6S: Creating an efficient and safer work environment

Abstract

Purpose: This paper explores the concept of workplace organisation and the role of safety. Specifically the objectives of the study were to identify the role of safety within 5S and to test how the extension of the method (to 6S) can explicitly and effectively integrate safety with productivity and quality.

Design/methodology/approach: An action research approach was employed which enabled the development, execution and data collection of a 6S method at a manufacturing company located within the UK. The 6S method was developed based on results from some early experiments of 5S and a critical review of the literature. The research was conducted using a five phase framework: 6S concept development; 6S process development; recording 6S quantitative data; 6S improvement activities and recognition; and 6S success measurement.

Findings: The results of this study show a visible productive change in different work areas of the case organisation along with creating a safer work environment for both employees and visitors. The testing of the 6S method achieved tangible results in relation to productivity, efficiency and safety, which included: improved housekeeping; improved usage of floor space; good visual management and control; and a safer environment supported by a systematic approach.

Relevance/contribution: The majority of published research refers to 5S. Although there is some discussion of safety in the use of this five stage method, it is not explicit as to how this is integrated or employed. This paper proposes a 6S method that explicitly states the role of safety and provides an auditing process.

Keywords: 6S, safety, workplace organisation, 5S, manufacturing, business improvement

Paper Type: Case study

1. Introduction

Total quality management (TQM) is critical for any business as high quality of products and services can give a sustainable competitive advantage. Deming's (1982) 14 point plan for TQM refers to continuous improvement in systems for production and service as a mechanism to improve quality and productivity, thus helping to constantly decrease costs. Michalska (2007) suggests that through the implementation of TQM, a workplace organisation approach referred to as 5S has increased in use.

Standing for Sort, Set, Shine / Sweep, Standardise / System and Sustain, 5S is a method of creating and maintaining a well organized, clean, highly effective and high quality workplace. 5S has roots emerging from Japan, where this method was popularised by Hiroyuki Hirano (1990). 5S links with successful change management by generating a high degree of motivation and involvement in an organisation. Previous research (Bayo-Maris et al., 2010; Gapp et al., 2008; Ho, 2010; Massey and Williams, 2005, 2006; Rich et al., 2006) indicates that applying the technique of 5S, sometimes referred to as workplace organisation or CANDO, can impact on many facets of an organisation, including quality control, process/information flow, layout, process design, supplies and inventory, asset management and maintenance. Bicheno and Holweg (2009) note that some companies add a sixth step for safety but the authors fail to document the practicalities of how this is achieved. In fact they advocate that safety should be implicit across the existing five stages as adding a sixth stage causing confusion.

This paper investigates whether a high risk manufacturing environment such as the case company collaborating in the research can benefit from improved productivity and enhanced safety in the workplace by incorporating an extra "S for safety" into a 5S programme. In so doing this paper reviews the literature associated with the 5S methodology and illustrates, through action-based research, some 5S experiments and the development of a 6S method.

The objectives of this paper are to:

- Justify the need for an additional stage for safety within the existing 5S methodology.
- Provide a framework that makes the role of safety explicit within the methodology – providing an additional 'S' to create 6S.
- Provide an audit framework for 6S.
- Evaluate the success of a 6S implementation in making improvements to safety, productivity and quality.

2. A review of 5S and workplace organisation

5S refers to the first letters of five Japanese words;

- Seiri separate needed and unneeded materials and to remove the latter.
- Seiton - neatly arrange and identify needed materials for ease of use.
- Seiso –conduct a cleanup campaign
- Seiketsu - to do seiri, seiton, and seiso at frequent intervals and to standardize the 5S procedures
- Shitsuke - form the habit of always following the first four Ss.

Since being introduced within a Western context, the 5S terminology has been translated to Sort, Set in order, Shine or Sweep, Standardise or System) and Sustain.

An investigation into 5S practice in the UK showed that its implementation is relatively premature when compared to its use by Japanese organizations (Warwood and Knowles, 2004). In the UK 5S is more prevalent in the manufacturing sector even though in Japan the service sector have seen the biggest gains from 5S in terms of standardization of operations and improved quality. Despite the growing popularity of 5S in both Japanese and Western environments, research into its application is limited (Kumar et al., 2007; Bayo-Moriones et al., 2010).

According to Osado (1991), the main aim of practicing 5S is to embed the values of organisation, neatness, cleanliness, standardisation and discipline into a workplace. Gapp et al. (2008) suggest that 5S contributes to cost-effectiveness by maximising both efficiency and effectiveness. Ho (1997) proclaims that the 5S method not only improves the physical environment around employees but also improves their thinking process. He observed the adoption of 5S practice can help to resolve many of the everyday problems at a workplace. Warwood and Knowles (2004) suggest 5S principles provide a framework within ISO 9001:2000 requirements can be built.

According to Michalska (2007) sustaining 5S best practice leads to an increase in staff consciousness about quality and a decrease in the number of non-conforming products and processes. It also brings improvements to the organisation's internal communication by improving staff relations.

2.1 Evaluation of 5S

5S is a non-statistical and visual oriented method. It requires self discipline and continuous improvement by staff to make progress on a sustained basis. 5S activities require management and employee support to ensure the improvements are maintained.

5S has been criticized by researchers and practitioners for being nothing more than 'housekeeping' (Gapp et al., 2008). Furthermore, it is reported to be "easy to understand" at an abstract level but far more difficult to have a complete understanding of what lies behind 5S when developed as a value driven business model, as seen in organisations like Toyota and Boeing (Gapp et al., 2008).

The main inhibitors to implementing 5S are reported as cost, time and staff resisting change (Webber and Wallace, 2007). Kumar et al., (2007) suggest the limited uptake of 5S is due to the absence of any mechanism to measure its performance. They also suggest the need to identify where the method adds value which would improve its acceptance or make adoption more likely. The majority of improvements from 5S method are not obviously financial and conventional financial accounting systems do not have the facility to portray the intangible inputs and outputs. The absence of suitable financial measurement for 5S improvements limits its implementation and the ability to acquire the limited internal funding often required to support 5S (Kumar et al., 2007).

Recently, Ho (2010) has further developed his integrated Lean-TQM model and introduced a new term "5S + " which combines 5-S and lean 5-S (L5S) audit checklists. These checklists were used as a foundation to developing the 6S audits developed as part of this study.

2.2 The role of safety in the existing 5S method

Several authors (e.g. Ho 1997; 1999; Hirano 1990; Gapp et al. 2008; Michalska and Szewieczek 2007) have suggested that the main focus of 5S is on improving productivity, reducing waste, saving cost, and improving the work environment through housekeeping. Whereas, Gapp et al., (2008) note the primary objective of 5S as maximising the level of workplace health and safety in conjunction with increased productivity. They quote a longitudinal study conducted by the Japan Industrial Safety and Health Association (JISHA, 1999) which reported on the evolution of 5S between 1945 and 1998 and more specifically the addition of a sixth 'S' for "Safety" which is occasionally added to promote the reduction of work injuries. Table 1 illustrates the evolvement of 5S and its significance towards improving productivity and the reduction of industrial accidents.

Period	**Activity**	**Work Injuries**		**Productivity**
1. (1950-1955	2S	44.08 24.49	(1950) (1955)	1
2. (1956-1972)	4S	22.99 7.25	(1956 (1972)	3.6 times up from the previous period
3. (1973-1980)	5S	7.25 3.59	(1972 (1980)	1.4 times up from the previous period
4. (1981-1998)	6S	3.23 1.75	(1981) (1998)	1.5 times up from the previous period

Table 1. The development of 5S

Source: JISHA, 1999 cited in Gap et al., (2008: 567)

Typically, many organisations follow the five-step model, Gapp et al., (2008) explain some Japanese organisations might take alternative routes, for example some adopt 3S (Nakamura, 1992) whereas others implement 6S (Sprague, 2002; Zelinski, 2005). These variations in approach seem to link to the level of maturity of the 5S practice within an organisation.

Although some of the literature refers to 6S and safety it does not provide any definitive measures to improve safety. Safety is generally assumed and an additional step considered unnecessary since it is perceived that carrying out 5S will naturally result in a safe work environment (Bicheno and Holweg, 2009). However, to date no one has empirically tested the impact of specifically addressing safety in a 5S type method.

Despite the classic 5S method not being explicit in addressing safety, a number of authors have discussed the role of safety within operations management. For instance, Ridley and Channing (2003) acknowledge that benefits of good health and safety provisions are not always a priority and the consequences of poor risk management only become apparent once it is too late. They suggest that businesses can suffer high financial costs in neglecting safety – in terms of lawyer fees, insurance premiums, legal claims, reduced business functions, recruiting, training and loss of brand image.

