# Quality Management in a Research and Development Environment

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## ABSTRACT

This research paper reviews application of quality management in research and development (R&D) environments, focusing on the specific systems, processes, and principles that have proven successful and the criteria these must meet for successful implementation. Innovation and flexibility are key requirements and successful systems include total quality management (TQM), the quality characteristics (QCs)-linkage model, and adaptations of several quality process models. Based on the needs for flexibility and autonomy in an R&D environment, TQM principles and the QCs-linkage model are selected as the most likely candidates for successful implementation. The TQM principles of leadership, continual improvement, and customer focus are common across the literature as key to improving quality focus and practices in R&D environments. Heavy intervention from quality management staff and highly structured quality management systems may decrease performance and innovation in R&D environments.

KEYWORDS: Total quality management, Quality characteristics-linkage model, R&D Quality Process Model, Autonomy, Innovation, Flexibility

## INTRODUCTION

Since a research and development environment is less predictable, projects are more likely to have lack of scope definition, and outputs and expectations are variable, implanting quality management is more challenging. The purpose of this paper is to identify quality management methods that are suitable for R&D environments and to make recommendations for how to implement them. Innovation and flexibility are key requirements and successful systems include total quality management (TQM), the quality characteristics (QCs)-linkage model, and adaptations of several quality process models. Based on the needs for flexibility and autonomy in an R&D environment, TQM principles and the QCs-linkage model are selected as the most likely candidates for successful implementation. The TQM principles of leadership, continual improvement, and customer focus are common across the literature as key to improving quality focus and practices in R&D environments.

## LITERATURE REVIEW AND SYNTHESIS

A review of the literature must begin by ensuring that there is evidence that quality management methods and programs are appropriate for an R&D environment. Wiengarten, et al. (2013) explore the linkage between a company's innovativeness and its success with total quality management (TQM) by analyzing the results of survey data (p. 3056). Wiengarten et al. (2013) found that all seven TQM practices—visionary leadership, cooperation, learning, continuous improvement, employee fulfillment, and customer satisfaction—had a stronger positive impact on operational performance in organizations with high levels of innovation than in those with low levels of innovation (p. 3068).

Implementation is also a key consideration. The hallmark of TQM is total employee involvement in the quality process to include training and teamwork, which helps engage employees, enable them to take ownership of quality processes, and promotes buy-in (Foster, 2013, p. 17). Shiu, Jiang, and Tu (2013) note the importance of effective change management when implementing any quality system in an R&D environment (p. 286). Kumar, Kim, and Kumar (2012) note that “it is essential for companies to fully understand the core concepts of QM as a way of life for daily operations” (p. 157) rather than impose individual quality processes and procedures that may be unsuitable for an R&D environment.

Jo and Park (2015) state that a major advantage of TQM when it comes to implementation is its focus on employee empowerment, which may make TQM principles more palatable for research engineers who are not accustomed to structured quality systems (p. 264). Maier and Fulea (2012) also make a strong case for the integration of TQM principles into an R&D environment based on the link between innovation and quality (p. 78).

Jayawarna and Holt (2009) argue that the most effective use of quality systems in R&D environments “provide an organisational background or frame” (p. 775) to allow for flexibility. The companies with the largest barriers to the integration of quality systems into R&D environments experienced difficulties communicating information between departments; that is, R&D departments often resisted quality systems because they did not understand how a system that they perceived to belong to a different department was applicable to their work (Jayawarna & Holt, 2009, p. 781). Cabeza-Pullés, Gutierrez-Gutierrez, and Lloréns-Montes (2016) argue that if a quality system is successfully implemented in an R&D environment, it improves communication between departments (p. 316). The flexible quality capabilities that Jayawarna and Holt (2009) found useful in R&D environments are: “corporate framework for quality, quality product/service delivery, improved customer perception, quality of research output, quality of research input, effective problem solving, managing of feedback processes, feed forward planning and information processing, [and] sophisticated infrastructure” (pp. 780-781).

**Quality and Innovation**

Much is written on the connection between quality and innovation, which justifies the need for quality tools, processes, and techniques to be integrated into and implemented in R&D environments. Dubey et al. (2014) note that R&D capabilities are increasingly being seen as part of an organization’s underlying business strategy, due in part to an R&D department’s positive correlation with high levels of innovation (p. 1007). Leavengood, Anderson, and Daim (2014) identify that the major total quality management (TQM) predictor of whether or not an organization achieved both quality and innovation is its customer focus (p. 1126). Firms that work with customers to identify unmet needs and develop products to meet those needs have higher levels of innovation than organizations that select research and development projects based on researcher interest or an educated guess as to what a customer may want. Maier and Fulea (2012) note that the TQM concept of continual improvement is harmonious with an R&D environment’s primary function: to develop new products and improve existing products (p. 78). Innovation is one of the bedrocks of TQM, which makes TQM an appropriate framework to implement in an R&D environment.

