Development of a Dynamic Model of Quality Control Circles: A Case of ABC Packaging Company

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Abstract

Quality control circles are considered an effective tool in the organization to best utilize the potential of the workforce. The objective behind using quality control circles is to use employees’ brains to generate savings and create an impact on the bottom-line of the company. The framework of the quality control circles shown in Table 2 proposed the structured seven steps strategy to use the workforce’s potential for continuous improvement in the organization. Companies confront multi-faceted issues and challenges in the operational processes and corporate excellence thus mainly depends upon the effective and efficient quality controls to overcome the product, process, machine, and material related issues that hamper the production efficiency, quality of the product, and overall productivity of the company. This paper attempts to develop the system dynamics model of quality control circles based on normalized data of the case company. Participation in quality control circles is voluntary in nature and passion to learn and improve is the intrinsic motivation for employees and organizations to join these circles. Employee involvement to participate and produce creative ideas in these circles is the key to the success of these quality-enhancing programs (Jerman et al. 2019) and model outcome depicts the same story. The quality control circle model indicates that a set of inter-related and interdependent skills and behaviors are a necessary condition to increase participation in the quality

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control circles and productivity of projects under consideration. The computer-based software STELLA is used for programming the model of quality control circles using the generic structures of the company under study. Underlying feedback structures and interactions among various variables makes the model closer to the real-life setting.

**Keywords**: computer simulation, employee involvement, project savings, quality control circles, systems dynamics

1. **Introduction**

Continuous improvement is a mandatory practice in every organization’s quality programme (Van & Pretorius, 2014). From quality inspection to quality performance awards, improvement is an essential element for organizational development. Creativity and innovation have become important realities of today’s business world. The companies who are capable of innovating faster than the rival firms can manage to excel quickly in the given competition. To explore people's intellectual potential and use it for organizational betterment and growth is the need of the day. Quality Control Circles were initiated by Japan in 1962 (Ishikawa, 1985) to use employees’ brainpower for continual improvement in every stage of the manufacturing process. The concept was so powerful that just in a few years it was adopted by almost every organization in Japan which helped the country to achieve unprecedented economic growth and prosperity. Later, many other countries of the world adopted this approach with different names such as quality improvement teams, productivity improvement teams, small group activities, and Kaizen teams (Rohrbasser et al., 2019) with the same aspiration of tapping human capital’s potential and incorporate changes in the systems (Salaheldin, 2009; Ishikawa, 1970). Continuous improvement is just a philosophy that encourages all the employees in an organization to perform their tasks effectively and efficiently (Yusuf, 2005). Employee involvement and motivation lead to cost-saving and creation of impact at the bottom level productivity goals in the organization. The outcome of the employee involvement in quality control circles projects must be translated into financial terms. This is the knowledge gap that needs to be addressed by using the mixed method approach and simulation
modelling framework of system dynamics to determine the complexity and dynamism of different variables over time. It is pertinent to understand that quality circles are not only restricted to quality, instead they consider all kinds of improvements in the complete supply chain and value chain process.

The objective of this research paper is to develop a simulation-based model of the quality improvement teams or quality control circles that can be used to identify areas of improvement for project savings, enhancing the ability for continuous improvement, and building the quality culture within the organization (Yusuf & Azhar, 2018). This paper thus deals with the identification of important factors of the quality circles and its link with savings generation while simultaneously addressing the quality and productivity issues. Employee involvement and quality culture is the dream of every organization. Every company believes in the tacit knowledge of the employee but does not know how to tap the employee potential for the betterment of the organization (Arrfou, 2019). This study portrays the potential of human capital and employee commitment that unveils the underlying structures to gain insight into the model and find out the policy interventions for better financials in terms of project savings.

2. Literature Review
2.1. Background

A quality circle is a “group of factory workers from the same area who usually meet for an hour each week to discuss their quality problem, investigate causes, recommend solutions, and take corrective actions when authority is in their purview” (IAQC). That leads to employee empowerment and involvement in the process improvement activities. There are multiple objectives of the quality circles, but the main objective is to use the human potential for the good of the company (Hill, 1991; Rohrbasser et al., 2018) and to bring the tacit knowledge to the surface. QCC members are free to select the group leader and circle secretary. Quality control circles can choose any topic as a theme if it is based on SMARTY (specific, measurable, achievable, result-oriented, time bound, and yield-based) principle.
There have been different definitions and interpretations of quality among scholars and practitioners. For instance, William Edwards Deming calls quality “a predictable degree of uniformity and dependability suited to the market at the lowest cost”. Juran sees quality as “fitness for use” and fitness for function (Juran, 1985). Deming’s theory of profound knowledge defines quality as the reduction of variation (Stepanovich, 2004). Similarly, according to many scholars, quality is a way of managing the organization (Feigenbaum, 1991) and meeting the customer requirements (Mikalauskas, Statnické, Habánik, & Navickas, 2019). Cost reduction is the result of process improvement and reducing the waste level within the organization. High scrap, increased number of defective units, rework, customer rejection, and low productivity are a few interrelated and interdependent factors that can be managed through quality orientation. Poor quality means more scrap, a higher level of rework and defectives are in abundance that kills the profitability of the organizations. That is the reason companies earn quality certifications like ISO 9001, ISO 45001 along with quality improvement self-initiatives like 5S, total quality control, total productivity maintenance, and the Six Sigma approach. Quality auditing (Yusuf & Azhar, 2018; Arrfou, 2019) is another quality practice to enhance supply chain performance and improve productivity. The goal of all these efforts is to bring improvement in processes and reduce the cost of operations. Quality control circles is a way to involve the employees (Jerman, Erenda, & Bertoncelj, 2019; Kumar et al., 2020) encourage them to identify the problems and root cause, invest authority to initiate the corrective measures to solve the day to day operational problems (Ishikawa, 1970; Yusuf, 2005).