Health and Safety Executive[1] (HSE) (2010) case studies indicate that companies have paid and continue to pay a high financial and social price for neglecting safety. Many fatalities and injuries could have been avoided if the workplace activities were carried out within well defined procedures that were properly displayed and strictly followed in a work environment. A system that has a clear focus to constantly monitor aspects of health and safety at work place is integral to the success for any business. Therefore, a

[1] HSE is the UK's national independent watchdog for work-related health, safety and illness

workplace organization method is needed that supports the continuous improvement of safety. In additional, productivity is improved by due consideration of safety issues (HSE, 2008).

Fillingham (2007) describes how Bolton General Hospital modified the traditional 5S approach to include an additional step for safety. For Bolton the steps were:

1. Sort – Separate needed from not needed
2. Straighten – A place for everything
3. Shine – Clean and wash
4. Standardise – Build into accepted routines
5. Sustain – Discipline to ensure maintained
6. Safety – checking for hazards and defects (Fillingham, 2007: 234)

Fillingham (2007: 234) goes on to say "6S is more than just a clean up…, it is a way of ensuring that calm and orderliness are built in to the day to day way of doing things". As a result of a weeklong 6S exercise in the A&E resuscitation room 71 separate improvements were made which led to fewer clinical incidents, fewer medication errors and higher staff morale. What the paper does not discuss is the reasoning for and the positioning of the additional safety step (Fillingham, 2007: 237). There is also no detail as to what is done differently in implementing 6S as opposed to 5S and a generic method is not suggested.

Kimsey (2010) describes a 6S workplace organisation programme that was adopted by a rapid improvement team in the Lehigh Valley Health Network, Pennsylvania. This was included as part of a plan, do, check, act (PDCA) improvement cycle to determine problems in the central sterile processing department. The 6S approach positioned safety between stage 3) Shine and stage 4) Standardise. No explanation is given in the paper for the addition and positioning of safety within the traditional approach. No mechanisms to audit progress or measure the outcome/impact are mentioned by the author. This suggests that this 6S approach is anecdotal in nature and the inclusion of safety could reflect the increasing profile of patient safety.

This paper therefore addresses the gap in our current understanding of the merits of explicitly addressing Safety and provides the academic rigour, albeit in an industry environment, in developing, implementing and measuring a 6S exercise.

3. Methodology

Action research (AR) is thought to be most effective for technique development or as in this paper for theory building (Wood-Harper, 1985; Eden and Huxham, 1996; Eden and Huxham, 2002). Coughlan and Coghlan (2002) described AR as an approach to research that aims to take action and create knowledge or theory about that action. Revans (1983, p 11) defines action learning as "taking up from the start the need to help managers, and all others who engage in it, acquire the insight into the posing of questions by the simple device of setting them to tackle real problems that have so far defied solution". Eden and Huxham (2002) consider defining AR unnecessary and instead provide 15 guiding characteristics which they recognise are difficult to achieve.

As previously noted AR is not usually concerned with developing new theories but elaborating the work of others (Eden and Huxham, 2002). Therefore, for this study, the ability to observe the testing of the traditional 5S process was fundamental to the incremental and cyclical process of AR (Eden and Huxham, 2002). Also critical is a staged and reflective approach taken by the researchers which was based on the work of Eden and Huxham (2002) and Collis and Hussey (2003). Figure 1 illustrates this approach with the initial planning stage where it was necessary to gain a pre-understanding of the existing 5S programme. A review of the literature on 5S was undertaken which assisted in defining the problem. Once the issues associated with safety were discovered the literature review was extended to include safety. In addition, the 6S method was designed. From this planning stage came the inclusion of the 'safety' step and a focused intervention of 6S was undertaken. The points of reflection enabled a cyclical approach to be developed and further data gathered where appropriate. The following sections of this paper explain this approach in detail.

Insert figure 1 here

Collis and Hussey (2003) approach has previously been employed within case study research (Yin, 1994; Eisenhardt, 1989). The limitation of using a single case organisation to develop and test the 6S method can reduce the generalisation and external validity of theory generation. However, Braa and Vidgen (1999) argue the hybrid action research case study can facilitate the development of theory. In order to overcome the limitations of a single case further research is recommended to provide multiple case studies of action research interventions to enable defensible generalisations (Checkland and Holwell, 1998).

Through action research opportunities exist for cyclical data collection (Eden and Huxham, 2002). Multiple data sources were used in the action research which included questionnaires and quantitative performance data. Furthermore, being onsite enabled the researchers to exploit various observational opportunities that might not have existed in more controlled research environments (Eden and Huxham, (2002).

The case organisation in which this research was undertaken is a global manufacturer of semiconductor devices for various industries including aerospace, automotive, healthcare and domestic appliances. It has around 4,000 employees and it has a number of ISO-9001 certified wafer fabrication and assembly facilities. To protect the anonymity of the organisation a pseudonym of RELCO has been used.

At the time when this research was conducted one of the authors was the 6S programme manager who initiated and managed the implementation of the 6S method and was central to the data collection at all stages. This links to one of the fundamental AR characteristics proposed by Eden and Huxham (2002: 255) which proposes AR research requires "an integral involvement of the researcher in an intent to change the organisation".

The actual 6S method deployed is as shown in Figure 2.

Insert figure 2 here

i. Research on 5S Literature

A comprehensive review of the literature on 5S was completed, a summary of which appears in this paper. This review focused on critically analysing the advantages and limitations of 5S, and then extended to include the role of safety. This review was pertinent to incorporate suitable measures in 6S to resolve various shortcomings in RELCO's existing 5S method. The literature review also informed the method deployed as depicted in Figure 2.

ii. Performance management & staff survey

It was noted from the 5S literature that one of the success factors of 5S is active participation of employees. As part of the development of the 6S concept, a survey was conducted with management and staff to identify training needs and understand the importance of workplace organisation. Consideration was also given to ways in which to record and feedback progress of 6S activities.

The description and development of Stages 2 – 5 are given in Section 5 following a description of the 5S experiments in Section 4. While the 6S development as shown in Figure 0 is an iterative process in this paper we show in Section 6 an example deployment of the method in RELCO.

4. Experimenting with 5S at RELCO

In order for RELCO to first test the applicability of 5S an experiment was conducted. This consisted of calculating total hours taken by a repair and maintenance (R&M) technician to carry out typical maintenance work on equipment in three different scenarios as listed below and shown in Figure 3.

- **Scenario 1:** Work area where no 5S work was done.
- **Scenario 2:** Work area after carrying out three stages of 5S: sorting, straightening and sweeping.
- **Scenario 3:** Work area after carrying all five stages of 5S.

Insert figure 3 here

It is evident from Figure 3 that implementing the first three stages of 5S the total time taken for the maintenance work was reduced from 6.7 hours to 6.2 hours. Time was saved on searching for documentation and preventative maintenance parts and tools. However, when all stages of 5S were implemented the total time taken was reduced further to 3.6 hours. Time was saved mainly in communication, cleaning equipment parts and searching for tools, parts and documentation.

Although this experiment showed significant results in relation to the total time saved there was evidence that safety remained an issue for the organization. Prior to undertaking this research safety incidents were running at approximately 15 per month, scrap rates were at about 5%, with tool downtimes at typically 10%. Despite the discipline of the traditional 5S and workplace organization safety was still a concern. One example was a water leak on an open electrical cabinet which resulted in fire sparks and electrical short circuit that caused burn marks and bruises to a maintenance technician. This example demonstrates that safety related incidents can still occur despite implementing the 5S method. Following an investigation the following observations were made:

- Signs, labels and other 5S methods improved efficiency of maintenance jobs but gave low priority to issues related to safety, due to absence of any specific safety questions in the 5S audit sheets.

- More emphasis on workplace organization but low awareness of safety was observed among the operators and technicians.

According to the technician involved in the incident, while doing the maintenance work, he assumed that the open door of an electrical cabinet did not affect production processes or operation of the equipment and therefore non-significant. His perception changed completely after the incident. Neglecting safety hazards could have serious implications as experienced in this incident. Neglecting the safety profile of the surroundings was one of the prime reasons for the incident to occur and prompted the traditional 5S approach to be reviewed by RELCO and new measures developed to prevent reoccurrence of similar incidents.

A review of the typical 5S audit sheets (e.g. those proposed by Ho, 1997) identified that these reflect and reaffirm that there is little or almost no emphasis on issues related to safety, which for RELCO and its manufacturing environment was a major shortcoming in 5S.

