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CASE REPORT

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# Strategic facility & space planning utilising Design for Lean Six Sigma

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**ABSTRACT**

This study aims to develop and implement a Strategic Facility Planning process at a highly regulated manufacturing site to optimise manufacturing space and capacity in a facility running out of space. The project demonstrates the application of Design for Lean Six Sigma and a structured Define, Measure, Analyse, Design, and Verify methodology in designing and implementing a process that enables the case study manufacturing site to improve its space utilisation and free up space. The project resulted in increased space usage of approx. 38000 sq. ft. equating to a hard cost saving of over $13 million for the organisation and a cost avoidance of $22 million. The study's contribution is that it highlights for the first time that the Design for Lean Six Sigma methodology can be utilised for space and facility utilisation and can be leveraged by other manufacturers. This study has academic and managerial implications for identifying best practices for Design for Lean Six Sigma methodology application in Strategic facility planning. This study contributes to the few academic published works to utilise Design for Lean Six Sigma methodology for space utilisation in a highly regulated environment. This study will contribute to managerial practice in aiding other manufacturing organisations with recommendations on utilising Design for Lean Six Sigma and design for improved space utilisation to reduce costs.

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**KEYWORDS**
Define for Lean Six Sigma (DFLSS); lean six sigma; space management; facility layout planning

## 1. Introduction

Competition in global markets and changing customer demands require manufacturing organisations to strive for cost reductions and efficiency improvements to maintain competitiveness. One critical resource all manufacturing organisations require is space to manufacture (Yang, Su, and Hsu 2000). According to Tompkins *et al.* (2010), efficiently using space in a manufacturing facility can save up to 50% on operating costs. Therefore, decisions in relation to manufacturing layout and space decisions are considered one of the most important strategic decisions in the design of operations strategies due to their consequences on operations systems and costs, efficiencies and productivity (Pérez-Gosende, Mula, and Díaz-Madroñero 2021).

Kovacs (2020) utilised facility line planning (FLP) to achieve many benefits including minimised material workflow, reduced travel distances of materials, reduced material handling costs and space used for manufacturing; improved cycle-time, fewer workstations and operators, less work-in-progress and inventories, improved space utilisation as well as improved product quality, standardisation, and ergonomics.

Lean Six Sigma (LSS) methodologies have been developed successfully to improve manufacturing processes and Quality and reduce waste (Antony et al. 2021). Many studies have demonstrated how LSS can enhance space utilisation, reduce floor space and improve material flow (McDermott and Nelson 2022; McDermott et al. 2022; Trubetskaya, Manto, and McDermott 2022). However, the application of LSS into facility design has not been as widespread, but some studies are available that utilise the LSS DMAIC model to improve existing processes and space utilisation problems. Design for Lean Six Sigma (DFLSS), with its structured methodology of Define, Measure, Analyse, Design, and Verify (DMADV), is a data-driven quality strategy that focuses on the design of new products and services (Burke and Silvestrini, 2017). For example, Trubetskaya *et al.* (2023) applied DFLSS methodology in a Medtech manufacturing facility and resulting in the creation of 15% new space for the pilot manufacturing area and identified opportunities to free up 45% of the total manufacturing floor space and realise over €2.2 million cost savings as well as enabling the manufacture of new products being launched.

The manufacturing site is nearly at full capacity in the manufacturing organisation where this case study research occurs. If the site reaches full capacity, its ability to manufacture new products or be given new products by its parent company to launch on its site will be removed. This will lead to a loss of revenue and competitiveness of the subsidiary site and potential job losses for their location. Thus, the organisation needs to develop a sustainable space or layout planning process to provide a line of sight to free the space required to satisfy its strategic goals for the next two years. Furthermore, the organisation makes products required to meet patient and hospital needs and adheres to strict regulations around production infrastructure (ISO 2016). Thus, the layout planning process must ensure no impact on the continuity of supply, the quality of manufactured products and avoid impacting the

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organisation's regulatory compliance in the event of a notified body or Federal Drug Authority (FDA) audit (Trubetskaya, Manto, and McDermott 2022). Outsourcing elements of health products production is not an easy option to aid space planning in highly regulated industries. The manufacturer's product marketing approval is based on strict compliance with different global regulations and validation of their processes. Outsourcing and revalidation can take months and even up to a year to gain regulatory approvals (McGrane et al. 2022), thus making facility layouts more complex in their organisations.

There is a gap in the literature in relation to defining a process to plan space to meet strategic plans, particularly in complex manufacturing sites with eight different highly regulated product types manufactured, as in this case study.

The research question (R.Q.) for this project are as follows:

**R.Q:** How can a robust Strategic Facility Planning (SFP) process for a manufacturing facility be designed utilising the Define, Measure, Analyse, Design and Verify (DMADV) Lean Six Sigma framework?