3. Research Methodology

Saeed (2014) describes system dynamic as a versatile methodology to gain insight into the problem under investigation. System Dynamics (SD) concept was conceived in the late 1950s by Professor Jay Forrester at the Massachusetts Institute of Technology (Forrester, 1968). System dynamics is a computer-based modeling approach for analyzing and solving complex problems through policy design and analysis (Sterman, 2000). System dynamics focuses on the structure and behaviour of
systems due to interactions of the positive and negative loops. Behaviour of the model as the outcome of feedback loops creates an understanding of the structure-behavior link. System Dynamics model must help to organize the information more understandably by linking the past to the present and showing how present conditions arose, then extending the present into persuasive alternative futures under a variety of scenarios determined by policy alternatives (Forrester, 1980). If dynamic behaviour arises from feedback within the system, finding effective policy interventions requires understanding system structure. The development of the quality control circle model requires the modeler himself to operate in feedback mode. Industrial dynamics is a powerful modeling tool to study the flow of material, flow of information, and many interconnected, interlinked, and inter-related dynamic variables having feedback notion.

System dynamics is a computer-based modelling framework that can effectively deal with complex, dynamic, and multidisciplinary problems. It requires many phases from conceptual to technical i.e. from cognitive schemes of the problem to the policy design, and from policy intervention to behavioral and operational improvements. Followings are the phases highlighted for the modelling process shown in Table 1.
Table 1. 
*Phases of System Dynamics Modelling*

| Phases                          | Description                              | Nature                  | Research Inquiry            |
|---------------------------------|------------------------------------------|-------------------------|-----------------------------|
| Phase 1                         | Problem Identification                   | Conceptual              | Qualitative Reflection      |
|                                 | Problem Definition                       | Conceptual              | Qualitative Reflection      |
|                                 | System Perspective                      | Conceptual              | Qualitative Reflection      |
|                                 | Reference Mode-Historical Data           | Conceptual              | Qualitative Reflection      |
| Phase 2                         | System Conceptualization                 | Conceptual              | Qualitative Reflection      |
|                                 | Causal Loop Diagram                      | Conceptual              | Qualitative Reflection      |
|                                 | Influence Diagram                        | Conceptual              | Qualitative Reflection      |
|                                 | Dynamic Hypothesis                       | Conceptual              | Qualitative Reflection      |
| Phase 3                         | Level-Rate Block Diagram                 | Technical               | Quantitative Inquiry        |
|                                 | Stock-Flow Diagram                       | Technical               | Quantitative Inquiry        |
|                                 | Model Formulation                        | Technical               | Quantitative Inquiry        |
|                                 | Model Representation                     | Technical               | Quantitative Inquiry        |
|                                 | Model Structure                          | Technical               | Quantitative Inquiry        |
| Phase 4                         | Equation Writing                         | Technical               | Quantitative Inquiry        |
|                                 | Model Simulation                         | Technical               | Quantitative Inquiry        |
|                                 | Model Testing and validation              | Technical               | Quantitative Inquiry        |
|                                 | Model Behaviour and evaluation            | Technical               | Quantitative Inquiry        |
|                                 | Experimentation and Policy Exploration   | Technical               | Quantitative Inquiry        |
| Phase 5                         | Understanding and redefining phase 3 and phase 4 | Conceptual-Technical | Inductive-Deductive Logic |
| Phase 6                         | Re-designing the structures and perception maps (graphical functions) for policy design | Conceptual-Technical | Inductive-Deductive Logic |
Phase 1 and 2 describe the qualitative reflection based on the information collected through the case study method. Phase 3 and 4 explain the quantitative information and technical part of the model based on real-life setting and initial conditions of the company by normalizing the values of the case company to hide the propriety information of the company. System dynamics is like a mixed-method approach where qualitative and quantitative information is used to draw inferences and conclusions. Causal loop diagrams test hypothesis based on symbols used in Appendix A and equations shown in Appendix C. They represent the technical stream of the model while unveiling the underlying structures of the case company.

