A Principal Component Analysis of Lean Six Sigma Tools and Techniques

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ABSTRACT

The usage of Lean Six Sigma (LSS) in manufacturing industries has been a major research theme. Industries have combined different LSS tools and techniques based on their suitability to the company's process, on the level of awareness of the tool and available knowledge. These combinations bring about questions bordering on the level of usage of individual tools, thus the need to comprehensively deconstruct their cluster usage, identify the most used tool, and make recommendations.

This work uses principal component analysis (PCA) to identify the most dominant tool used in selected Nigerian manufacturing companies. The analysis is done using the PCA tool box in the Statistical Package for Social Science (SPSS) and the result shows that Jidoka is mostly used in conjunction with other LSS tools.

(Keywords: Lean Six Sigma, LSS, principal component analysis, PCA)

INTRODUCTION

Lean Six Sigma (LSS) is a combination of well-known waste elimination and process improvement techniques - Lean Manufacturing and Six Sigma (Zhang, Irfan, Khattak, Xiaoning, Hassan, 2012). It is a continuous improvement methodology that aims to reduce the costs of poor quality, improve the bottom-line results, and create value for both customers and shareholders (Jiju, Albliwi, Abdul Halim Lim, Wiele 2014), and offer companies many advantages (Pojasek, 2013).

LSS offers a dual approach for variation reduction and provides customers with a product that meets their needs precisely (Langston, 2015). While the Lean strategy takes care of waste across all processes and focuses on speed and time, the Six Sigma strategy focuses on design, eliminating defects, driving out process variability as well as reducing costs (Andersson, Hilletofth, Manfredsson, Hilmola, 2014). It has been used severally by large organizations with standing success story such as Motorola, General Electric, Honeywell, Caterpillar, and many others.

Principal Component Analysis (PCA) is a dimensionality reduction technique that creates a smaller number of components or factors from relatively large series of data that allows for the easy interpretation. These new components (Principal Components) account for most of the variance in the original variables Ringnér (2008). It is a technique used to emphasize variation and bring out strong patterns in a dataset. It is a simple non-parametric technique for extracting information from complex and confusing data sets. Principal component analysis is focused on the maximum variance amount with the fewest number of principal components.

Lean Six Sigma Tools and Techniques

DMAIC Framework: The tools of LSS are most often applied within a simple performance improvement model known as Define-Measure-Analyze-Improve-Control (DMAIC). In Table 1, a comparison of Six Sigma and Lean manufacturing shows the synergy between them and how they combine under the DMAIC framework to form a structured methodology for improving process and product performance.

Table 1: Overview of the DMAIC Framework.

Process	Six Sigma	Lean Manufacturing
Define	Identify (select) process suitable for improvement.	Specify value from customer stand point - voice of the customer.
Measure	Determine what and how to measure performance of selected process	Identify value stream: Current state mapping
Analyze/Flow	Understand the variables that create process variations.	Analyze the current value stream map.
Improve	Identify means to remove causes of defects and modify process.	Improve Process Flow: Invent future value stream.
Control	Maintain improvement	Perfect future map: Sustain the continuous improvement.

Use of DMADV Procedure: Stands for Define, Measure, Analyze, Design and Verify.

The *Define* stage identifies the goals of the design activity. The *what, why, and relevance* of the desired activity is clearly outlined. The goals (activities) are consistent with customer demands and enterprises strategy.

At the *Measure* stage, critical to stakeholder metrics are determined and customer requirements are translated into project goals.
During the *Analyze* phase, the options available for meeting the goals clearly evaluated, while the performance of similar best-in-class designs are determined.

In the *Design* phase, the new product, service or process is drawn using predictive models, simulation, prototypes, pilot runs, etc. to validate the design concept's effectiveness in meeting goals.

The *Verify* phase is simply to verify the design's effectiveness in the real world.