Section 2 outlines the literature review, while section 3 elucidates the methodology. Finally, the results, discussion and conclusion are presented in Sections 4, 5 and 6.

## 2. Literature review

Layout and space problems are found in several manufacturing systems and are typically related to the location of facilities (e.g. machines, departments) in a manufacturing plant; they are known to greatly impact the system's performance (Drira, Pierreval, and Hajri-Gabouj 2007). Manufacturing layout planning is a broad field of research. Many different but interrelated terms can be used, for example, layout planning (Hegazy and Elbeltagi 1999), space layout planning (Jagielski and Gero 1997), space layout planning (Dino 2016), strategic space planning (Jugulum and Sefik 1998), facility layout planning (Pérez-Gosende, Mula, and Díaz-Madroñero 2021) and systematic layout planning (Yang 2020) to name but a few.

Domschke and Krispin (1997) categorise layout planning into three subcategories: microeconomic location planning, facility location planning, and layout planning. They define layout planning as the process of locating required facilities within a building. Tools exist within the subcategory of layout planning, with many different routes to follow.

Jo and Gero (1998) borrow a concept from genetics, seeking to utilise an evolutionary approach to the topic, especially for designing large-scale problems. They address the general approaches taken; topological and geometrical, and the issues with both: the lack of ability to deal with layout complexity; the combinatorial nature of potential solutions; and the sophistication of the control required.

Jiang and Nee (2013) have leveraged the capability of virtual reality tools to preview layout plans in augmented reality. The use of augmented reality allows users to experience a layout design, essentially in person, without the cost of the physical construction and thus identify issues with the layout that physical drawings may not highlight. Karlen and Fleming (2016) provide a framework to aid the planning of space, discussing factors which can influence layout designs, such as building regulations, acoustic requirements and service provision which can be overlooked when a design is started. Systematic Layout Planning (SLP) is a similar concept that seeks to provide more structure to designing and changing layouts (Muther and Hales 2015). The process of carrying out SLP is broken into four key stages: Identifying Location; Overall Layout Design; Detail Layout Design; and Installation. These four stages are essential in the efficient design of manufacturing layouts and should form the basis of any process designed. The authors also present key considerations that should be addressed within the design, such as the flow of materials, the process flow, and relationships of elements outside of flow.

Ali Naqvi et al. (2016) present a modified version of the SLP process. The basis behind the modification is its focus on implementing Lean tools within the design of a layout. The authors also seek to address the biggest perceived problem with SLP – it is considered a slow and time-consuming process and utilise a simplified process for selection criteria to reduce the time taken to reach a solution.

King *et al.* (2004) refer to a case study seeking to address an issue in the manufacturing centre of a cigarette manufacturer, whereby the growth of departments and facilities has been addressed in an ad-hoc nature, leading to sub-optimal locations of many departments. As a result, the company introduced a new storage system which freed up 500,000 square feet of space, allowing the re-layout of the facility. The case study documents how the redesign was completed, initially generating eight options before two final designs were presented from which to choose.

Dynamic layout issues have also been reviewed (Arabani and Farahani 2012). In this review, different dynamic layout problems are analysed, and the authors suggest that uncertainty surrounding plans must be factored into models designed to solve the problems. While a facility would ideally be designed with current needs in mind, this cannot always be accommodated. Therefore, design flexibility must be considered when designing layouts to avoid the high cost of converting an area from one use to another (EC and Keraita 2018). The use of partition walls is an example of such. While their use would limit soundproofing, it would allow for easy space conversion for future needs (Hua et al. 2010).

DFSS was introduced in the late 1990s to support the design of new products, processes and services (Huang, Chen, and Chang 2010) and has become more popular for space planning by integrating Lean to be called DFLSS (Thomas and Singh 2006). Design for Lean Six Sigma (DFLSS) has been described as an evolution of the DFSS, and LSS approaches but with the principles of Lean incorporated to aid waste reduction, improve flow, and reduce non-value add (Thomas and Singh 2006). Within the DFLSS or DFSS structured DMADV methodology, it is more suitable for creating new processes, whereas DMAIC is suitable for solving problems within existing processes (O'Shanahan, McDermott, and Noonan 2023). For example, Trubetskaya *et al.* (2023) discussed how repeated changes at the departmental level without a design process for strategic oversight utilised was hugely expensive in a medical device company but that utilising DMADV for the