3.1. Positive and Negative Causal Loops

Causal loop diagramming technique (Forrester, 1968; Sterman, 2000; Yusuf & Azhar, 2018) is used to provide the linkages between various variables in the form of positive and negative loops. A positive loop is often defined by the fact that an initial change in any factor eventually induces further self-change in the original direction (Richardson & Pugh, 1981). A positive loop reinforces the change and amplifies the deviations (Petermann et al., 2019). Link polarity represents the connection between two variables and loop polarity represents the nature of the loop, either reinforcing or balancing. Loop dominance decides the behavioural growth or equilibrium state. When a feedback loop response to a variable opposes the original perturbation, the loop is negative or goal-seeking. The negative loop is usually interpreted as “a change in one element is propagated around the circle until it comes back to change that element in a direction opposite to the initial change” (Meadows et al., 1974). The outcome behaviour is considered the result of interactions of positive and negative loops (Inman et al., 2020).

3.2. Level and Rate Variables

System dynamics is essentially a modelling methodology made up of two basic elements i.e. “Level” and “Rate” (Nielsen & Nielsen, 2015). The technical phase begins with level and rate variables. Feedback structure can be portrayed through equations or stock-and-flow diagrams (Richardson & Pugh, 1981). Levels reflect on conditions within the system at a given point in time.
Stocks emerge if we suddenly freeze the activity within the system. Levels are just like the bathtubs in the sense that they accumulate or collect flows. Rates represent the stream of activity associated with stocks. Flows are depicted by a conduit pipe through which goal-seeking activities flow (Sterman, 2000).

4. Model Structure and Behaviour

Case Company

ABC Packaging is selected as a case because after successfully completing the ISO 9001 certification it wants to start a quality improvement initiative similar to Japan Quality Control Circles. The case company has started the journey of the quality circle under the name of Quality Improvement Teams within the company. The company initially started with two teams in the offset printing section. Later on, the same arrangement was implemented in all sections of the carton line including paper store, coating, cutting & creasing, and folding & gluing sections. All sections of the carton line of the ABC packaging were provided training for the seven basic but widely used tools like a flow chart, Pareto diagram, scatter plot, check sheets, Ishikawa diagram, histogram, and control charts (Sokovic et al., 2009).

The data was obtained from the company using in-depth semi-structured interviews, the company’s official documents, and check sheets highlighting chronological details of quality circles. Interview questions were designed mostly open-ended following the guidelines given by the previous researchers. Normalized values of the initial conditions are shown in Appendix B. Code of conduct of quality control circles are provided in Figure 1, and the seven-step strategy is highlighted in Table 2. Code of conduct and seven-step strategy are the two main drivers that help to achieve operational excellence in terms of productivity enhancement through generating savings while tapping the human capital.
Figure 1. Code of Conduct of Quality Control Circles

Feedback Structure

The system dynamics model was developed using simulation software STELLA that contained 38 variables, 4 stocks, 6 flows, 28 convertors, 19 constants, 2 graphical functions or table functions, and 15 equations. It is the 4th order differential equation with associated flows (Forrester, 1968) that generates the oscillatory waveform. Model is a combination of reinforcing and balancing loops and behaviour generated is the results of interactions of these loops (Lane, 2007). There are two types of loops i.e. reinforcing loops and balancing loops that are as under:

The reinforcing loops are:

Figure 2. QCC Members and QCC Projects
Figure 3. QCC Projects and QCC Savings Loop

Figure 4. Employee Involvement and QCC Members Loop

Figure 5. QCC Members and Labour Productivity
The balancing loops are:

Figure 6. Product Quality Index and Labour Productivity Loop

Figure 2 shows a positive loop. More QCC members mean there are more QCC projects because each project is usually limited to 4 to 8 members. More numbers of projects indicate that each QC circle is motivated to generate more savings as the result of the stock of savings is increasing as shown in Figure 3. The company has taken various initiatives like awareness campaigns, job rotation, and participation incentives that encourage employee involvement, and consequently, there are more QCC members and enhanced labour productivity as highlighted in Figure 4 and Figure 5. Figure 6 represents the balancing loop to try to seek the balance.

Table 2.
Seven Steps Strategy

| Steps  | Description                  | Statistical Tools                                      |
|--------|------------------------------|-------------------------------------------------------|
| Step 1 | Select the theme             | Brainstorming, Multi-voting, Graph, Why-Why Analysis. 5W & 1H method |
| Step 2 | Data collection and analysis | Check sheets, Process Chart, Flow Diagram, Pareto Chart |
| Step 3 | Identify the root cause      | Pareto Chart, Cause and Effect Diagram, Scatter Diagram, Histogram |
| Step 4 | Plan and Implement the solution | PDCA Cycle, Control Charts |
Step 5  Confirm the results  Control Charts, Design of Experiments

Step 6  Standardize the solution  Quality Assurance Management System, Work Instructions, SOPs

Step 7  Reflect on the process  Findings and measures have been deployed on all similar processes.