An empirical study by Song and Ding (2013) on the link between QM and innovation in R&D environments concluded “that quality management practices do not significantly influence firm innovation directly, but indirectly through the mediating effect of R&D capability” (p. 889).

Song and Ding (2013) caution that managers should not conclude from this that full-blown QM systems should be imposed on R&D departments and organizations, as this may actually decrease innovation (p. 890). Song and Ding (2013) specifically take issue with QM processes that are dependent on repeatability and process reliability and stability, as these are useless in R&D environments where innovation stems from product variations (p. 890). As to managerial approach, Song and Ding (2013) advocate the incorporation of “soft elements” (p. 890) such as “leadership, quality strategy, and quality culture” (p. 890).

## Quality Control Linkage Model

In their 2013 case study, Duan and Wang show that a “QCs-linkage model based framework of quality characteristic variation analysis and control” (p. 6573) was effective for the development of an internal combustion engine. The quality characteristics (QCs)-linkage model as applied to R&D is based on the idea that even products that are in the early stages of development have identifiable characteristics in early stages that, if compromised, negatively impact the quality of the end product. The challenge of applying this model to R&D is that traditional QCs model is heavily based on variation control, which is not practicably measureable when creating a prototype (Duan & Wang, 2013, p. 6575). Because variation among units or products could not be measured, the concept was instead applied to the prototype’s actual quality characteristic variation from the target or design quality characteristic (Duan & Wang, 2013, p. 6576). This model is called QCs-linkage because it takes the traditional aspects of a QC model and links the characteristics to target or goals instead of looking for variation (Duan & Wang, 2013, p. 6576). Weighted values are used instead of hard measurements to assess variation or impact in order to apply quantitative measures that allow for flexibility to suit the R&D environment (Duan & Wang, 2013, p. 6576).

When applied to the internal combustion engine, the QCs used are specific and measurable control data such as air inlet efficiency, intake valve lag angle, and maximum output torque (Duan & Wang, 2013, p. 6590). These are the kinds of characteristics that would not be measured in production models but are commonly measured in engine prototype development. Variation source-tracing analysis was used to identify unreliable components, and variation propagation analysis was used to determine the impact of eliminating or replacing those components (Duan & Wang, 2013, p. 6589). Through multiple analyses, the prototype was refined so that the data better matched the target values.

Shepherd (2015) echoes some of Duan and Wang’s thoughts on the challenges and benefits of implementing quality processes in an R&D environment in his proposal to NASA for using quality procedures in aerospace test programs (p. 1). Shepherd (2015) contends that despite the challenges of finding processes that are not dependent on variance control and reproducibility, quality concepts such as “process improvement and defect control” (p. 1) are highly applicable to testing environments.

## Quality Management in Early Stages of R&D

Fiehe et al. (2014) develop and implement a custom quality management (QM) system for university research department (p. 142). The process was a joint effort between QM staff and research department staff and comprised the following stages: initiation and concept, definition, design, realization, integration and test, and completion (Fiehe et al., 2014, p. 143). The development process focused heavily on meeting the needs of the research department as far as control, monitoring, measuring, equipment, purchasing, financial, and resource management (Fiehe et al., 2014, p. 138). The diverse requirements of the research department were also considered, accounting for both the diversity of projects and the diversity of the educational backgrounds of research staff (Fiehe et al., 2014, p. 139). Some of the specific QM tools implemented were a document identification system, a design specifications and identification system, technical risk analysis, a traceability matrix to track requirements, and test protocols (Fiehe et al., 2014, pp. 140-143).

The major challenged faced in Fiehe et al.'s (2014) case study was "carrying the use of new tools to excess" (p. 144) during the implementation phase. Users initially found the new processes confusing and felt overburdened by new abbreviations and a high level of granularity, so some processes were streamlined and document categories were combined to better accommodate users (Fiehe et al., 2014, p. 143). Research department staff did some of their own streamlining after the project was complete, and some of the tools implemented remain unused (Fiehe et al., 2014, p. 144). Overall, however, the implementation of the custom QM system was considered a success. It improved workflow efficiency, generated tools that are transferrable to new projects, and received positive feedback from users (Fiehe et al., 2014, p. 144). Supporting Fiehe et al.'s findings, Bapat and Soni (2015) also argue in favor of quality tools that can be transferred from one research project to the next to formalize quality standards in an R&D environment, though their specific focus is on management information system (pp. 144-145).