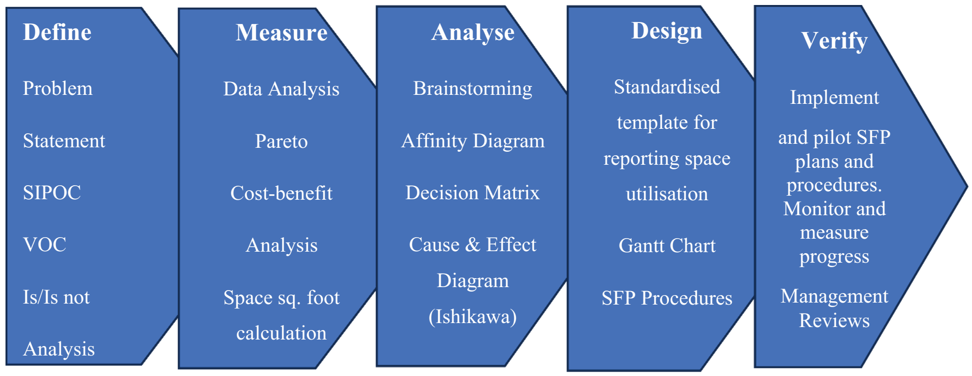


Figure 1. DFLSS – the DMADV methodology.

design of facility layout added more structure and inclusion for the internal V.O.C. in the process and saved unnecessary expenditure via ad hoc layout decisions. However, Trubetskaya et al. (2023) did not implement a long-term framework and continuous evaluation model as it was a single-time design case study. Other studies on Lean deployment in manufacturing have highlighted how Lean tools can improve flow, space utilisation and product visibility and reduce online material storage (Agyeman 2021; Antony 2002). However, when integrated with DFSS, a systematic process for designing improved layouts and achieving enhanced space utilisation can be achieved (Antony 2002; Cronemyr 2007; Huang, Chen, and Chang 2010). While not an enormous body of work is available where DFLSS is utilised for manufacturing space utilisation purposes, some related applications and studies exist. For example, Alvarez (2015) has utilised DFLSS in the new product development (NPD) process to improve quality and product reliability, but this study was specific to product design; Gonzalez-Aleu *et al.* (2018) utilised DMADV to aid strategic planning for repurposing kitchen equipment production operations during the COVID-19 pandemic in a once off design scenario, and Johnson *et al.* (2006) utilised DMADV for designing new dormitory housing at the University of Miami which was also a once off scenario or design.

### 2.1. Conclusion

DFLSS has been applied in space management in previous studies, as mentioned in the literature above; however, many applications are for one-off design changes or a single-time space utilisation enhancement. This study will address a gap in the literature by investigating how DFLSS can be used to design a process or framework for SFP that is robust enough for future needs rather than a single-time application.

## 3. Research methodology

This case study research was undertaken in the Manufacturing support department at a manufacturing site. It had become apparent to management that their campus faced a serious issue. Without urgent attention, the site was on track to go negative on space within two years. In essence, the planned future usage for the manufacturing footprint exceeded the existing manufacturing footprint. As the problem became more evident, it also became clear that there was no existing in-house process to strategically plan and design the use of space within the site, which meant that there was no line of sight to the required free space to satisfy the site's strategic goals. A complicating factor in the manufacturing organisation's case was the manufacturing site's organisational structure. The site operates as a set of Production Rooms (P.R.s), essentially individual mini factories under a single roof. There are currently eight P.R.s in the manufacturing organisation campus, with a ninth P.R. due to be added.

The eight current P.R.s are:

- Sterilisation and Packaging (S&P)
- Assembly Product A
- Assembly Product E
- Assembly Product C
- Assembly Product D
- Assembly Product F
- Assembly Product B
- Assembly Product G

A further P.R. was deemed necessary due to the size and rapid growth of Assembly Product D. Therefore, a Strategic Facility Planning process had to be developed. At the beginning of the work, the manufacturing footprint of the manufacturing organisation was over 200,000 square feet. As the company was well established in its L.S.S. transformation, having had an L.S.S. program for over 20 years, there was a strong application of L.S.S. and DMAIC (Define, Measure, Analyse, Improve, Control). As the organisation did not have a robust process for SFP to improve, it was felt that a new SFP process needed to be designed. The framework adopted for the project is the DFLSS methodology of DMADV. DFLSS is a proven methodology for designing a new process, product or service (Cronemyr 2007). The five stages of the DMADV process are outlined below in Figure 1. It differs from DMAIC in that the 'I' is replaced by the 'Design' phase, and a new design is proposed theoretically designed to be right first time. The 'C' of DMAIC is replaced by 'Verify', where the new design is piloted, launched or installed, and the design is verified or a proof of concept is carried out (Thomas and Singh 2006).