Figure 7. Block Diagram of the Quality Control Circles (Symbols from Appendix A)

Model Validation

Model validation (Pidd, 2010) gives confidence to the reader as well as to modeler. Various tests for model validation have been conducted. Details of validation are provided below.
Dimensional Consistency

Each variable in the model has a certain unit of measure and all the equations written in the model have dimensional consistency that reflects the real-life representation (Forrester & Senge, 1980; Qudrat-Ullah, 2010; Yusuf & Azhar, 2018).

Structure Verification

All the variables that are part of the model structure mentioned in the literature (Qutrat-Ullah, 2008) and the company structure that leads to structure verification shown in Table 3.

### Table 3.
**Structures Adopted from Literature**

| Variables/Structures       | Sources                                      |
|----------------------------|----------------------------------------------|
| QCC Circles                | (Anderson et al., 1995; Ishikawa, 1985;      |
|                            | Yusuf & Azhar, 2018; Salaheldin, 2009)       |
| QCC Projects               | (Sila & Ebrahimpour, 2005; Anderson et al., |
|                            | 1995; Tan et al., 1999; Yusuf & Azhar, 2017;|
|                            | Salaheldin, 2009)                            |
| QCC Members                | (Sila & Ebrahimpour, 2005; Anderson et al., |
|                            | 1995; Tan et al., 1999; Yusuf & Azhar, 2017;|
|                            | Salaheldin, 2009)                            |
| Ability to Continuous      | (Yusuf & Azhar, 2018; Salaheldin, 2009)      |
| Improvement               |                                              |
| Training Hours             | (Sila & Ebrahimpour, 2005; Ahire et al.,     |
|                            | 1996; Kaynak, 2003; Tan et al., 1999;        |
|                            | Yusuf & Azhar, 2018; Salaheldin, 2009)       |
| Product Quality Index      | (Sila & Ebrahimpour, 2005; Ahire et al.,     |
|                            | 1996; Tan et al., 1999; Yusuf & Azhar, 2018;|
|                            | Anderson et al., 1995)                       |
| Learning                  | (Sila & Ebrahimpour, 2005; Tan et al., 1999) |
**Extreme Condition Verification**

This test is deployed to verify the behaviour of the model structure. The selected variables must be justified in the extreme condition (Qudrat-Ullah, 2008; Sterman, 2007; Forrester & Senge, 1980) and should exhibit the logical behaviour if there are no potential members to be the part of quality control circles, there is no tasks accomplishment (as shown in Figure 8), QC Team member must be zero, and consequently, there are no savings (see Figure 9 and Figure 10).

![Graph 1](image1)

**Figure 8.** Labour Productivity is zero when no QCC Team Member

![Graph 2](image2)

**Figure 9.** QCC Projects are zero when no QCC Team Member
Parametric Verification

Parameter verification means comparing model parameters to the observation of the real-life system (Forrester & Senge, 1980; Sterman, 1987). Parametric values are consistent with the relevant knowledge of the case company and support is also obtained from the company documents, archival materials, judgmental opinions, participant experience, and expert opinion of the top management. Appendix B indicates a list of variables with base run values and Appendix C indicates the modelling equations.

Behaviour Reproduction Test

This test is being carried out for the validation of the model behaviour. Behavioral validity is to compare the model-generated behaviour to the observed behaviour (Steman, 2007; Qudrat-Ullah & Seong, 2010) of the case company. Base run values represent the reference model of the ABC Packaging.

5. Policy Analysis

Models created for policy design perspective must incorporate multiple patterns potentially existing in the system and observed and recorded at different times and locations so that the mechanisms of change from one pattern to another can be searched through experimentation (Saeed, 1992). In this model, policies are
designed and explored based on parametric changes. Multiple simulations are run exploring plausible policies. The output of these simulations is presented as a time plot and phase plot (Saeed, 2013) for a better understanding of the reader. To answer the research questions base run results of the model are discussed. Employee involvement motivates the member to conceive new projects for quality and productivity improvement and generate savings. More QCC projects mean more people are involved in QCC activities and consequently more savings may be generated as an outcome. The certain number of company employees is the staff constraint that reflects the stock adjustment process and QCC projects equilibrium state.