Photographs were taken of the areas where 5S had been piloted which evidenced actual chemical related safety hazards still existed. It was agreed by the 6S team at RELCO that these were issues that could be commonly spotted in manufacturing plants and should be addressed by an agreed method that could identify safety issues and assist in finding timely fixes. Therefore, the team concluded in order to reduce the risk profile of the work area, it was important to include an additional section in the 5S audit sheet that focused on safety.

5. Development and testing of the 6S method

5.1 Stage 1

The primary outcome of Stage 1 was rearticulating the 5S approach into a 6S method with 6S now standing for Sort, Set, Shine, Safety, Standardise and Sustain. It should be noted that Safety in RELCO, unlike in the Bolton General Hospital case (Fillingham, 2007), is the fourth S and proceeds Standardise and Sustain. RELCO saw it as critical that Safety is explicitly dealt with early on in a 6S application with appropriate measure taken to ensure that it is addressed, rolled out throughout the work environment and continually addressed.

A further outcome of the first stage of development was the provision of a strategic context to the 6S programme. This was achieved by creating a 6S vision statement which provided strategic direction and located the 6S programme within the context of RELCO. The vision statement is:

"6S will be a cornerstone of the RELCO culture, practical and sustainable, empowering staff to control, improve and protect their physical workplace."

This statement provides a framework to the whole programme in which to develop the right attitude, skills and knowledge to support 6S becoming a cornerstone for continuous improvement thereby preventing accidents, scrap and improving productivity. The dissemination of the 6S vision was to set up systems that enable anyone to distinguish between normal and abnormal physical conditions at a glance and involve all staff in a systematic process to improve the physical workplace.

5.2 Process development

In order to clearly understand and tackle the issues related to safety, productivity and housekeeping, it was decided to divide RELCO's production facility into different 6S work zones. The subdivision was carried out based on the type of operations performed in a specific work zone during the process of fabrication of a product up to completion. For example, a product "P1" requires five steps A, B, C, D and E. A particular work zone consisted of all the tools and equipments required to perform a particular manufacturing function like step A. These were collated into one particular zone.

5.2.1 6S Selection Matrix

The cost of carrying out 6S activities can be high during the initial stages of the programme. The earlier reviews of 5S noted that one of the limiting factors in implementing 5S was the cost associated with its activities (Webber and Wallace, 2007). The financial commitment required to carry out 6S related work could also make management reluctant to provide sufficient funds to roll out activities on a wider scale, unless some 'pilot to prove' activities can demonstrate that 6S can add value to the organisation. For RELCO the preferred option to implement 6S was to introduce it in phases. This helped to keep the initial costs low whilst demonstrating the benefits of 6S. This phased introduction helped to secure long term financial commitments from the sponsors of the 6S programme. A matrix was developed to select 6S work zones based on factors like historic and current safety records, scrap rates, production criticality and product yields.

5.2.2 Setup of 6S training bay and information pack

The next step was to setup a training bay to help train managers, manufacturing staff and engineers. This was to demonstrate the tangible benefits of using visual cues and other 6S principles in transforming a work zone. A 6S information pack was developed and used as part of training material. This consisted of the following:

- Training materials and practical examples related to 6S method
- Example of 6S score sheets used to audit work zones
- Picture books that list 6S standards to facilitate the audit of 6S non-compliance
- 6S standards catalogue for ordering parts related to 6S activities – e.g. labels, shelving.

5.2.3 6S Training and 6S Team Framework

According to Huczynski and Buchanan (2004), providing autonomy and feedback are important factors towards motivating employees. Therefore, intensive 6S training along with a suitable 6S team framework was an essential part of the development.

An inverted triangle 6S team structure was designed as shown in Figure 4. This structure was employed to provide more autonomy and empowerment to employees in shaping their work space in accordance with the 6S method. In this structure, 6S champions together with module based work groups would independently execute 6S in their respective zones. A small 6S core team which included representatives from logistics and finance was formed to support the champions and their teams but also to reinforce the communication channel between the champions, sponsors of the 6S method (comprising of selected members from senior management team (SMT)), and the entire SMT.

Insert figure 4 here

The main control to carry out 6S activities was given to module functional groups in the manufacturing product based work groups, who were in turn supported by 6S champions who acted as change agents under guidance of the core team. The main role of the sponsors was to define the overall strategy of the 6S programme, observe progress and elicit financial support for various 6S projects.

5.3 Recording 6S data

The approach was to design a balanced score sheet (to record 6S non-compliance and improvement activities. A blank sheet is provided in Appendix A and an example of a part of a completed sheet is given in Figure 5. The 6S audit sheet provided a holistic picture of 6S status in a particular work zone. The sheet measures all six "Ss" between a score of 0 points (non compliance) and 5 points (total compliance). The bar graph at the top left of the score sheet gives an overview of 6S status in a work zone by displaying each of the 6Ss in the scale of 0.0 to 5.0. Top right of the 6S score sheet gives more information about the audit, i.e., date of audit, name of the 6S champion, total number of 6S non-compliances observed, number of 6S non-compliances closed and the average 6S score for that particular zone.

Insert figure 5 here

5.4 Improvement activities & recognitions

The development of the 6S method included establishing activities to remove 6S non-compliance observations captured in the 6S audits in the various 6S work zones. Activities to improvise the workplace, as per 6S standards, were designed to be carried out by small teams comprising of manufacturing operators and maintenance technicians. Each team was led by a 6S champion and supported by the core team. Workshops were designed for teams to acquire visual management skills to enable them to carry out 6S activities such as labelling of gauges/instruments, creating of shadow tool boxes, and preparing visual work procedures.

To recognize employees' achievements management and operator training was required. An employee motivation survey by Goal Manager (2000) cited in Podmoroff (2005) shows that a caring attitude by management towards employees is a key motivator. A way for management to show their appreciation to operators is to reward them when they have achieved set objectives hence a recognition and reward system was established for the 6S method.

5.5 Success measurement

The focus here was to determine the parameters by which the impact of 6S implementation could be measured. One of the reasons for poor uptake of 5S is the absence of a performance matrix (Kumar, 2007). Such data were deemed important, as the RELCO senior management team were interested in quantifying the benefits and justifying the expenditure. Key measures are number of incidents, scrap and productivity as given by downtime and number of wafers missed.

6. Implementation

Improvement projects were selected as a result of low scores during 6S audits and negative impact of observed 6S non-compliance, on either safety or operations. Several pilot projects were undertaken as part of the testing stage which enabled the development of the 6S concept to be reviewed through approximately four iterations.

An example of a 6S pilot project was transforming the parts clean room. This project was executed during the first phase of 6S improvement activities. The improvement activity was designed to improve safety as well as work efficiency in the parts clean room.

The parts clean room is a work area where dirty or contaminated equipment parts are disassembled, cleaned and reassembled. The majority of the parts cleaned are from "Implanters". The purpose of Implanters is to dose semiconductor wafers with chemical elements like Boron, Phosphine and Arsenic, which contaminate the parts.

Among these three chemical elements, Arsenic and Phosphine are the most toxic chemicals and are regularly used as a dopant in the semiconductor industry. These Implanter parts could themselves contaminate anything they came in contact with and so posed a great health risk to staff that either handled these parts or visited the parts clean room to deliver or collect parts for other equipment.

A 6S audit was performed in the parts clean room and 6S score sheet completed. It showed that the parts clean room had a very low average 6S score of around 2.4 points out of total 5.0 points, mainly due to poor scores in 6S audit items 17 & 18 related to safety as shown in Figure 6.

Insert figure 6 here

Further investigation of the parts clean room identified the following main causes of 6S non-compliance;

- Storage cabinets stocked with redundant equipment parts.
- No visual system to identify equipments and process for cleaning parts.
- Single work bench used to disassemble contaminated parts and assemble contaminated parts.
- No proper cabinets in the room to store personal safety equipment and gears.
- Sink used to clean contaminated parts was found to be contaminated by arsenic.
- The floor of parts clean room was extremely dirty and contaminated
- Inadequate toxic extract air flow observed in the sink used to clean contaminated parts. The gauge used to measure toxic extract flow did not have any specifications marked on it.
- No control over the staff who were accessing the parts clean room.

All of the above posed serious issues for staff working in that area due to the high amount of arsenic contamination in the environment. 6S non-compliance related to safety due to improper handling of equipment parts contaminated by toxic chemical could put ISO certification for RELCO at risk.