Value Stream Mapping: Value stream mapping is the process of identifying all the specific activities required to bring a specific product through the critical management tasks of any business: the problem-solving task running from concept through detailed design and engineering to production launch, the information management task running from order-taking through detailed scheduling to delivery, and the physical transformation of raw materials to a finished product in the hands of the customer.

Kaizen: Kaizen is a Japanese word for continuous endeavor for perfection. It is a systematic approach to gradual, orderly, continuous improvement in a manufacturing setting which can include reduction of defective parts, reduction of inventory, etc.

Kanban: This is a card or sheet which serves as a specific tool which authorizes production or movement. Kanban for an item is determined by the demand rate for an item and the time required to produce and acquire more. This number is generally being established and altered dramatically; in this way inventory is kept under control while production is forced to keep pace with shipment volume. All production and movement of parts and movement take place only as required by a downstream operation which means card or sign, but it can also be legitimately referring to a container or other authorizing device.

Just In Time: Just In Time is a production philosophy that involves a company producing the right product at the right time in the right quantity in response to demand pattern. It is used as an inventory control system in most organizations and it consist of JIT production, JIT distribution, and JIT purchasing.

Single Minute Exchange of Die (SMED): Also known as Quick Changeover, SMED is the process of converting a line from one type of product to another. It involves designing production line to minimize that time to whilst increasing production flexibility. Its key lies in studying and separating internal and external activities in changeover so that production can continue while changeover occurs.

Mistake Proofing: Mistake proofing is thinking about the design of the products and production and designing ways to prevent mistakes. It is also called Poka Yoke.

Cellular Manufacturing: This is the arrangement of equipment and workstations in an order that maintains smooth flow of materials and components through the process. Cellular manufacturing helps to reduce work in process inventory, utilize space, identify can use and effect of machine problems amongst others.

Jidoka: This is the practical use of automation to mistake-proof the detection of defects and free up workers to perform multiple tasks within work cells.

5 S- (Sort, Set, Straighten, Shine, Sustain): This is a five step tool which is used for good housekeeping and better workplace organization. It entails *sorting* through the contents of an area and removing unnecessary items, (s*et in order)* arranging necessary items for easy and efficient access, and keeping them that way, *straighten* to have the right items in the right area, *shine* or clean everything, and keep the workplace methodically, and maintain (*sustain*) a high standard of housekeeping and workplace.

Failure Mode Effect Analysis (FMEA): The FMEA is a design tool used to systematically analyze postulated component failures and identify the resultant effects on system operations. Successful development of a FMEA requires that the analyst include all significant failure modes for each contributing element or part in the system. FMEAs can be performed at the system, subsystem, assembly, subassembly or part level. It should be scheduled and completed concurrently with the design. FMEAs are usually based on function, design (concept & detailed), and process.

Fishbone Diagram: Also known as the Ishikawa diagram, or Cause and Effect diagram, the Fishbone diagram is a tool that is used to organize and graphically display all of the knowledge a group has relating to a particular problem. Usually, the steps include developing a flow chart of the area to be improved, defining the problem to be solved, brainstorming to find all possible causes of the problem, organizing the brainstorming results in rational categories, and drawing a cause and effect diagram that accurately displays the relationships of all the data in each category.

Design of Experiments: Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output.

Statistical Process Control & Control Charts: Statistical process control (SPC) is an effective method of monitoring a process through the use of control charts. The data from measurements of variations at points on the process map is monitored using control charts. Control charts attempt to differentiate "assignable" *(special)* sources of variation from "common" sources. Common sources are expected part of the process, and are of much less concern to the manufacturer than assignable sources. Using control charts is a continuous activity, ongoing over time. SPC is used to understanding the process and the specification limits, eliminate assignable (special) sources of variation, so that the process is stable and monitor the ongoing production process using the use of control charts to detect significant changes of mean or variation.