**Base Run Result of Underlying Structure of QCC**

Base run values are the result of the underlying structure of the quality control circles. Employee involvement and sharing the benefits of the quality control circles indicate that the code of conduct of quality circles is followed and each circle has completed the seven steps strategy religiously using the statistical quality control tool. In the beginning under the motivational awareness sessions and production incentives, the number of QCC members is high which was settled down over time. As can be observed in graphs 1 through 5, project savings are the proven fact and the impact on the company's bottom line in terms of cost savings. In the beginning, the quality of team members start increasing, and then due to the dominance of the balancing loop it tries to maintain the status quo position shown in graph 1; QCC projects follow the same curve pattern shown in graph 2 as the number of projects depends upon the QCC members. Projects savings and product quality index start increasing as the project continues solving the day to day operational problems shown in graph 3 and graph 4 respectively. Labour productivity reaches the maximum level and then acquiring the oscillatory waveform achieves the equilibrium state shown in graph 5. The Scatter diagram (see graph 6) shares the surprising results irrespective of the reduction of the number of projects overall savings is increasing.
Graph 1. Quality Team Members

Graph 2. Quality Control Circle Projects
Graph 3. Projects Savings

Graph 4. Product Quality Index
Graph 5. Labour Productivity

Graph 6. Scatter Diagram between QCC Projects and Project Savings
Policy Run 1 Increasing the Management Pressure (70 percent to 85 percent)

This parametric based policy is suggested based on the management approach. For instance, when the company started to generate savings, there was a motivation for the management that they should increase pressure on the quality manager and quality control circle facilitators to ensure the timely conduction of the QCC meetings, availability of the resources, and support to accomplish the corrective measures suggested by the QCC team members. Management focus is measured in the interval scale of 0 to 100 (zero to hundred) in terms of a percentage (see details in graphs 7 through 12). The graphs from 7 to 12 indicate that QCC members and QCC projects after few oscillations achieve the equilibrium state whereas QCC project savings and product quality index keep on increasing over time.

Graph 7. Comparison of QCC Projects between base run and policy run
**Graph 8.** Comparison of Projects savings between base run and policy run

**Graph 9.** Comparison of Product Quality Index between base run and policy run
**Graph 10.** Comparison of Quality Team Members between base run and policy run

**Graph 11.** Comparison of Ability for Continuous Improvement between base run and policy run
**Graph 12.** Comparison of Labour Productivity between base run and policy run

**Policy Run 2 Enhance Employee Involvement (60 percent to 80 percent)**

Employee involvement is the backbone of quality control circles. It is well-known that when employees are respected and empowered (Arrfou, 2019) to take the corrective measures, they show responsibility and try to come up to the aspirations of the management. This model depicts this story that as soon as the employee involvement is boosted on an interval scale (0 to 100 percent) from 60 percent to 80 percent there will be a significant improvement in every factor such as the number of projects, savings generated, improvement in product quality index, and rising labour productivity. See graph 13 to 17 to understand this trend. Employee involvement does not depict the spiral behaviour because employee involvement capacity is limited by multiple constraints like time assigned, motivation level, and overall potential.
Graph 13. Comparison of Q Team Members between base run and policy run

Graph 14. Comparison of QCC Projects between base run and policy run
Graph 15. Comparison of Projects Savings between base run and policy run

Graph 16. Comparison of Product Quality Index between base run and policy run
Conclusion

Policy analysis indicates that human capital can be converted into financial capital while generating project savings. It is possible through the careful development of the model and intelligent implementation of quality control circles. The code of conduct and seven steps strategy require the deployment in a conducive environment. Employee involvement (Hill, 1991) and management focus are the key parametric variables that contribute substantially to the success of the quality control circles. The result of the model is obvious that awareness sessions, motivational drive, and training are the operational instruments to enhance employee involvement and make the quality circles success stories within the company. Increasing members of the QCC projects enhance labour productivity and then gradually settle down as the human potential reaches its maximum limit within the given resources. Project savings are on the track of improvement and keep on increasing with the completion of each project. Project completion and projects savings are the driving forces to break the inertia in a system and further increase management focus for quality culture and environment of learning.

The model can be generalized for studying the underlying structure of various companies and changing initial conditions like
SPELL Packaging, KSB pumps, Indus Motors, Descon Engineering, Irfan Textile, and Thal Engineering. By changing the initial conditions of any company, the model can be used for that company and the behaviour generated will be the sinusoidal oscillatory waveform for QCC projects, QCC team members, and labour productivity whereas the behaviour of project savings and product quality index depicts the spiral growth. It has been revealed that the underlying structures and feedback concepts of the companies remain the same as per the seven-step strategy model.

Experimentation can be done with the model to explore more entry points for parametric based policy interventions and to find out the more plausible policies. New structures based on innovative and creative thinking can be added after gaining insight while playing with the simulation model to design the policies based on structural changes. Sensitivity analysis of the model can be taken as a future research agenda to make the model more robust and generic.
References

Ahire, S. L., Golhar, D. Y., & Waller, M. A. (1996). Development and validation of TQM implementation constructs. *Decision Sciences, 27*(1), 23-56. https://doi.org/10.1111/j.1540-5915.1996.tb00842.x

Anderson et al. (1995). A path analytic model of theory of quality management underlying the deming management method: Preliminary empirical findings. *Decision Sciences, 26*(5), 673-658. https://doi.org/10.1111/j.1540-5915.1995.tb01444.x

Arrfou, H. (2019). New business model of integration practices between TQM and SCM: The role of innovation capabilities. *Problems and Perspectives in Management, 17*(1), 278-288.