Also, it was observed that on a number of occasions, "Implanters" failed to meet particle specifications after the scheduled preventive maintenance (PM). During a typical PM, dirty equipment parts were replaced by refurbished parts from the parts clean room. Failure of equipment to meet particle specifications caused increased downtime and also caused yield loss in product wafers. During investigation of this issue, one of the reasons identified was contamination of refurbished parts by dirty parts as both parts shared the same working bench. Finally, cluttered work environment and absence of proper 6S methods in the parts clean room reduced work efficiency when refurbishing the dirty parts.

Once the problems were identified then the 6S principles were applied to the parts clean room. To begin with, the parts clean room was sorted and all redundant equipment were "red-tagged". This increased available working space in the parts clean and reduced obstructions to the movement. Straightening of the parts clean room was carried out by changing the layout of the equipments so that the process of cleaning parts could be made more efficient, productive and cost effective.

After sorting and straightening, the floor and other surfaces were chemically cleaned to remove toxic contamination. The floor was then re-painted to give the room a tidy and fresh look.

Further actions were taken as part of 6S activities to ensure parts clean room is completely safe for working. These are listed below:

- Replaced work-bench, sink for cleaning parts and storage cabinets with new cleaner ones
- Installed new and better designed pipe work for extracting toxic substances from the parts clean room.
- Installed correct storage cabinets to store personal protective equipment.
- Separated work areas used for disassembling contaminated parts from the work area for assembling the cleaned parts.
- Installed electronically locked doors that gave access to only certified persons to parts clean room.

Finally, after decontaminating and addressing safety issues, a new process flow sequence was established for cleaning the parts. The procedure to assemble parts was documented and made visually accessible next to the working bench. A system was put in place to regularly measure the performance of ducts extracting toxic materials and take dust samples from the parts clean room to check the levels of arsenic. In the newly established system, all the tools, parts and cleaning materials were kept in the parts clean room itself for quick accessibility as compared to going to the company stores as in previous system.

Also, all the transportation of dirty or cleaned parts to and from the equipments was done in secured enclosed trolleys instead of open types. The comparison between new and old process flow for parts clean room is shown in Figure 7. A number of visual cues were also put in the parts clean room to make technicians aware of this new process flow.

Insert figure 7 here

The above 6S implementation improved the health and safety standards in the parts clean room and the surrounding environment. It also improved the efficiency of performing daily work in the parts clean room. As a result of this improvement project, 6S scores in the parts clean room improved to 4.0. The resulting 6S audit showed complete safety compliance as shown in Figure 8.

Insert figure 8 here

It was also noted that the transformation of the parts clean room, based on 6S principles, improved the quality of work life of the technicians and other staff accessing the room. It also set an example of a good work practice for other 6S champions to learn the benefits of 6S and incorporate the method in their respective work zone. Also, a Health and Safety Executive audit soon after the implementation especially lauded the parts clean room improvements in making the facility safer and more environmental friendly.

7. Evaluation of 6S

Figure 9 shows the time series of average scores for a number of sample work zones in RELCO over a five-quarter period. The first phase of 6S execution showed a sharp increase in scores as both the 6S team and the SMT showed high levels of interest in this new method. Also, at the start of the 6S program the levels of 6S tasks were simple, relating mainly to sorting, straightening and sweeping.

During the second phase of 6S execution, the tasks became more demanding as efforts were focused on addressing issues related to safety, on setting up systems to sustain improvements in the work zones, and changing layouts of the work flows that needed long periods of time for completion.

In the third phase of 6S execution, the main challenge was to sustain 6S gains made in earlier phases and make further improvements. 6S activities also became more complex in phase three. As business dampened due to the economic slowdown, financial investments into the programme were affected. Dips in 6S scores were due to lower worker motivation leading to lower 6S compliance and failure to replace worn out visual symbols in an attempt to reduce costs. Also a reduction in human resources caused neglect in carrying out simple tasks such as sorting and sweeping. Pro-active steps like giving recognition to 6S teams by generous distribution of rewards, more frequent verbal communication with 6S champions and posting informative articles on 6S on to the company's newsletter, on the main notice boards and intranet in phase three of 6S execution brought back the focus on the 6S method. As a result of renewed focus on 6S, improvement activities in work zones gained back momentum and that led to an increase in 6S scores.

Insert figure 9 here

In phase four of 6S execution, the work zones showed significant improvements in terms of 6S compliance. Average 6S scores exceeded 4.00. As per the Pareto curve, any further improvement in scores required more financial and human resources with very limited benefits. The main efforts in phase four was to test if the work zones could sustain the improvement made in the past. During phase four it was observed that work zones were successful in maintaining their scores over several weeks. Given the notion of previous peak performance the 6S teams decided that a score of 4.05 was a realistic target to attempt to maintain.

Further evaluation of the 6S method was conducted by comparing 6S scores against key performance metrics such as safety incidents, scrap rates and tool downtime as shown in Table 2.

Parmeters to measure 6S performance	Fab Performance- 2009						
	Number of product wafer processed/ww	5000					
	Work Week	ww01	ww12	ww24	ww36	ww48	ww52
	6S Score	2.63	3.17	3.29	3.46	3.64	4.05
Safety	Safety Incidents	15	11	7	5	4	3
Product Yield	Product wafer scrapped (%)	4.0%	3.5%	2.0%	1.2%	1.0%	0.9%
Productivity	Tool Downtime (%)	10%	9%	7%	6%	5%	3%
	Product wafer missed (%)	7.0%	5.0%	2.0%	1.8%	1.5%	1.2%

Table 2. Safety Performance at RELCO after implementation of 6S (ww = working week)

It can be seen that safety incidents have been reduced from 15 in week 1 to 3 in week 52. For the same time period scrap rates were cut from 4% to 0.9%, equipment downtime reduced from 10% to 3% and the number of missed wafer production deadlines reduced from 7% to 1,2%.

8. Conclusion

Since the introduction of 5S in the early 1990s, workplace organization has been growing in popularity for both manufacturing and service sectors. This paper builds on previous research (e.g. Bayo-Maris et al., 2010; Gapp et al., 2008; Ho, 2010) by evaluating and evolving 5S to explicitly incorporate an additional 'safety' step. This step has been integrated within the existing five stage approach and not simply added to the end of the sequence as often reported by other authors (Fillingham, 2007). The results demonstrate the benefits of establishing this extra step and indicate that safety is not inherent within the traditional 5S approach as previously advocated by Bicheno and Holweg (2009). Maintaining the analogy between English and Japanese the 6S may be defined as;

- Sort or Seiri
- Straighten or Seiton
- Shine / Sweep or Seiso
- Safety / Reliability or Shinrai sei
- Standardise / System or Seiketsu
- Sustain or Shitsuke

Bayo-Moriones et al., (2010) highlighted the lack of empirical evidence regarding the adoption of 5S. Through action research we have empirically assessed the impact of adopting 5S which highlighted, for the specific operation application investigated, the lack of consideration for safety. This paper for the first time proposes a 6S framework and an improvement project has been used to illustrate its implementation. Some of the key elements of the implementation were: the "Inverted triangle" 6S team structure which provided greater opportunity for autonomy and empowerment of staff involved in 6S activities; the division of manufacturing plant into 6S work zones helped to phase the implementation and prioritise areas; the integrated 6S score sheets to monitor progress of 6S activities and the overall five-stage 6S method.

Previously Kumar et al. (2007) suggested the inability to measure the performance of 5S inhibited implementation. In addition, they highlighted the need to identify where 5S adds value. Ho (2010) provided a series of measures by which to test 5S. This paper employed Ho's measures as a foundation for understanding the improvements made by 6S and more importantly establishing a mechanism to frequently audit, record results and take actions. The action research shows the advantages of such an approach in ensuring the sustainability of improvements.

One of the key components of action research is the ability to extrapolate the learning to a broader context and articulate broader knowledge. This manufacturing case provides learning for those organisations in similar industries. The learning needs to be tested further by employing the 6S framework within other sectors, especially those where safety is critical. The 6S methodology illustrates that creating a safe work environment is equally important as other benchmarks such as improved worker productivity, improved equipment performance, higher work efficiencies, higher yields and reduced product scrap. The action research approach has enabled the observation of developing and implementing the 6S method.