Quality Function Deployment: QFD is a customer-driven process for planning products and services. It starts with the voice of the customer, which becomes the basis for setting requirements. QFD matrices, sometimes called *the house of quality*, are graphical displays of the result of the planning process. QFD matrices vary a great deal and may show such things as competitive targets and process priorities. The matrices are created by interdepartmental teams, thus overcoming some of the barriers which exist in functionally organized systems.

Applications of Principal Component Analysis

PCA has been used severally in different industries and sectors. Grané and Jach (2014) used PCA in multivariate regression in the food science and technology industry. In Geographic Information Systems (GIS) modeling, Petrişor, Ianoş, Iurea, Maria-Nataşa (2012), Principal Component Analysis is used to pinpoint the input variables that best account for the level of development, describing economic, social, demographic, education, infrastructure and cultural aspects. Yeung and Ruzzo (2001) used PCA in analyzing data from DNA expressions. Érica, Nascimento and Martins (2012), Ingunn and Bauer-Brandl (2012) have also demonstrated the use of PCA in the pharmaceutics industry. In artificial intelligence, Chen, Chang and Huang (2010) proposed a learning algorithm for 2D-PCA for solving problems in facial expression recognition and object recognition; Zhou and Shang (2012) proposes a method of principal component analysis (PCA) for solving complex structure problems in using probabilistic neural network (PNN) to recognize human speaker recognition system. In manufacturing, Multiway Principal Components Analysis (MPCA) methods was used by Thieullen, Ouladsine and Pinaton (2013) to analyze data from equipment behavior and process dynamics in a semiconductor manufacturing context; Hachicha, Masmoudi, and Haddar (2006) used PCA to solve a problem of machine cell formation in designing a cellular manufacturing system.

Lean Six Sigma Tools and Techniques to PCA

In most industries, the selection of use of the LSS tool or technique is dependent on the type of process being used and suitability to the company's framework. This selection is also based on level of awareness of the tool and available knowledge. Oftentimes, these tools are used concurrently with each other as fit to the organization. Questions about the coeval use of each tool and technique arises, thus there is need to comprehensively deconstruct their cluster usage, identify the most used tool and make recommendations.

METHODOLOGY

The information about the use of various LSS tools and techniques from various organizations was collected via a questionnaire developed based on different tools as explained by Shah and Ward (2003), Rahman et al (2010), and Bhamu and Sangwan, (2013). A 5 –point Likert scale (never used, seldom used, sometimes used, often used, almost always used) indicating the level of use of the various tools. This method of data collection for research is suitable for analyzing lean manufacturing tools and techniques used in manufacturing companies in Nigeria. Using SPSS software, the Principal Component Analysis toolbox

