. 12).
- ⑤: Dolly moves to its home position automatically by its own weigh (Fig. 12).

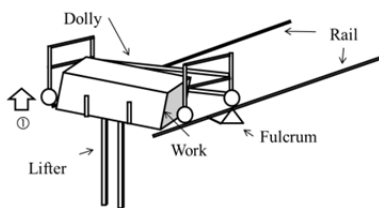


Fig. 9. State Transition ① (Before Improvement)

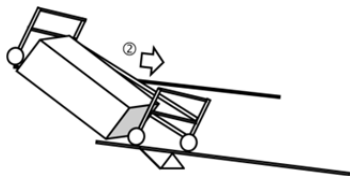


Fig. 10. State Transition ② (Before Improvement)

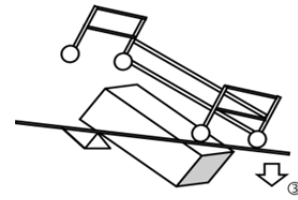


Fig. 11. State Transition ③ (Before Improvement)

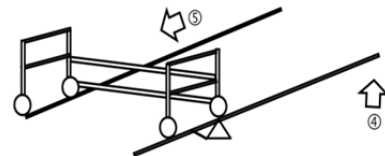


Fig. 12. State Transition ④ & ⑤ (Before Improvement)

Improvement of this operation is examined especially focusing on energy-saving and, for this purpose, project target is how to remove air-cylinder. Concerned state transitions are ① & ④ and idea is energy supplied by air-cylinder have to be replaced by using seesaw mechanism. From knowledge summarised by the analysis in the previous section, gravity force, lever and weight-shift are identified as the key issues to construct seesaw mechanism. Based on this support information, fulcrum was shifted to right-side to utilize these elements effectively. Actually, heavy rail can incline left-side by its own weight that causes suppress of energy from air-cylinder.

Following is the operation sequence of revised system.

- ①: Rail is raised vertically by lifter and, simultaneously, rail automatically inclines right-side (Fig. 13).
- ②: Then, dolly moves to right-side automatically by its own weight (Fig. 14).
- ③: Dolly stops at the prefixed position, parts/products is removed from dolly and stacked (Fig. 15).
- ④: Then, rail inclines left-side automatically by its own weight (Fig. 16).
- ⑤: Dolly moves to its home position automatically by its own weigh (Fig. 16).

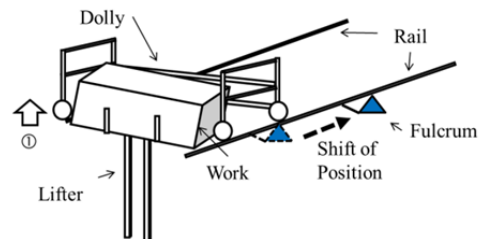


Fig. 13. State Transition ① (After Improvement)

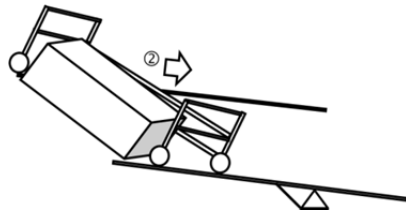


Fig. 14. State Transition ②  
(After Improvement)

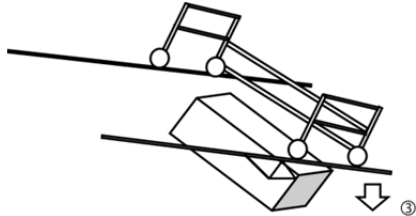


Fig. 15. State Transition ③  
(After Improvement)

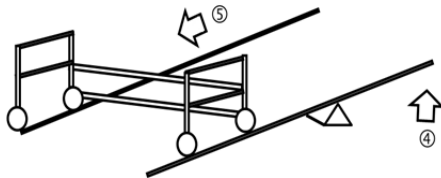


Fig. 16. State Transition ④ & ⑤  
(After Improvement)

## VII. CONCLUDING REMARKS

In this paper, based on the template procedure proposed in our past research, relations among the objectives, provided functions, essential mechanisms and elementary contributors of the collected Karakuri cases were settled in terms of bill of functions, Karakuri mechanisms and elementary phenomena/mechanisms, and analysed through application of a statistical quantification model with its extension. Obtained results indicate there are some strong relations among the members of each stage of bill, which must be useful in developing new Karakuri contrivances as well as their improvement. Finally, a Karakuri case was examined to improve with information obtained through the analysis and the outcome suggests relevance of the result of this research.

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