**R&D Quality Process Model**

In the literature, the application of quality process models to R&D environments is also explored. Maier and Fulea (2012) use the eight QM principles developed by the International Organization for Standardization (ISO) to develop a list of five principles that are specific to innovation and R&D: structure, leadership, culture, continual improvement, and management commitment (p. 79). A key component of culture is customer focus, as Maier and Fulea (2012) recognize that private R&D facilities do not operate for the sake of research alone (p. 79).

Wang (2014) showed that there is "an inverted U-shaped relationship between R&D expenses and ISO 9000 quality management" (p. 400), which means that organizations that are ISO 9000 compliant receive greater benefit from R&D expenditures. Hwang, Kim, and Jeong (2012) note that the ISO 9004 self-assessment scheme combined with a quality management system (QMS) internal audit process show improvements in development and performance enhancement of an R&D organization (p. 190). Zhu and Qian (2012) find that the "quality control in large scientific experiments corresponds with ISO9001 quality management systems" (p. 323) in the development of a high energy physics detector. Biasani (2012) describes the successful implementation of a quality management system based on ISO 9001:2008 and ISO 17025:2005 standards in a public research facility in Italy (p. 621).

Yoon et al. (2015) identify best practices from Capability Maturity Model Integration (CMMI), European Industrial Research Management Association (EIRMA), and ISO to create a new process model specific to R&D (p. 746). Yoon et al.'s (2015) model comprises the following processes: R&D planning, portfolio management, organizational performance management, quality management, project planning, project monitoring, gate assessment, risk management, business feasibility analysis, specification definition, design, and market test (p. 758). Yoon et al. (2015) that these broad processes can be applied across multiple R&D organizations while remaining flexible enough to account for individual differences depending on specific environmental needs and project requirements (p. 758).

## DISCUSSION

The key factor in all of the proposed models and theories is flexibility, and all of the discussions around implementation make a case against too much interference from a quality department. The R&D department, facility, or organization best understands its own needs and must have input into and ownership over its processes. The arguments in favor of using TQM to guide quality in R&D environments focus on the flexibility of such principles as well as individual organizations' ability to implement TQM without creating significant resistance to change. Leadership, continual improvement, and customer focus are the three TQM principles that show up across the literature as creating successful environments for both experimentation and innovation while improving quality focus and practices.

Duan and Wang's QC-linkage model is an excellent example of a quality management model that integrates nicely into an R&D environment with imposing the kind of strict quality that may be perceived by researchers as designed for other departments, as Jayawarna and Holt (2009) warn can be problematic (p. 781). This author's experience working in an applied research laboratory has been that data acquisition and control (DAQ) is a very important aspect of prototype development. The QC-linkage model allows researchers to use the measurability of data as QC for research projects. In R&D projects, data are measured because the researchers do not know what the data will be. In research projects, targets are not always known. This model allows for a vast flexibility in what is considered a "quality" unit, whether that unit is a test stand that's sole purpose is to gather data or a prototype unit that has specific design targets. Furthermore, the QC-linkage model could be implemented without talk of Ishikawa diagrams, Lean Six Sigma, and other quality management concepts that this author has seen research engineers find extremely off-putting. This author has seen the same quality manager who used Ishikawa diagrams, which are used to identify the root cause of a problem, to great success in a manufacturing environment fail miserably using one in an R&D environment, thereby losing the confidence of the research engineers (p. 236). Not all quality tools are appropriate in all environments.

While Fiehe et al.'s (2014) implementation of a custom QM system in a university research department was considered successful, this author questions the practicality of a similar solution applied to a corporate environment (p. 144). In certain industries, however, a custom solution may already be available. The Cooperation on International Traceability in Analytical Chemistry (CITAC) (2016) has published guides on applying QM to R&D, though they are highly industry-specific. First, research and development engineers often act defensively when employees from other departments are brought in to audit their work (Jayawarna & Holt, 2009, p. 781). Despite evidence that ISO 9000 compliant organization receive more benefits from R&D expenditures, that does not mean that the research facilities themselves see any of the type of auditing that goes on in the ISO compliant manufacturing and production facilities (Wang, 2014, p. 400). Finally, one must question how much the university research department was simply cooperating for cooperation's sake, since some of the tools went unused. The QM staff's understand of the needs of the research department is also questionable, given that the early phases of implementation were challenging and the tools required rework (Fiehe et al., 2014, p. 143). Although research on ISO and other process models show that R&D environments benefit from the implementation of quality process models, flexibility appears to be a key component and implementation difficulties are abundant in processes that are highly structured. The best QM systems for R&D environments may well be ones that research staff can primarily customize and implement themselves.