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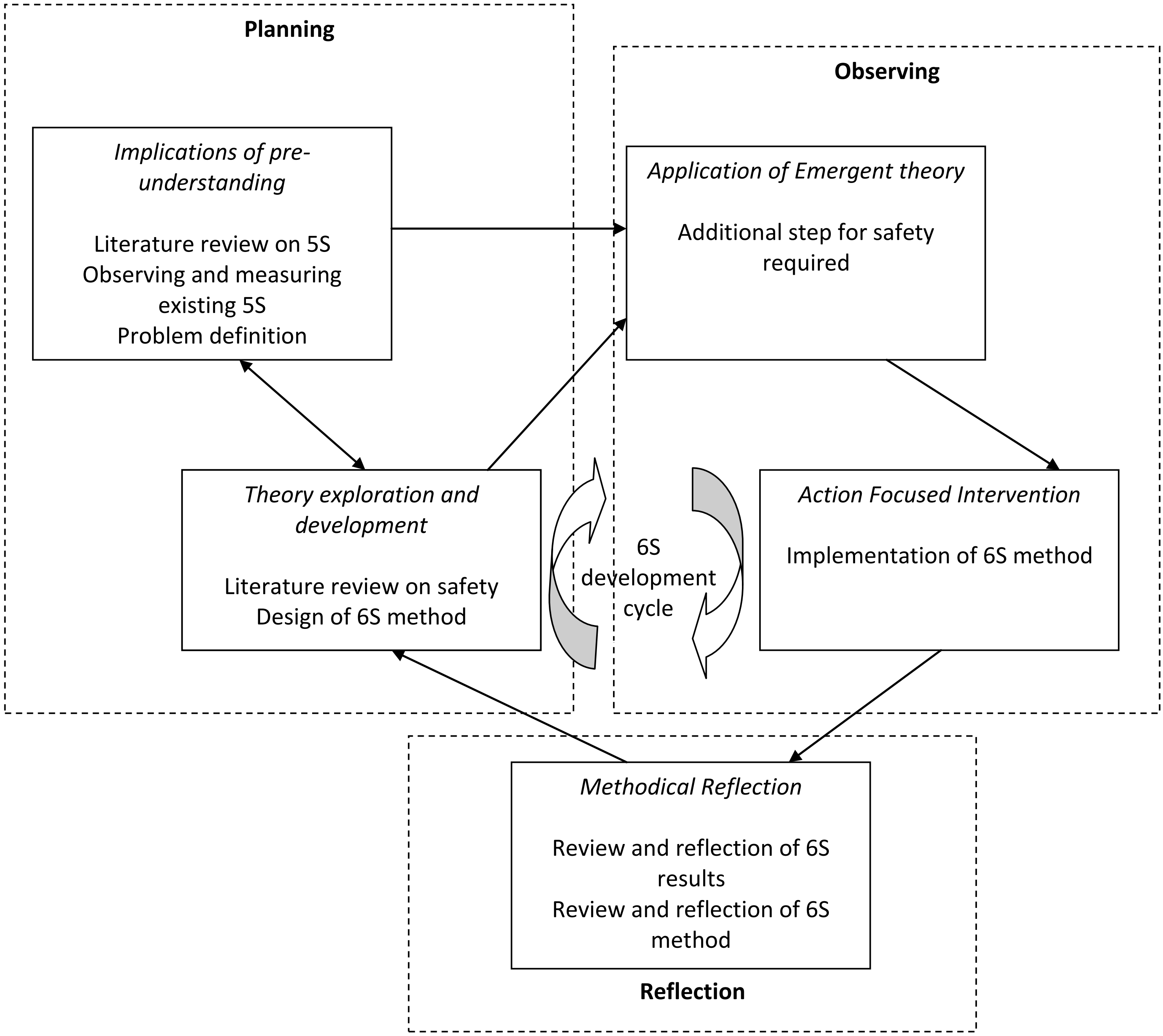


Figure 1: The cyclical process of action research (adapted from Eden and Huxham, 2002:260 and Collis and Hussey, 2003)