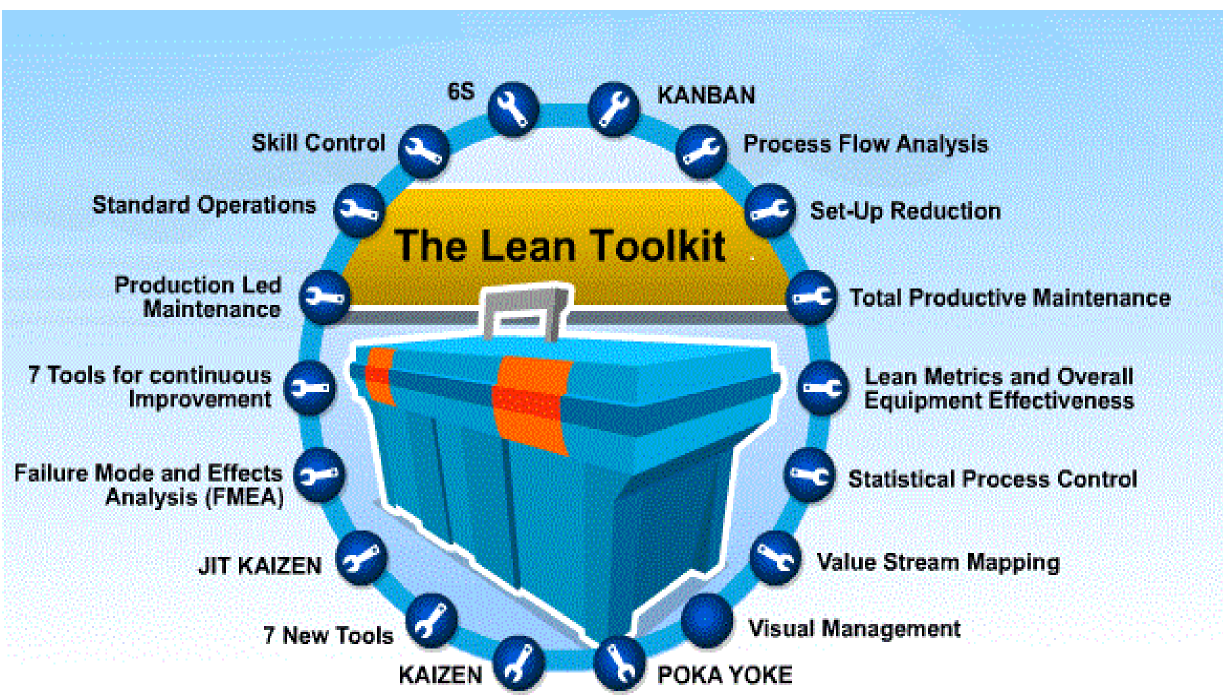

Figure 1: An Overview of Lean Tools.

RESULTS ANALYSIS

Kaiser-Meyer-Olkin Measure of Sampling Adequacy

The KMO and Bartlett's test of Adequacy shows the justification for performing a data reduction procedure. In this test, the KMO which is relatively high (0.902) indicates that there is at least one statistically significant correlation in the correlation matrix.

Table 2: The KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.902
Bartlett's Test of Sphericity	Approx. Chi-Square	838.072
	Df	136
	Sig.	.000

The Scree Plot

The Scree plot is a plot with eigenvalues on the ordinate and component number on the abscissa. Scree is the rubble at the base of a sloping cliff. In a scree plot, scree is those components that are at the bottom of the sloping plot of eigenvalues versus component number.

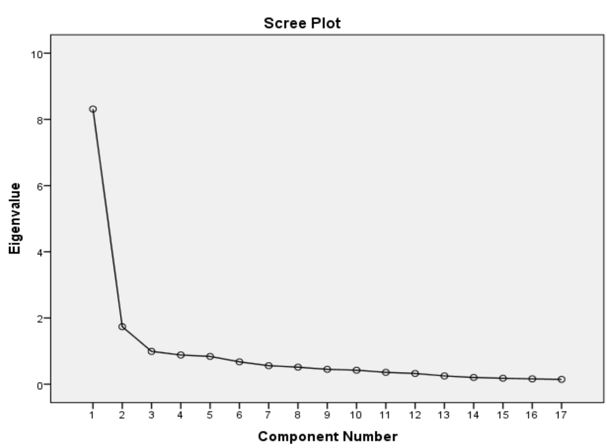

Figure 2: The Scree Plot of Components.

The plot provides a visual aid for deciding at what point including additional components no longer increases the amount of variance accounted for by a nontrivial amount, in essence, it helps to know the number of components to extract. In the scree plot produced by SPSS above, the major break in the components lies in the component 2. This shows that the most significant contribution would come from two components and indicates that the analysis would be best performed using two components.

Commonalities

The commonalities (Table 3) are based on the two components being extracted from the data. The commonalities represent the percentage of variance that is being accounted for by the components analysis. Jidoka (77.5%), Kanban (73.7%) and Mistake Proofing (72.3%) have the highest variances that are been explained by the analysis. 5.5% of the variability of Quality Function Deployment is only explained for by the component analysis.