### 3.1. Define

The define stage captured the wants and needs desired by the ultimate customer. These wants and needs would steer the project scope (Selvi and Majumdar 2014). A SIPOC (Suppliers, Inputs, Processes, Outputs, Controls) diagram is a very useful tool in the definition stage of a project, particularly for complex problems such as this one. The diagram identified the relevant process components the team could focus on for the remainder of the project (Yun and Chun 2008). Stakeholder analysis is key to the success of a project. An underlying premise of stakeholder management is the project leader's influence to ensure that all stakeholders deliver contributions to the project effectively and efficiently (Jepsen and Eskerod 2009). The first step of stakeholder analysis was to complete a stakeholder map, plotting the influence of stakeholders on one axis and the interest of the stakeholders on the other. The next step was to complete a stakeholder commitment matrix, listing the stakeholders and identifying their level of commitment on a scale; in this case, a five-point scale from 'Strongly Opposed' to 'Strongly in Favour' was chosen.

### 3.2. Measure

The measure phase was completed to set a baseline for the project. Using the metrics identified early in the project, the measurements influenced the project's direction (Selvi and Majumdar 2014). For this project article, the team utilised bar charts to support understanding the impact this project would have on the level of work conducted under the heading 'Space Improvement within the Site'. Pareto analysis subsequently utilising the '80/20 rule' aided in prioritising actions (Powell and Sammut-Bonnici 2015).

### 3.3. Analyse

A DMADV project's analysis phase was used to critically review the data gathered in the measure phase. The data was put to the test by the project team and used to propose ideas to resolve the issue at hand (Selvi and Majumdar 2014). Brainstorming is a key tool within the Lean and Six Sigma toolset as it provides a blank canvas in which any idea, regardless of perceived suitability, is accepted. The team shared ideas spontaneously, and everyone participating was encouraged to share their ideas (Al-Samarraie and Hurmuzan 2018). An affinity diagram operates similarly to an Ishikawa diagram (both were used) and groups ideas into logical subgroups. This activity intended to group large amounts of data concerning the space project, which would otherwise be too overwhelming if presented in its raw form (Lucero 2015).

### 3.4 Design

The design phase seeks to utilise the analysis completed above to create a process that will meet the end customer's needs (Selvi and Majumdar 2014). In this case, a process will be designed to strategically plan the creation, transfer, and use of space within the manufacturing organisation's campus. Process maps were utilised to visualise how the process delivers the end product to its customer (Marriott 2018). For the design phase of this project, it was imperative to create and maintain a process map to aid communication efforts during the rollout of the process. A Kaizen event was held to aid with the design of the new process as aiding the finding of rapid bursts to provide a quick solution to a major issue (Glover et al. 2013).

### 3.5 Verify

The final stage of the methodology is ongoing (Selvi and Majumdar 2014). Processes are rarely, if ever, perfect the first time around. As feedback is received, improvements can be made to a process. It was, however, also critical at this stage to confirm that the process designed using the DMADV methodology is substantially fit for purpose. Managing change is an important element that can dictate whether a change is successful. Resistance to change is a risk that must be anticipated, and managing the resistance is imperative. Communication, education, participation, and involvement are useful tools to manage and limit resistance to change (Kotter and Schlesinger 2008).

## 4. Application of DMADV framework

### 4.1. Define phase results

The project's first stage was to complete a problem statement encompassing the research question. The key deliverable identified during this define phase was a robust space planning process. The next step of the definition phase of the project was the completion of a SIPOC diagram. The completed SIPOC diagram is available in Figure 2.

The SIPOC diagram was a visual aid to help define project scope elements. This SIPOC diagram aimed to capture an undefined and ad-hoc process. As a result, it highlighted some key areas where definition would be required as part of the design phase later.

Before proceeding to the measurement phase, a stakeholder analysis exercise was conducted. The first step was a stakeholder map and a stakeholder commitment matrix. The results of both activities are available in Figure 3 and Figure 4. Completing a stakeholder map helped identify who had the most power to influence the project and, thus, who must be consulted for approval of any design and who had the most interest in the new design and thus must be involved in the communications. It was important to gain commitment to the project from the stakeholders outlined in Figure 4 and maintain their support. In this project, fortunately, there were no opposed or strongly opposed stakeholders, thus making the project somewhat easier.

A final project definition table was created following the problem statement and research question. This clearly outlined the problem statement, the objective and the project's scope (Table 1), with the areas in scope and areas out of scope.

| Process or Function Name: Strategic Facility Planning | |
|---|---|
| Scope: Production Rooms, Labs, Material In/Out, R&D, NPD, Equipment Engineering | Notes: |

SIPOC Diagram

| Suppliers | Inputs | Processes | Outputs | Customers |
|---|---|---|---|---|
| Who supplies the process inputs? | What inputs are required? | What are the major steps in the process? | What are the process outputs? | Who receives the outputs? |
| Area managers | Required Space | Space Request Process | Planned Space Moves | Manufacturing Areas |
| Operations Director | Build Plans | Monthly Review | Plan to Achieve Free Space | |
| Site VP | Capacity Models | Parent Organisation Strategic Plans | | |
| SFP Lead | Space Concepts | | | |

Figure 2. SIPOC diagram.