Forrester, J. W. (1968). Principles of Systems, Wright. *Allen Press/MIT, Cambridge, MA, 274, 12.*

Forrester, J. W. (1997). Industrial dynamics. *Journal of the Operational Research Society, 48*(10), 1037-1041.

Feigenbaum, A. V. (1991). *Total Quality Control.* New York: McGraw Hill.

Hill, S. (1991). Why quality circles failed but total quality management might succeed. *British Journal of Industrial Relations, 4*(1), 541-568. https://doi.org/10.1111/j.1467-8543.1991.tb00371.x

Inman, D., Bush, B., Newes, E., Peck, C., & Peterson, S. (2020). A technique for generating supply and demand curves from system dynamics models (No. NREL/JA-6A20-72286). *System Dynamics Review Rev, 36*, 373-384.

Ishikawa, K. (1985). *What is total quality control?* NJ: Prentice-Hall, Englewood Cliffs.

Jerman, A., Erenda I., & Bertoncelj, A. (2019). The influence of critical factors on business model at a smart factory: A case study” *Business System Research, 10*(1), 42-52. https://hrcak.srce.hr/ojs/index.php/bsr/article/view/12636

Juran, J. M. & Gryna, F. M. (2001). Quality planning and analysis from product development through use (pp. 120-138). New York: McGraw Hill.
Ishikawa, K. (1970). General principles of QC circles. QC Circle headquarter, JUSE.

Kaynak, H. (2003). The relationship between total quality practices and their effects on firm performance. Journal of Operations Management, 21(4), 405-435. https://doi.org/10.1016/S0272-6963(03)00004-4

Kumar, J., Kataria, K. Krishan, L., Sunil (2020). Quality circle: A methodology to enhance the plant capacity through why-why analysis. International Journal of Mathematical, Engineering and Management Sciences, 5(3), 463-472.

Lane, C. D. (2007). The power of the bond between cause and effect: Jay Wright Forrester and the field of system dynamics. System Dynamics Review, 23(2-3), 95-118. https://doi.org/10.1002/sdr.370

Meadows, D. L., Behrens, W. W., Meadows, D. H., Naill, R. F., Randers, J., & Zahn, E. (1974). Dynamics of growth in a finite world (p. 637). Cambridge, MA: Wright-Allen Press.

Mikalauskas, R., Statnickë, G., Habánik, J., & Navickas, V. (2019). Management quality evaluation of sports clubs for the disabled applying the Common Assessment Framework (CAF). Economics & Sociology, 12(1), 329-368.

Nielsen, S. & Nielsen, E. H. (2015). The balanced scorecard and the strategic learning process: A system dynamic modelling approach. Advances in Decision Science, 2015, 1-20.

Petermann, A., Schreyögg, G., & Fürstenau, D. (2019). Can hierarchy hold back the dynamics of self-reinforcing processes? A simulation study on path dependence in hierarchies. Business Research, 12(2), 637-669.

Pidd, M. (2010). Why modelling and model use matter. Journal of Operations Research Society, 61, 14-24.

Richardson & Pugh (1981). Introduction to System Dynamics Modeling with Dynamo. MIT Press.

Rohrbasser, A., Harris, J., Mickan, S., Tal, K., & Wong, G. (2018). Quality circles for quality improvement in primary health care: Their origins, spread, effectiveness and lacunae—a
scoping review. *PloS One*, 13(12). https://doi.org/10.1371/journal.pone.0202616

Qudrat-Ullah, H. (2008). Behaviour validity of a simulation model for sustainable development. *International Journal of Management and Decision-Making*, 9(2), 129-140. https://doi.org/10.1504/IJMDM.2008.017195

Qudrat-Ullah, H., & Seong, B. S. (2010). How to do structural validity of a system dynamics type simulation model: The case of an energy policy model. *Energy policy*, 38(5), 2216-2224. https://doi.org/10.1016/j.enpol.2009.12.009

Rohrbasser, A., Kirk, U. B., & Arvidsson, E. (2019). Use of quality circles for primary care providers in 24 European countries: An online survey of European Society for Quality and Safety in family practice delegates. *Scandinavian Journal of Primary Health Care*, 37(3), 302-311. https://doi.org/10.1080/02813432.2019.1639902

Salaheldin, S. I. (2009). Problems, success factors and benefits of QCs implementation: a case of QASCO. *The TQM Journal*, 21(1), 87-100. https://doi.org/10.1108/17542730910924772

Sila, I. & Ebranhimpour, M. (2005). Critical linkages among TQM factors and business results. *International Journal of Operations & Production Management*, 25(11), 1123-1155. https://doi.org/10.1108/01443570510626925

Saeed, K. (1992). Slicing a complex problem for system dynamics modeling. *System Dynamics Review*, 8(3), 251-261. https://doi.org/10.1002/sdr.4260080305

Saeed, K. et al. (2013). Farmers, bandits and soldiers: A generic system for addressing peace and agendas. *System Dynamics Review*, 29(4), 237-252. https://doi.org/10.1002/sdr.1507

Saeed, K. (2014). Jay Forrester’s operational approach to economics. *System Dynamics Review*, 30(4), 233-261.