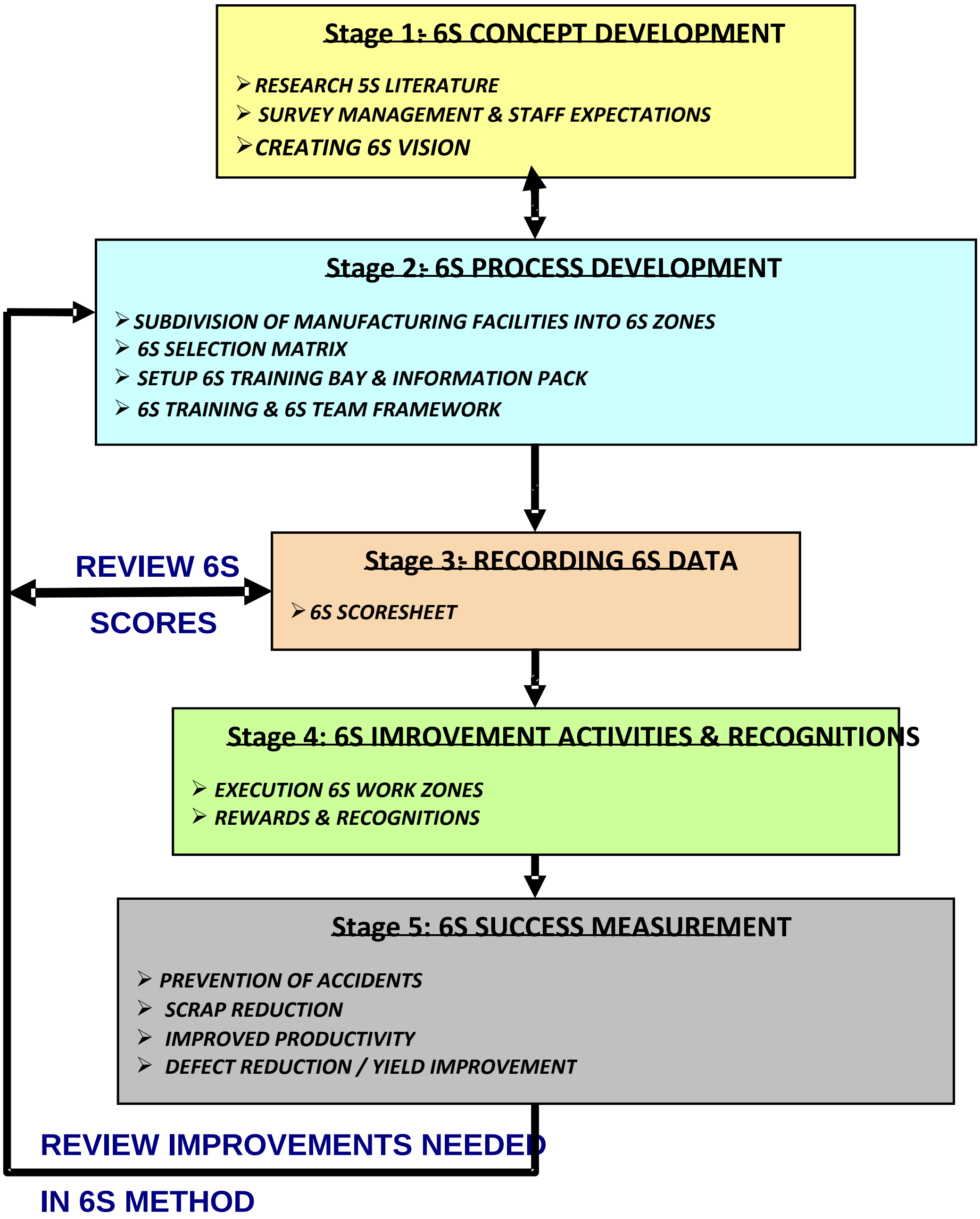


Figure 2: The 6S development method

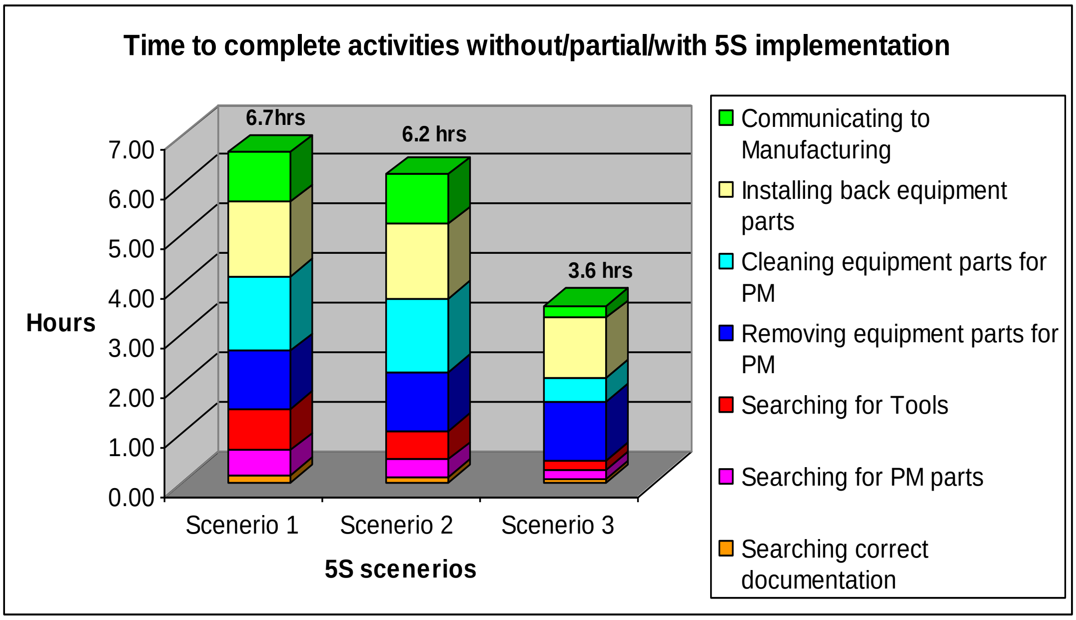


Figure 3: Measuring the impact of 5S implementation

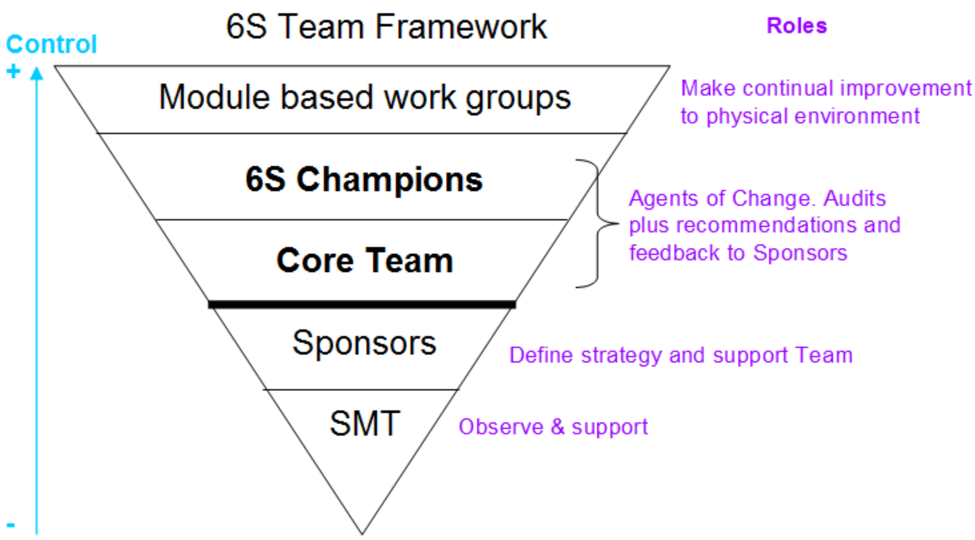
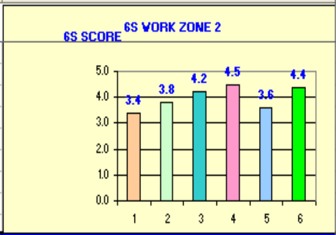


Figure 4: Inverted triangle 6S Team Framework



6S WORK_ZONE 2

AREA	6S WORK ZONE 2	
DATE OF AUDIT :	FY10Q1	
AUDIT TEAM :	OWEN	
CORRECTIVE ACTIONS IDIENTIFIED	15	3.98
CORRECTIVE ACTIONS CLOSED	2	
OPEN CORRECTIVE ACTIONS	13	
REPEAT OFFENCES		
FWR PlannedRaised/Closed	6/4/2	

SCORE

Q	6S stage	6S category	AUDIT ITEM	5	4	3	2	1	0	AREA 6S SCORE	What's Wrong?
1	S1	SORT	Area housekeeping - All materials, equipment and tools sorted and kept in their correct location?	All items stored correctly		1 item not stored correctly		2 items not stored correctly	>2 items not stored correctly	3	Area not Sorted
2	S1	SORT	Red Tag items - Equipment and materials no longer utilised are removed. Area clearly defined, all items must have a red tag and also compliant with red tag process.	100% compliance	Red Tag process in place items Red Tagged	1 item (not part of process)	2 items (not part of Process)		>2 items	3	Obsolete items
3	S1	SORT	Cable Tidy - Wires and cables from phones, pc's and equipment, pneumatic lines are tidy & correctly routed.	100% compliance		1 item not bundled and routed correctly		2 items not bundled and routed correctly	>2 items not bundled and routed correctly	5	Cables not routed near tool
4	S2	STRAIGHTEN	Walkways - All walkways clear of obstructions	100% compliance			1 obstruction blocking walkways		>1 obstruction blocking walkways	5	
5	S2	STRAIGHTEN	Signs and Labels No hand written signs/labels allowed, good condition of all signs and labels, No missing signs or labels when required. Standardization of Labels	100% compliance		1 Sign or label missing		< 3 signs or labels missing	Any handwritten signs or labels,	3	

Figure 5: Snapshot of a typical 6S score sheet

Item	6S stage	6S category	AUDIT ITEM	5	4	3	2	1	0	6S Score	What's Wrong?
17	S4	SAFETY	Chemical hazards: No Unlabelled liquid containers, spills, leaks, mixed storage of chemicals, toxic parts, chemicals in undesignated area. Chemical cabinet itemised. (Safety reminder: assume all liquids as toxic.). Proper chemical handling.	100% compliance	Same as score 5 but chem cabinet not itemized				1 or more instance reflecting poor condition	0	Multiple instance of improper to handle and storage of toxic parts and chemicals
18	S4	SAFETY	Mechanical hazards (equipment): Equipment with moving parts inside should always be secured and enclosed (guards in place). Pinch points should be clearly labelled.	100% compliance				Panels closed but not secured/ locked	1 or more instance	1	Heavy equipment parts stored in unsecured way on racks
19	S5	SYSTEM	Gauges & Flow meters : All gauges & flow meters must be clearly readable with tolerances identified & Within Correct Operating Specs	100% compliance		<25% do not conform			> 25% do not conform	3	25 % gauges not marked.

Figure 6: Section of 6S score sheet highlighting safety related 6S non-compliance.