The Component Matrix

The Component matrix (Table 4) shows the unrotated solution method of extraction. Since our goal is the oblique component.

The Pattern Matrix

The pattern matrix (Table 5) describes the oblique rotated solution for extraction of components. It helps to identify the nature of the extracted components. For component 1, Jidoka has the strongest loading (0.947) while 5S has the lowest negative showing (-0.004). Component 2 has the highest positive loading in Control charts (0.871) with DOE (0.762), and 5S (0.7) closely following.

Table 3: The Commonalities in Extraction.

TOOLS	DMAIC	DMADV	VSM	KAI	KAN	JIT	SMED	MISPR	CM	JID	5S	FMEA	FISBO	DOE	SPC	CC	QFD
Initial	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Extraction	0.47	0.675	0.424	0.514	0.737	0.6	0.673	0.723	0.587	0.775	0.487	0.659	0.67	0.683	0.633	0.68	0.055

Table 4: The Component Matrix.

TOOLS		MISPR	FISBO	FMEA	JID	KAN	DMADV	SMED	CM	JIT	DMAIC	KAI	SPC	VSM	DOE	CC	5S	QFD
Component	1	0.849	0.818	0.805	0.803	0.802	0.793	0.769	0.755	0.75	0.682	0.676	0.649	0.64	0.634	0.484	0.47	0.153
	2	-0.05	0.024	-0.103	-0.36	-0.307	0.213	-0.286	-0.13	-0.19	-0.076	-0.24	0.46	-0.12	0.53	0.669	0.516	0.178

Table 5: The Pattern Matrix for Extraction.

TOOLS		JID	KAN	SMED	JIT	FMEA	KAI	MISPR	CM	FISBO	DMAIC	VSM	DMADV	CC	DOE	5S	SPC	QFD
Component	1	0.947	0.905	0.861	0.775	0.751	0.748	0.747	0.731	0.664	0.627	0.626	0.498	-0.11	0.122	-0.04	0.19	-0.01
	2	-0.168	-0.109	-0.095	0	0.116	-0.07	0.186	0.069	0.259	0.11	0.051	0.459	0.871	0.762	0.7	0.689	0.239

The Correlation Matrix

Component analysis is used to reduce the variance of each variable in a standardized format. Overall, there is positive correlation between usage of the LSS tools studied. A brief overview of the correlation matrix indicates that a number of the tools and techniques of LSS have been used concurrently in varying degrees.

The use of DMAIC with DMADV (0.635), Kanban (0.516), Just in Time (0.531), Mistake proofing (0.526), Jidoka (0.572), and Failure Mode Effect Analysis (0.534) have been higher compared to the other tools. Similarly, DMADV has been used more often with the DMAIC methodology (0.535), Just in Time (0.611), Mistake proofing (0.674), and Fishbone diagram (0.615) when compared with others.

Value Stream Mapping is being used more with Kaizen, Single Minute Exchange of Die, Mistake proofing, and Fishbone diagram. Kaizen is used more with Kanban (0.7) and Mistake proofing (0.6), its simultaneous use with DMAIC, VSM, JIT, Single Minute Exchange of Die (SMED), and Jidoka, usage of Kaizen is the same. Worthy of note is that Kaizen is not been used with Quality Function Deployment QFD(0).

Kanban usage with all other tools is relatively high except for QFD (0.1), Control Charts (0.27), Design of Experiment DOE (0.29), and 5S (0.27) which shows. 5S (0.2) and QFD (0.1) are least used with Just in time as LSS tools in organization. 5S (0.158), CC (0.189), and QFD (0.103) are the least used with SMED. 5S (0.321), CC (0.387), and QFD (0.11) are the least used with Mistake proofing.

Also, the matrix (Table 6) shows the use of Cellular manufacturing CM with Jidoka (0.7), SMED (0.63), Mistake proofing (0.66) as the highest and QFD (0.1) as the lowest. QFD (0.091), CC (0.111), SPC (0.291), and 5S (0.246) are least used with Jidoka.