Sokovic, et al. (2009). Basic tools in continuous improvement process. *Journal of Mechanical Engineering*, 5, 1-9.

Sterman, J. D. (2007). Exploring the next great frontiers: System dynamics at fifty. *System Dynamics Review*, 23(2-3), 89-93. https://doi.org/10.1002/sdr.380
Sterman, J. D. (1987). Testing behavioural simulation models by direct experiment. *Management Science*, 3(12), 1-40.
Sterman J. D. (2000). Business dynamics systems thinking and modeling for a complex world. USA: McGraw-Hill.
Stepanovich, P. L. (2004). Using system dynamics to illustrate Deming’s system of profound knowledge. *Total Quality Management*, 15(3), 379-389. [https://doi.org/10.1080/1478336042000183442](https://doi.org/10.1080/1478336042000183442)
Sud, I. (2000). *Quality circle master guide*. Printice Hall India Pvt. Ltd.
Senge, P. & Forrester, J. W. (1980). Tests for building confidence in system dynamics models. *System dynamics, TIMS studies in management sciences*, 14, 209-228.
Tan et al. (1999). Supply chain management: an empirical study of its impact on performance. *International Journal of Operations and Production Management*, 19(10), 1034-1052. [https://doi.org/10.1108/01443579910287064](https://doi.org/10.1108/01443579910287064)
Van, D. J. & Pretorius, L. (2014). A systems thinking approach to the sustainability of quality improvement programmes. *South African Journal of Industrial Engineering*, 25(1), 71-84.
Yusuf, M. & Yusuf, I. (2005). Corporate excellence through quality circles: The case of Pakistani Industries. *Proceedings of 6th International Conference of Quality Managers*, 2005, Tehran, Iran.
Yusuf, I. & Azhar, M. T. (2018). Policy interventions for supply chain performance through quality auditing: The case of packaging company. *Journal of Quality and Technology Management*, 15(1), 107-139.
Appendix A

STELLA is a simulation software named as the “Structured Thinking Experiential Learning Laboratory Animation (STELLA)”. Following is the detail of symbols used in modelling language

Table (1)
Symbols for Flow Diagram in STELLA

| Description                        | Symbol | Associated Equation Type | Explanation                                                   |
|------------------------------------|--------|--------------------------|---------------------------------------------------------------|
| Level                              | ![Level Symbol](image) | L                        | Stock                                                         |
| Rate                               | ![Rate Symbol](image)  | R                        | Flow                                                          |
| Auxiliary                          | ![Auxiliary Symbol](image) | A                        | Convertor                                                     |
| Graphical Function / Table Function| ![Graphical Function Symbol](image) | T                        | Perception map between two variables on x-y plane             |
| Exogenous variable                 | ![Exogenous Variable Symbol](image) | E                        | Occasionally affect the model behavior but not part of model  |
| Constant                           | ![Constant Symbol](image)   | C                        | Constant which has unique value and which is prone to change. |
| Source or Sink of Material         | ![Source or Sink Symbol](image) | Define                   | Out of boundary, defines the model scope                      |
| Material / Information Flow        | ![Material / Information Flow Symbol](image) |                        | Use for the movement of material and information              |
# Appendix B