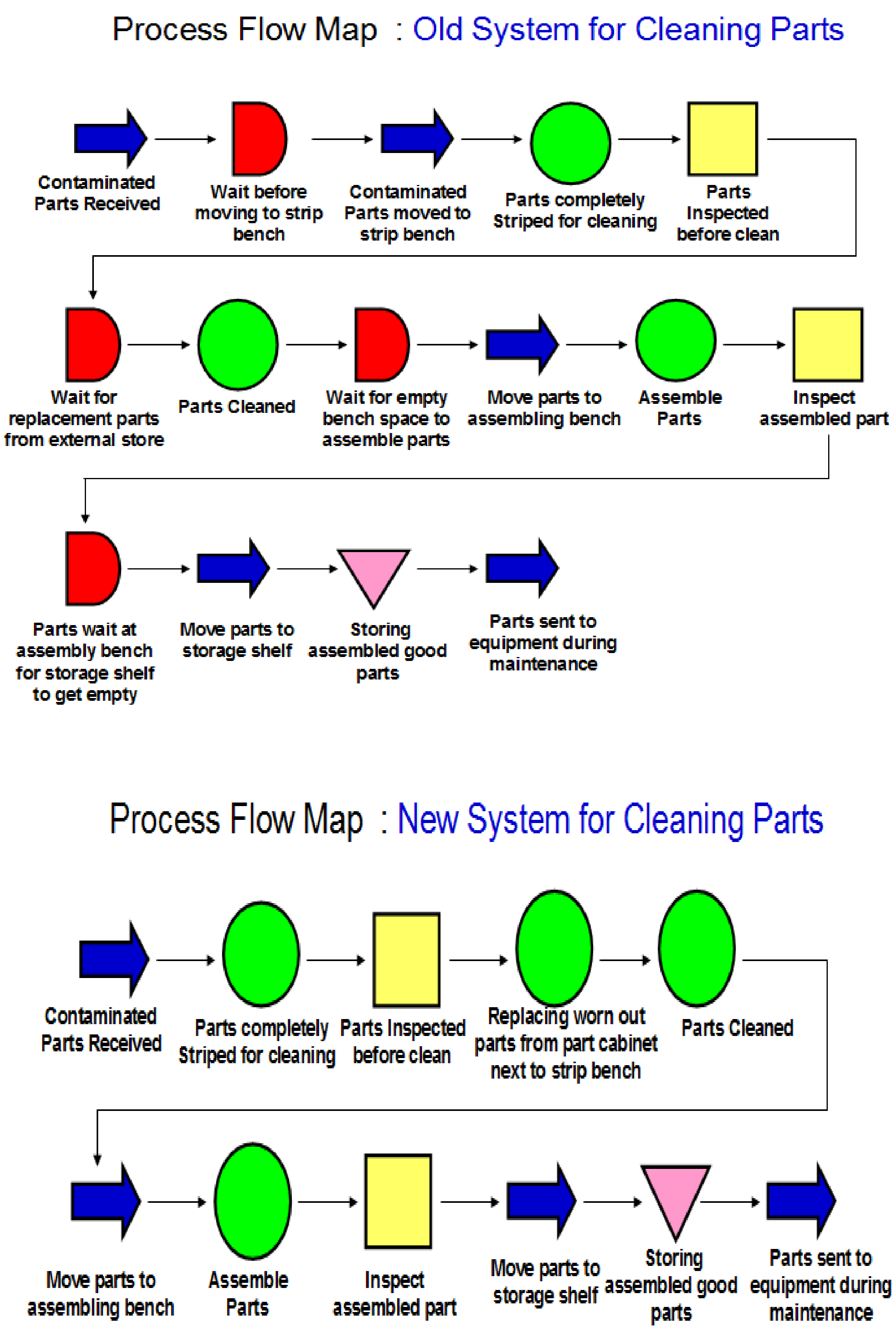


Figure 7: Process flow map comparing old and new parts clean methods.

Item	6S stage	6S category	AUDIT ITEM	5	4	3	2	1	0	6S Score	What's Wrong?
17	S4	SAFETY	Chemical hazards: No Unlabelled liquid containers, spills, leaks, mixed storage of chemicals, toxic parts, chemicals in undesignated area. Chemical cabinet itemised. (Safety reminder: assume all liquids as toxic.). Proper chemical handling.	100% compliance	Same as score 5 but chem cabinet not itemized				1 or more instance reflecting poor condition	5	100% Compliance
18	S4	SAFETY	Mechanical hazards (equipment): Equipment with moving parts inside should always be secured and enclosed (guards in place). Pinch points should be clearly labelled.	100% compliance				Panels closed but not secured/ locked	1 or more instance	5	100% Complance
19	S5	SYSTEM	Gauges & Flow meters : All gauges & flow meters must be clearly readable with tolerances identified & Within Correct Operating Specs	100% compliance		<25% do not conform			> 25% do not conform	5	100% Complance

Figure 8: Section showing resulting audit sheet after completion of part clean room 6S improvements

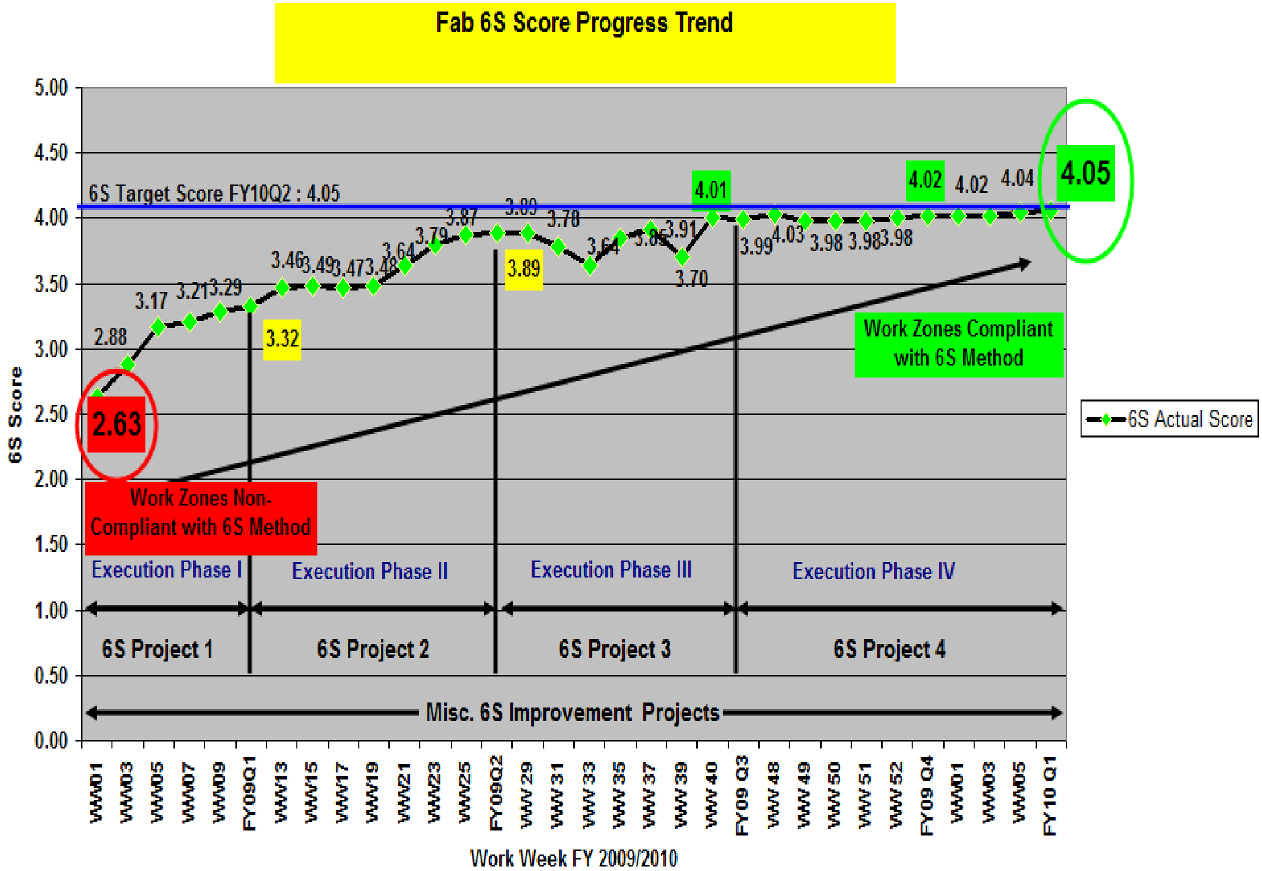
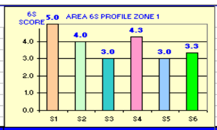


Figure 9. 6S scores for a number of sample work zones

Appendix I: 6S Audit Score Sheet



FAB11 Zone 1

AREA	FAB 11 Zone 1 OVERALL
DATE OF AUDIT :	FY10Q1
AUDIT TEAM :	Simon/Mathey
CORRECTIVE ACTIONS	40
PREVIOUS ACTIONS CLOSED	20
OPEN CORRECTIVE ACTIONS	20
REPEAT OFFENCES	
IMPROVEMENT AREAS	