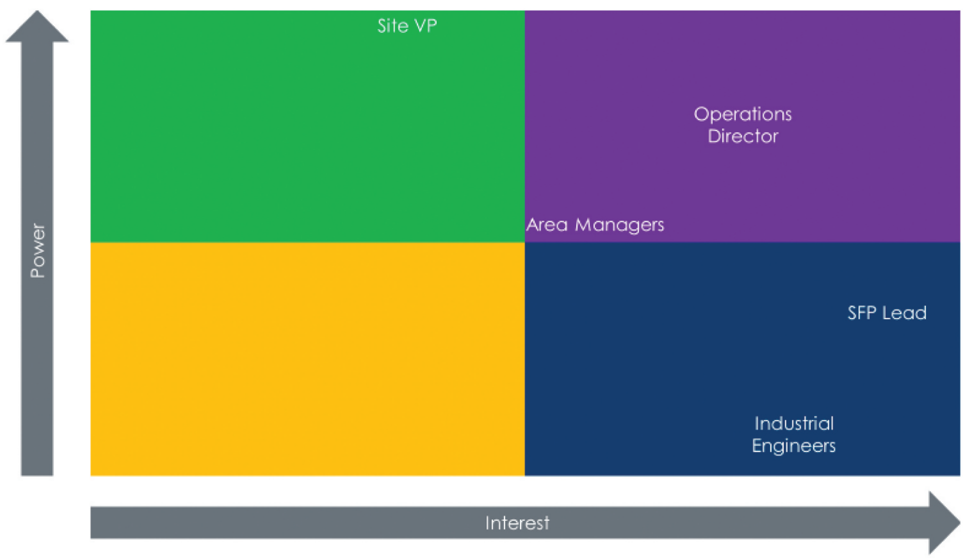


Figure 3. Stakeholder map.

| Stakeholder Commitment Matrix | | | | | |
|---|---|---|---|---|---|
| Position | Strongly Opposed | Opposed | Neutral | In Favour | Strongly In Favour |
| Site VP | | | | X | |
| Operations Director | | | | | X |
| Area Managers | | | | X | |
| SFP Lead | | | | | X |
| Industrial Engineers | | | X | | |

Figure 4. Stakeholder commitment matrix, screenshot of stakeholder spreadsheet.

## 4.2. Measure phase results

The key tools used in the measure phase were bar and line graphs. In addition, the researcher utilising Voice of the Customer (VoC) analysis tasked each area within the scope (Production Rooms, Incoming and Outgoing Materials, etc.) with completing an analysis of their immediate space needs and space needs over the following 24 months. This V.O.C. data was sourced and quantified from the internal customer stakeholders who reviewed their space location allocation in square feet (from CAD drawings) and the site layout master

Table 1. Final project definition.

| | |
|---|---|
| Problem | The manufacturing organisation was on track to go negative on space within 2 years.<br>No process in place to provide line of sight to the required free space to satisfy the site's space requirements |
| Objective | Create a process to strategically plan space moves for the benefit of the manufacturing site using the DMADV methodology. |
| Scope | In Scope: Production Rooms(P.R.'s), Labs, Material In/Out, R&D, NPD, Equipment Engineering; Out of Scope: Facilities, Support Staff Offices, I.T., Canteen, Car Park, Finances |

Table 2. A 24-month space needs by production area.

| Product room | Reason | Space (square foot) | % allocation |
|---|---|---|---|
| Sterilisation & Pack | Expansion of Sterilisation area Phase 1 & 2 | 31,000 | 37% |
| Assembly Product D | Expansion of Products D1 & D3 | 22,500 | 27% |
| Assembly Product A | Expansion of Products A1, A2 & A3 | 12,500 | 15% |
| Assembly Product G | Expansion of Product G1 | 5,500 | 7% |
| Assembly Product B | Expansion of Product B1 | 5,000 | 6% |
| Assembly Product F | Expansion of Product F1 & F2 | 4,500 | 5% |
| Assembly Product E | Goods Storage | 1,200 | 1% |
| Assembly Product C | Expansion of Products C1 & C2 | 1,000 | 1% |

Table 3. Space options decision matrix.

| | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| Set Up Costs | 1 | 1 | 1 | 1 |
| Timelines | 3 | 4 | 3 | 3 |
| Operational Costs | 3 | 3 | 2 | 1 |
| Ease of Expansion | 4 | 5 | 3 | 2 |
| Complexity | 3 | 5 | 4 | 3 |
| **Total** | 14 | 18 | 13 | 10 |

plan. They then estimated what space they might need in the future based on the reasons mentioned in Table 2. The project team validated any square footage figures provided, both actual and estimates, to ensure accuracy.