The use of 5S with other tools is comparatively low; its application with DOE (0.54) is the highest. FMEA is almost equally used with CC (0.312) and QFD (0.097). The use of Fishbone diagrams with other tools is similar to the use of FMEA. It is almost equally used with the other tools except for CC (0.347) and QFD (0.138). DOE use with JIT (0.39), Jidoka (0.38), VSM (0.36), SMED (0.34), Kaizen (0.33), Kanban (0.29), and QFD (0.15) are relatively low.

The application of Statistical Process Control SPC with a variety of LSS tools is low especially Jidoka (0.291) and QFD (0.115). Control Charts and Quality Function Deployment are the least used tools with others. This might be not unconnected to their popularity. QFD and Control Charts are thus outlier tools.

Table 6: The Correlation Matrix.

Correlation Matrix		DMAIC	DMADV	VSM	KAI	KAN	JIT	SMED	MISPR	CM	JID	5S	FMEA	FIBO	DOE	SPC	CC	QFD
Correlation	DMAIC	1	0.635	0.32	0.5	0.52	0.5	0.458	0.526	0.4	0.572	0.24	0.534	0.49	0.4	0.349	0.27	0.06
	DMADV	0.635	1	0.429	0.4	0.54	0.6	0.487	0.674	0.5	0.556	0.41	0.582	0.615	0.52	0.592	0.51	0.144
	VSM	0.32	0.429	1	0.5	0.5	0.4	0.56	0.528	0.45	0.475	0.31	0.454	0.532	0.36	0.3	0.21	0.087
	KAI	0.497	0.431	0.515	1	0.66	0.5	0.525	0.613	0.44	0.528	0.18	0.445	0.445	0.33	0.365	0.23	0.025
	KAN	0.516	0.535	0.497	0.7	1	0.6	0.729	0.634	0.65	0.682	0.22	0.616	0.62	0.29	0.421	0.27	0.095
	JIT	0.531	0.611	0.388	0.5	0.64	1	0.522	0.64	0.49	0.67	0.2	0.668	0.56	0.39	0.346	0.28	0.055
	SMED	0.458	0.487	0.56	0.5	0.73	0.5	1	0.62	0.63	0.652	0.16	0.567	0.654	0.34	0.493	0.19	0.103
	MISPR	0.526	0.674	0.528	0.6	0.63	0.6	0.62	1	0.66	0.693	0.32	0.67	0.58	0.5	0.543	0.39	0.111
	CM	0.403	0.496	0.448	0.4	0.65	0.5	0.633	0.663	1	0.695	0.37	0.567	0.563	0.44	0.42	0.23	0.098
	JID	0.572	0.556	0.475	0.5	0.68	0.7	0.652	0.693	0.7	1	0.25	0.706	0.659	0.38	0.291	0.11	0.091
	5S	0.24	0.411	0.314	0.2	0.22	0.2	0.158	0.321	0.37	0.246	1	0.352	0.447	0.54	0.396	0.35	0.099
	FMEA	0.534	0.582	0.454	0.4	0.62	0.7	0.567	0.67	0.57	0.706	0.35	1	0.734	0.42	0.429	0.31	0.097
	FIBO	0.49	0.615	0.532	0.4	0.62	0.6	0.654	0.58	0.56	0.659	0.45	0.734	1	0.51	0.521	0.35	0.138
	DOE	0.401	0.516	0.357	0.3	0.29	0.4	0.335	0.498	0.44	0.377	0.54	0.421	0.509	1	0.536	0.59	0.148
	SPC	0.349	0.592	0.3	0.4	0.42	0.3	0.493	0.543	0.42	0.291	0.4	0.429	0.521	0.54	1	0.61	0.115
	CC	0.269	0.513	0.213	0.2	0.27	0.3	0.189	0.387	0.23	0.111	0.35	0.312	0.347	0.59	0.613	1	0.099
	QFD	0.06	0.144	0.087	0	0.1	0.1	0.103	0.111	0.1	0.091	0.1	0.097	0.138	0.15	0.115	0.1	1

Table 7: The Structure Matrix.