3.67

				SCORE								
Q	6S stage	6S category	AUDIT ITEM	5	4	3	2	1	0	WHITE AREA SCORE	CHASE SCORE	LOWEST SCOR
1	S1	SORT	Area housekeeping - All materials, equipment and tools sorted and kept in their correct location?	All items stored correctly		1 item not stored correctly		2 items not stored correctly	>2 items not stored correctly	5.00	5.00	5.00
2	S1	SORT	Red Tag items - Equipment and materials no longer utilised are removed. Area clearly defined, all items must have a red tag and also compliant with red tag process	100% compliance	Red Tag process in place items Red Tagged	1 item (not part of process)	2 items (not part of Process)		>2 items	5.00	5.00	5.00
3	S1	SORT	Cable Tidy - Wires and cables from phones, pc's and equipment, pneumatic lines are tidy & correctly routed.	100% compliance		1 item not bundled and routed correctly		2 items not bundled and routed correctly	>2 items not bundled and routed correctly	5.00	5.00	5
4	S2	STRAIGHTEN	Walkways - All walkways clear of obstructions	100% compliance			1 obstruction blocking walkways		>1 obstruction blocking walkways	5.00	5.00	5.00
5	S2	STRAIGHTEN	Signs and Labels No hand written signs/labels allowed, good condition of all signs and labels, No missing signs or labels when required. Standardization of Labels	100% compliance		1 Sign or label missing		< 3 signs or labels missing	Any handwritten signs or labels,	4.00	4.00	4.00
6	S2	STRAIGHTEN	Process Flow - Evidence of Process Mapping - Good Visual management. Is the work flow easy to identify based on the lay out of the area?	Clear Evidence of Process Flow & Visual Management			Some Evidence of Process Flow & Visual Management . >		No Evidence of Process Flow & Visual Management	3.00	3.00	3.00
7	S3	SWEEP	General cleanliness (Floors and walls) : Floors should be dust, stain and spill free. No items left on unmarked floors. Walls are dust free, have no stain, have no marks and is free of graffiti	All areas clean & free from dust			Clean but has permanent stains	Evidence of cleaning but dirty only due to daily activities	No evidence of regular cleaning, any spill	3.00	3.00	3.00
8	S3	SWEEP	General cleanliness (Surfaces) : Equipment tops, work tables, facilities panels, storage cabinets should be dust and stain free. Evidence of cleaning process in place	All areas clean & free from dust and evidence of	All areas clean & free from dust		Clean but has permanent stains, sticker marks	Evidence of cleaning effort but dirty due to daily activities	No evidence of regular cleaning	3.00	3.00	3.00
9	S3	SWEEP	Non-cleanroom materials - No non-cleanroom materials present (e.g. pencils, non-cleanroom paper, torn/shredded cleanroom paper, any wooden furniture).	100% compliance			One instance of non-compliance		>1 instances of non-compliance	3.00	3.00	3
10	S3	SWEEP	Contract Cleaning-Regime in place and recorded, only approved material used.	cleaning schedule completed correctly				Cleaning regime not followed	1 instance of unapproved materials. 1 instance of sub-standard cleaning	3.00	3.00	3.00
11	S4	SAFETY	General Hazards :No Trips, Slips, Falling , Punctures, Entrapment,	100% compliance					1 instance of hazard	5.00	5.00	5
12	S4	SAFETY	PPE : Is there immediate access to safety equipment/materials specifically required in the area? (i.e., Aprons, Gauntlets, Armlets, visors, SCBA, ear plugs.)	Yes				Yes, but needs sorting	No	4.00	4.00	4.00
13	S4	SAFETY	Fire extinguishers : Correct location, identified, labelled, test due date not expired (Max Limit 12 Months) mounted correctly	100% fire extinguishers in correct location.				Correct location but blocked or hidden or incorrectly	1 or more missing, incorrect location or expired	4.00	4.00	4.00
14	S4	SAFETY	Fire exits and evacuation awareness : Escape route obvious, visible and clear from obstructions from any point in the area. Fire exits should not be blocked and fully operational condition. Audit a person working in the area (if available) for awareness on the correct procedure for evacuation	100% compliance				Correct location but blocked or hidden	>1 instances of non-compliance	5.00	5.00	5
15	S4	SAFETY	Safety Showers and Eyewash and awareness of use : Fully equipped and accessible functioning safety showers. Does the person working in the area know where the nearest safety showers/eye wash is, and when and how to use them?	Full Equipped Safety Shower available with awareness			Same as Score 5 but person is not aware of its use.	Available but blocked or inaccessible	>1 item missing from Shower or Shower in poor condition	5.00	5.00	5.00
16	S4	SAFETY	Electrical hazards : Any open equipment/electrical panels, any exposed/broken/unterminated wires. Cables dangling or posing as a hazard. (Safety reminder: assume all wires and cables as LIVE)	100% compliance				electrical panels closed but not secured/locked	1 or more instance	4.00	4.00	4
17	S4	SAFETY	Chemical hazards: No unlabelled liquid containers, spills, leaks, mixed storage of chemicals, chemicals in undesignated area. Chemical cabinet itemised. (Safety reminder: assume all liquids as toxic.)	100% compliance	Same as score 5 but chem cabinet not itemized				1 or more instance reflecting poor condition	4.00	4.00	4.00
18	S4	SAFETY	Mechanical hazards (equipment) :Equipment with moving parts inside should always be secured and enclosed (guards in place). Pinch points should be clearly labelled.	100% compliance				Panels closed but not secured/ locked	1 or more instance	3.00	3.00	3.00
19	S5	SYSTEM	Gauges & Flow meters : All gauges & flow meters must be clearly readable with tolerances identified & Within Correct Operating Specs	100% compliance		<25% do not conform			> 25% do not conform	3.00	3.00	3.00
20	S5	SYSTEM	Notes Work Instructions : No hand written notes or work instructions allowed. All boxes correctly identified with either Engineering Run cards or monitor labels. No uncontrolled work instructions.	No instance of hand written notes work instructions found			1 instance found		>1 instance of hand written notes found	3.00	3.00	3.00
21	S5	SYSTEM	Promis Access : Terminal location / access, correct log-in (person) - (Terminal should be available in each work area and distance depending on operator requirements and frequency of use)	100% compliance			Proximity and access to terminals inadequate		any instance of incorrect PROMIS access	3.00	3.00	3.00
22	S5	SYSTEM	Documentation (Specs, TCNs, CNs) : In designated location or on Intranet.Ops can easily access them	100% of specs in correct location with correct revision		1 folder or document in incorrect location. 100% spec revisions ok			1 incorrect document rev or >1 documents/folders wrong location	3.00	3.00	3.00
23	S5	SYSTEM	Procedural Non-Compliance :Work undertaken does not comply with approved/designated procedure.	100% compliance					Any non-compliance	3.00	3.00	3.00
24	S5	SYSTEM	Product handling transport and storage : Wafer boxes are handled properly, stored and/or transported safely and securely on correct trolleys	100% compliance					> 1 evidence of improper handling/ storing and	3.00	3.00	3.00
25	S6	SUSTAIN	Telephone and Emergency numbers : Emergency numbers on telephones.Telephone in correct location,graffitti free and in working order	Number present and in good condition		Incorrect Location	Phone working but emergency number not legible		Phone dead, no emergency number, graffiti on phone	3.00	3.00	3
26	S6	SUSTAIN	Actions : Completion of actions from the last audit. Are self audits regularly being done by area owners (monthly)?	100% actions completed on time	>75% completed	>50% actions completed	>25% completed	Plan in place but no actions commenced	No Plan or No self-audits done	3.00	3.00	3.00
27	S6	SUSTAIN	Cleanroom Apparel :Dress Code, Safety glasses, yashmak correctly worn, correct shoes, cuffs, no head/facial hairs exposed. General appearance should be clean.	100% compliance					Any non-compliance	4.00	4.00	4.00
28	S6	SUSTAIN	Roof/Ceiling/Walls Fabric Integrity : Fab building fabric of high standard. No roof leaks or holes in flooring, floor tiles fitted	100% compliance		One instance of non-compliance		2 instances of non-compliance	> 2 instances of non-compliance	3.00	3.00	3
28	S6	SUSTAIN	Roof/Ceiling/Walls Fabric Integrity : Fab building fabric of high standard. No roof leaks or holes in flooring, floor tiles fitted correctly	100% compliance		One instance of non-compliance		2 instances of non-compliance	> 2 instances of non-compliance	3.00	3.00	3
29	S6	SUSTAIN	Lighting Condition : 100% lighting in place to high standard. Quality of lighting should be sufficient to carry out work in the area. No dark areas	100% compliance	1 light bulb not working but sufficiently lighted	>1 light bulb not working	Lighting >80% functioning or adequate	Lighting needs improvement	Area too dark for work	3.00	3.00	3.00
30	S6	SUSTAIN	Signs and Labels : No hand written signs/labels allowed, All Existing signs and labels in the area are in good condition.	100% compliance		Signs or labels peeling, marginally good		< 3 signs or labels in poor condition	Any handwritten signs or labels, or > 3 very poor condition, missing, illegible	4.00	4.00	4
31	S6	SUSTAIN	Defective/broken components : Any Faulty , broken or improperly working component that requires repair or replacement.	100% compliance		1 item defective			>1 item defective	3.00	3.00	3.00
32	S6	SUSTAIN	Waste material removal : Waste bin in designated area (floor marked) and not full or over flowing, with colour coded sacks	100% compliance	Bin in poor condition		bins in designated area but full or over flowing	Bin not in designated area or no floor marking	Bin missing, or 1 instance of incorrect sack in use	4.00	4.00	4.00
33	S6	SUSTAIN	Storage Cabinets / Cupboards for items and materials :cabinet in good condition - no paint chipping and dents and sticker marks. All items should be sorted and properly labelled. No chemicals allowed.	100% compliance			Cabinet in good condition but sorting can be improved		poor condition, not labelled, no evidence of sorting, chemicals stored	3.00	3.00	3.00
							Total Score			121.00	121.00	121.00
							Average Score			3.67	3.67	3.67