## List of Variables

| Variables                | Description                  | UOM          | Equation Type | Base Run Parametric Value |
|--------------------------|------------------------------|--------------|---------------|----------------------------|
| Initial QCC Projects     | Initial QCC Projects         | Number       | C             | 0                          |
| QCC Projects             | QCC Projects                 | Number       | L             |                            |
| Initial Projects Savings | Initial Projects Savings     | Rupees       | C             | 0                          |
| Projects Savings         | Projects Savings             | Rupees       | L             |                            |
| Initial Q Team Members   | Initial Q Team Members       | Persons      | C             | 0                          |
| Q Team Members           | Q Team Members               | Persons      | L             |                            |
| Joining Time             | Joining Time                 | Months       | C             | 10                         |
| Members Leaving Time     | Members Leaving Time         | Months       | C             | 36                         |
| SS Training              | SS Training                  | Hours        | C             | 1000                       |
| HS Training              | HS Training                  | Hours        | C             | 1000                       |
| Normal Labour Productivity| Normal Labour Productivity  | Tasks per person per month | C | 1 |
| Normal Employee Involvement| Normal Employee Involvement | Dimensionless | C | 0.5 |
| Employee Involvement     | Employee Involvement         | Dimensionless | C | 0.6 |
| Themes                   | Themes                       | Number of Ideas | C | 20 |
| Normal Quality Initial   | Normal Quality               | Dimensionless | C | 0.7 |
| Management Pressure Initial| Management Pressure Initial | Dimensionless | C | 0.7 |
| Project Team Size        | Project Team Size            | Number per person | C | 0.25 |
| Project Completion Time  | Project Completion Time      | Months       | C             | 6                          |
| Potential Members        | Potential Members            | persons      | C             | 100                        |
| TTPG                     | Time to cover potential members | Months     | C             | 24                         |
| Learning Fraction        | Learning Fraction            | Per month    | C             | 0.020                      |
| Variable | Description                                      | Unit               |
|----------|--------------------------------------------------|--------------------|
| Ability for Continuous | Ability for Continuous | Dimensionless |
| AIR | Ability Increase Rate | Dimensionless |
| MJR | Member Joining Rate | Persons/month |
| MLR | Member Leaving Rate | Persons/month |
| QCCSR | Quality Control Circle Start Rate | Number/month |
| QCCIMR | Quality Control Circle Implementation Rate | Number/month |

**Note:** Rupee is the abbreviation of Pakistani Currency.
Appendix C

STEELA is simulation software named as the Structured Thinking Experiential Learning Laboratory Animation (STEELA)

Followings are the equations written in STEELA

Top-Level Model:

Ability_for_CI(t) = Ability_for_CI(t - dt) + (AIR) * dt
INIT Ability_for_CI = Initial_Ability

INFLOWS:
AIR = New_Ideas*(HS_Training+SS_Training)*Effect_SQC_Tools/8*.25

Projects_Savings(t) = Projects_Savings(t - dt) + (Saving_Rate) * dt
INIT Projects_Savings = Initial_Project_Savings

INFLOWS:
Saving_Rate = QCCIMR*100000/3

Q_Team_Members(t) = Q_Team_Members(t - dt) + (MJR - MLR) * dt
INIT Q_Team_Members = Initial_Q_Teams_Members

INFLOW:
MJR = Perceied_Gap**"Management_Pressure-CI"/Joining_Time

OUTFLOW:
MLR = Q_Team_Members/Member_Leaving_Time

QCC_Projects(t) = QCC_Projects(t - dt) + (QCCSR - QCCIMR) * dt
INIT QCC_Projects = 0

INFLOW:
QCCSR = Themes*Q_Team_Members*(Fraction_Learning)*Project_Team_Size

OUTFLOW:
QCCIMR = QCC_Projects/Project_Completion_Time

Effect_SQC_Tools = GRAPH(SQC_Tools)
(0.000, 0.075), (0.700, 0.116), (1.400, 0.177), (2.100, 0.242), (2.800, 0.333), (3.500, 0.437),
(4.200, 0.554), (4.900, 0.688), (5.600, 0.840), (6.300, 0.965), (7.000, 0.965)

Employee_Involvement = 0.80

Fraction_Learning = 0.020

HS_Training = 1000

Initial_Ability = 125

Initial_Project_Savings = 0

Initial_Q_Teams_Members = 0

Joining_Time = 10

Labour_Productivity = Normal_Productivity*Ratio_Employee_Involvement*Q_Team_Members

Management_Pressure_Initial = 0.7

"Management_Pressure-CI" = Ratio_Employee_Involvement*Management_Pressure_Initial

Member_Leaving_Time = 36

Members_Gap = Potential_Members-Q_Team_Members

New_Ideas = 2

Normal_Employee_Involvement = .5

Normal_Productivity = 1

Normal_Quality = 0.7

Perceied_Gap = SMTH3(Members_Gap,TTPG )

Potential_Members = 100
Product_Qualitiy_Index = Normal_Quality*Effect_SQC_Tools*Ratio_ACI
Project_Completion_Time = 6
Project_Team_Size = 0.25
Ratio_ACI = Ability_for_CI/Initial_Ability
Ratio_Employee_Involvement = Employee_Involvement/Normal_Employee_Involvement
SQC_Tools = GRAPH(QCC_Projects)
(0.0, 0.000), (10.0, 1.416), (20.0, 2.727), (30.0, 3.854), (40.0, 4.483), (50.0, 4.981), (60.0, 5.427),
(70.0, 5.768), (80.0, 6.082), (90.0, 6.554), (100.0, 6.869)
SS_Training = 1000
Themes = 20
TTPG = 24
{ The model has 38 (38) variables (array expansion in parens).
In 1 Modules with 1 Sectors.
Stocks: 4 (4) Flows: 6 (6) Converters: 28 (28)
Constants: 19 (19) Equations: 15 (15) Graphicals: 2 (2)
There are also 10 expanded macro variables.}