## IMPLICATIONS FOR THEORY

This research paper has several implications for theory in the following areas: contributions to existing body of knowledge, limitations of current study, and directions of future research.

### Contributions to Existing Body of Knowledge

The existing body of knowledge focuses on which quality systems are appropriate for R&D environments and on how to implement quality systems in R&D environments. This research paper marries the two concepts by highlighting the feasibility of both general TQM principles and the QCs-linkage model because those quality approaches are most easily implemented with minimal input from QM staff, which is essential to successful implementation due to the highly specific needs of R&D environments and the high levels of resistance to change usually found therein.

### Limitations of Current Study

One limitation of this study is that the results are based on analysis of other scholarly publications rather than empirical evidence, as the purpose of this study was to identify quality methods and strategies for implementation in the broad area of R&D. Another limitation is that because there are different disciplines within R&D that operate across a number of industries and have different sized facilities and different access to resources, this study does not produce recommendations that will always work in any R&D environment.

### Directions for Future Research

Now that quality management methods that are effective in R&D environments have been identified and methods for implementation are recommended, further researchers can conduct empirical studies to determine a method to quantify the anticipated improvements. Because R&D is not a one-size-fits-all environment, it would be interesting to discover which methods work better in what industries, disciplines, or size facilities. By considering additional variables and conducting research on the impact of quality management in different R&D environments, further research could help managers identify what methods will work best in their specific organizations.

## IMPLICATIONS FOR PRACTICE

The implications of this research for management are fairly significant. Based on the results, managers of R&D organizations or of organizations that have R&D departments would increase performance by implementing quality management, but only certain types of quality management and only when implemented in the correct ways. R&D organizations are not the same as manufacturing companies, and different approaches must be used.

### Key Takeaways

There are several key takeaways from this research. First, quality systems that are implemented in R&D environments must be sufficiently flexible—TQM and QCs-linkage model are the preferred methods. Innovation is key to a successful R&D environment, and the facilitation of innovation should be the primary goal of any QM system or process that is put in place. Formal QM systems in the rest of an organization help facilitate innovation in R&D departments, even if those departments have no formal quality system or processes in place. Customer focus is essential to innovation in an R&D environment. Leadership, continual improvement, and customer focus create successful environments for research, development, and innovation while improving quality focus and practices The most successful implementations of QM processes and systems are those that are primarily developed and implemented by the R&D staff with only minimal support from QM staff.

### Lessons Learned

Highly structured, inflexible, or complex QM systems, which are often associated with high levels of QM staff involvement, do not always meet the needs of R&D environments, are likely to create more resistance to change, and can even reduce innovation. Although some of the literature showed success with process models, all of these models were adapted and only certain aspects of any existing model were successfully applied to R&D environments.

## IMPLICATIONS FOR MANAGEMENT

For an organization whose primary industry is the manufacture, delivery, and support of military equipment, innovation is essential to continued success and sustainability. In order to keep on top of the latest technologies in an effort to exceed customer demands, organizations should focus some resources on internal research and development (IR&D). Many manufacturing facilities have had a great deal of success implementing quality management practices—lean manufacturing, TQM, JIT inventory management, ISO 9001:2008, and Six Sigma—but a lack of quality management practices in R&D environments is a missed opportunity to improve innovation and therefore increase the bottom line.

Research has shown that quality management practices improve operational performance in R&D environments (Wiengarten et al., 2013, p. 3068). The application of TQM principles and a QCs-linkage model allow R&D environments both the flexibility that they need to operate as well as a goal-oriented, quality-focused structure that helps them succeed. Care must be taken not to impose manufacturing QM principles on R&D environment. Greatest success is had when the R&D staff themselves develop and implement QM processes and tools based on what best suits their needs, creating a sense of ownership over staff input into the quality of products and services.

## CONCLUSION

Existing literature focuses on either which quality systems or processes work in R&D environments or on how to implement QM in R&D environments. This research paper marries the two concepts and identifies the TQM principles of leadership, continual improvement, and customer focus and the QCs-linkage model as two successful QM approaches that are also in line with the managerial aspects of successful implementation of QM in R&D environments. These approaches allow flexibility and promote ownership by R&D staff. The implementation of QM in an R&D environment must not been seen by R&D staff as an effort by senior management to impose a one-size-fits-all solution on a department that already has difficulty communicating with the rest of the company due to the highly specialized nature of its work. Instead, success implementation must be done gently and gracefully. R&D departments already benefit from QM systems in other departments, so QM in R&D environments should only be implemented to enhance innovation—not to create fixed processes, which can have an adverse effect.

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