This request aimed to identify the scale of the issue facing the manufacturing sites campus in the short term and capture internal customer needs. The results of this request are available in Table 2.

### 4.3. Analyse phase results

The analysis phase was separated into two primary sections: analysis of the shorter-term space needs and analysis of the longer-term strategic goals. The tools utilised were brainstorming, a decision matrix, and an affinity diagram.

First, each Production Line in need of space was requested to come up with a proposal of a suitable location for their space needs based on the fact that they, as customers, knew more about their needs (VoC). Then, the four concepts were gathered by the project team and grouped to create four options for the site leadership team to discuss and from which to choose the most suitable for the site's long-term strategy. As with any installed equipment and manufacturing lines, there are constraints in what can be moved, adjusted and redesigned depending on the given line, but these concepts were designed to work within and around any existing facility constraints.

The Pareto graph showed that Assembly Product A, Assembly Product B, Assembly Product G, and Assembly Product D were the four P.R.s with the most urgent space needs. These graphs were put together on PowerPoint after a brainstorming session to create the options and to aid visibility and decision-making. More complex drawings were created on the CAD system, but these were more detailed and less visible for the decision process. Therefore, the four options are presented below in Figures 4–7.

A decision matrix was created to review each option against common criteria. This table is presented in Table 3. Higher values signify better business benefits.

The site leadership opted for Space Option 2, the schematic of which as highlighted in Figure 5, citing several reasons, including:

- The lower complexity of the moves, especially given regulatory compliance, restraints and maintains continuity of supply.
- The move to a ninth P.R. is optimal through the movement of the Assembly Product D (D1) P.R. elements.
- The opportunity for Assembly Product A growth in its current location
- The maintenance of additional free space in the second building for Assembly Product D (D1)'s future growth.

Following the completion of the choice of the option, the chosen option was logged as the 'Plan of Record'. Then, the team began analysing the process of creating and deciding the best plan from the four options. First, the team held brainstorming sessions to identify the positives and the opportunities for improvement. The team then grouped the brainstorming results into an affinity diagram. This affinity diagram became the basis for the design phase of the project. The affinity diagram is available in Figure 8.

### 4.4. Design phase results

The team's target for the design phase was to optimise and build on the successful elements identified in the affinity diagram while addressing and improving the elements which were not successful. The first step of the design phase was to put more structure on the Space Planning monthly reviews. The space reviews had long been in the form of a verbal update to site leadership. The researcher proposed that the space reviews become a more structured event. Each production area is tasked with completing a standardised digital template to provide the site's leadership team with accurate information about production volumes, constraints, and space requests to enable leadership to address any issues with these. An example of the standardised template can be seen in Figure 9.

Using this standardised template greatly improved the structure of the meeting, with the meeting operating on a beat rate with time towards the end of the meeting. This time was reserved for discussion of conflicting space requests

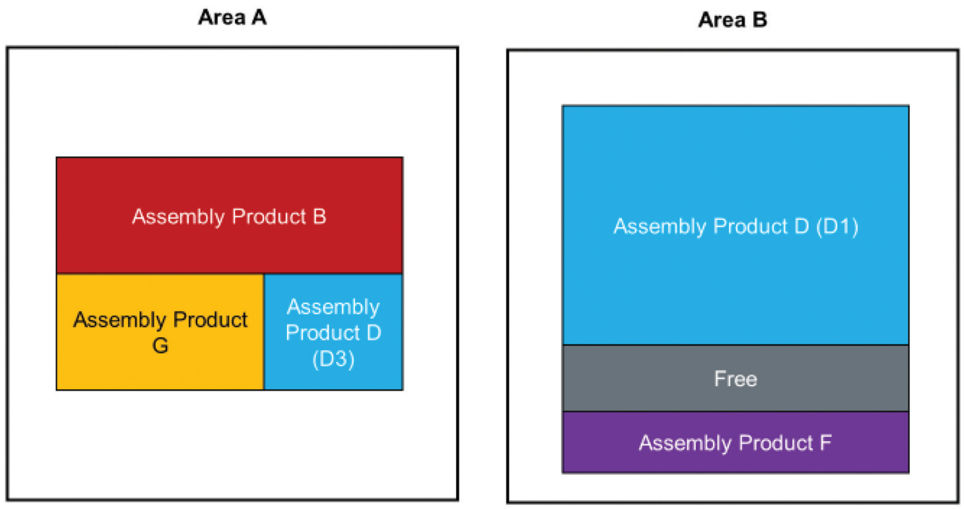


Figure 5. Space option 2.