TOOLS		JID	KAN	MISPR	SMED	FMEA	FIBO	JIT	CM	KAI	DMADV	DMAIC	VSM	CC	DOE	SPC	5S	QFD
COMPONENT	1	0.868	0.853	0.834	0.816	0.805	0.786	0.775	0.764	0.715	0.714	0.679	0.65	0.301	0.481	0.513	0.325	0.104
	2	0.278	0.316	0.538	0.31	0.469	0.571	0.364	0.414	0.281	0.694	0.405	0.345	0.82	0.82	0.778	0.698	0.235

The Structure Matrix

The Structure Matrix (Table 7) shows the correlation between each tool and their respective component in the analysis.

The Component Correlation Matrix

The Component Correlation matrix (Table 8) shows the correlation between the two components extracted. The correlation between components 1 and 2 is positive and correlate with each other to a fair degree.

Table 8: The Component Correlation Matrix.

Component Correlation Matrix		
Component	1	2
1	1.000	.471
2	.471	1.000

Total Variance Explained

The Extracted Sum of loadings (Table 9) are the eigen values for each components extracted, 8.312 and 1.737 for components 1 and 2 respectively while the cumulative percentage of variance for component 1 and 2 is 48.89% and 59.11% respectively.

The rotated components solutions of the eigen values (oblique) are 7.899 and 4.747 for components 1 and 2 respectively.

Table 10 shows the Component Score Coefficient Matrix.

Table 9: Total Variance of Extracted Components.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Initial Eigen values	Total	8.312	1.737	0.992	0.882	0.838	0.676	0.558	0.515	0.449	0.423	0.357	0.324	0.25	0.202	0.178	0.16	0.146
	% Variance	48.893	10.218	5.834	5.187	4.931	3.975	3.284	3.03	2.64	2.489	2.102	1.906	1.47	1.19	1.049	0.943	0.859
	Cumu-lative %	48.893	59.111	64.945	70.132	75.063	79.039	82.323	85.353	87.993	90.481	92.583	94.489	95.959	97.149	98.198	99.141	100
Extraction Sums of Squared Loadings	Total	8.312	1.737															
	% of Variance	48.893	10.218															
	Cumulative %	48.893	59.111															
Rotation Sums of Squared Loadings	Total	7.899	4.747															

Table 10: Total Component Score Coefficient Matrix.

Component	DMAIC	DMADV	VSM	KAI	KAN	JIT	SMED	MISPR	CM	JID	5S	FMEA	FISBO	DOE	SPC	CC	QFD
1	0.09	0.062	0.092	0.113	0.138	0.115	0.131	0.106	0.107	0.146	-0.02	0.109	0.092	-0.01	0.01	-0.04	-0.01
2	0.023	0.155	0.001	-0.046	-0.065	-0.021	-0.059	0.048	0.005	-0.09	0.257	0.022	0.077	0.276	0.248	0.323	0.088

SUMMARY

From the commonalities matrix, Jidoka accounts for the highest percentage of variance explained by the component analysis, and this evident is from the pattern matrix. In terms of usage with other tools, Jidoka and Failure Mode Effect Analysis indicate a higher correlation with other tools examined.

Single Minute Exchange of Die (SMED) and Statistical Process Charts recorded low usage with other tools, it is recommended that they are used in conjunction with other. Other techniques such as Design of Experiment, Fishbone diagram, 5S, Control Charts, and Cellular manufacturing which have been used sparingly give better results when used often more and increase accuracy in process yields.

In all, the various tools have their advantages and disadvantages in different manufacturing environment. Further research can be done on the implementation of each tool in specific production setup.

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