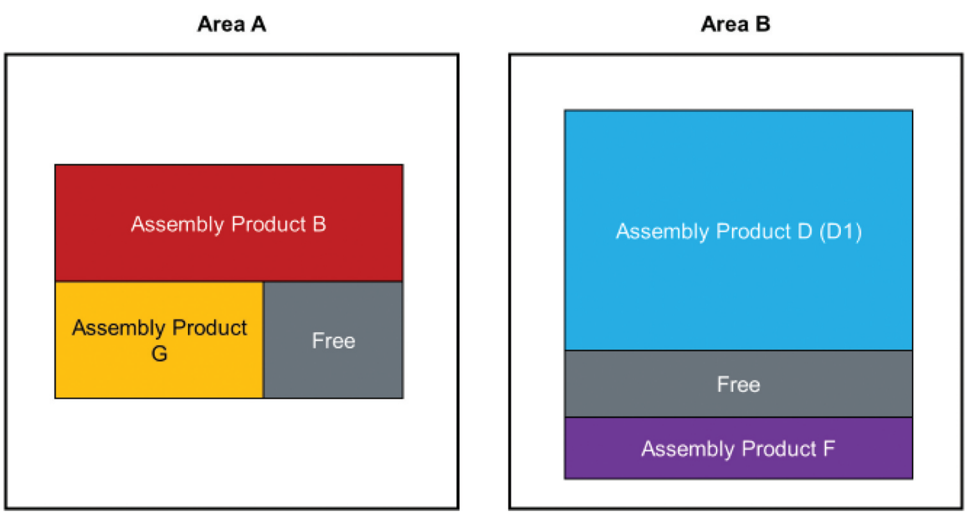


Figure 6. Space option 3.

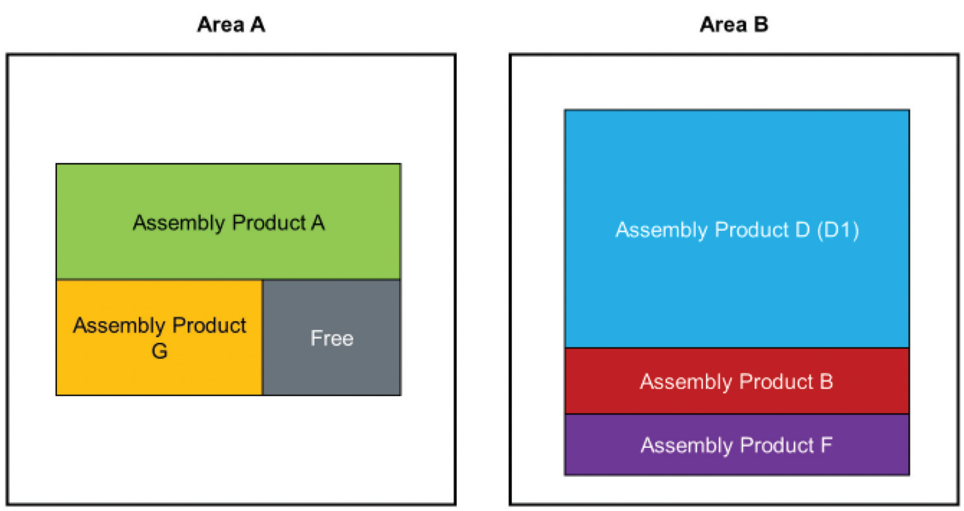


Figure 7. Space option 4.

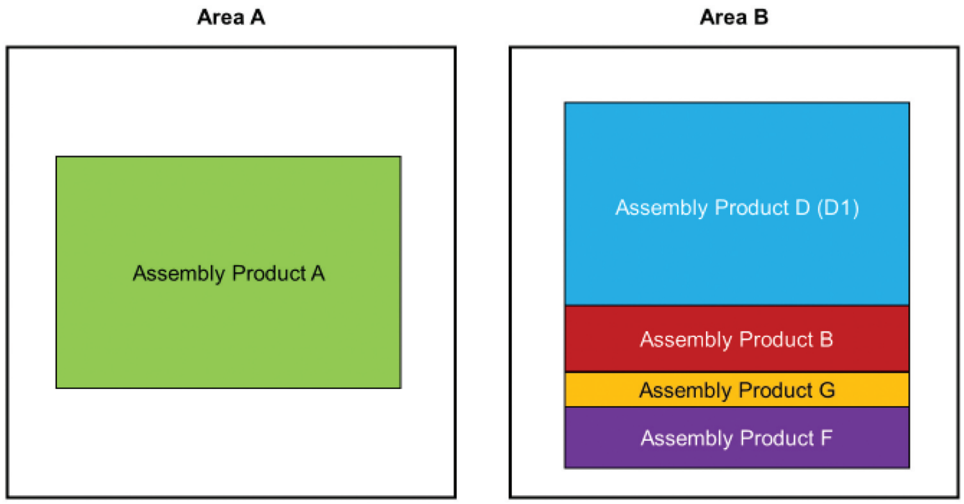


Figure 8. Space option 4.

rather than having those issues side-tracking a meeting and consuming more productive time earlier in the meeting.

The option chosen in the Analyse phase of the project became the Plan of Record. The Plan of Record was presented at each monthly space review. The site's leadership agreed that no significant layout changes could take place until they were documented on the Plan of Record. For an item to be documented on the Plan of Record, the production area must prepare a Space Change Impact Assessment (SCIA) to amend their production area boundaries. The SCIA process was already embedded in the site and its processes but was often treated as an afterthought and a 'tick box' exercise after all plans were made and Capital arranged. It was making this a pre-requisite to appearing on the Plan of Record which made the process more robust.

In order to support the SCIA process, a wider 'Space Request Process' was devised, which set out the correct process for requesting space in the manufacturing site. The process set out the steps from the initial concept to the final sign-off at a local level for the floor plan of the new area. This process can be seen in Figure 10.

The purpose of documenting and defining this process was to avoid the ambiguity that had begun to appear during the Analyse phase. During this phase, it was noted by some production areas that they were under the belief that they had a site leadership agreement to acquire space and had been planning with that understanding with other elements of their roles, including volume commitments. This had happened because there was an agreement to develop a concept rather than an agreement and sign-off to acquire space. This ambiguity was removed with the introduction of the above process.

The penultimate element of the design phase was to begin running a Gantt chart with a Critical Path Review regularly,

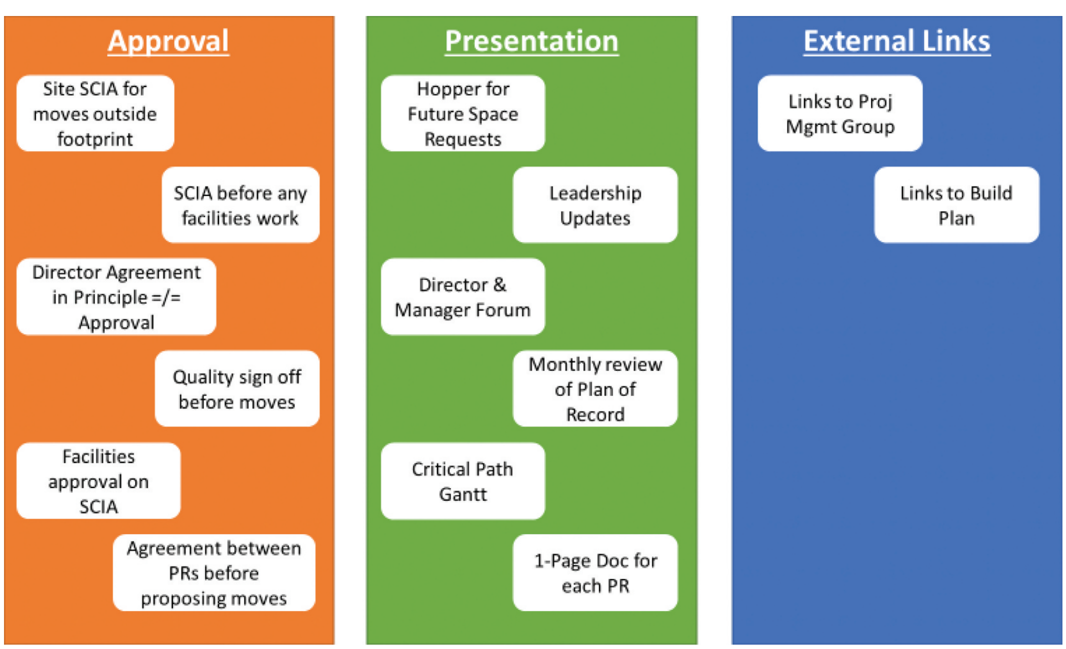


Figure 9. Affinity diagram (note: SCIA = site change).

the frequency of which would be flexible to the activity level on-site at a given time. The Critical Path Review's purpose was to ensure a touch point with ongoing space moves which impacted other production areas, defining the critical path for the projects and providing an update and an opportunity to escalate where necessary. An example of the Critical Path Review Gantt Chart can be seen in Figure 11.

The final stage of the design phase of this project was to document the Strategic Facility Planning process roadmap to ensure the process could be concisely communicated to new employees. This would ensure they understood and embraced the process from the beginning of their time with the company. It also made all stakeholders aware of not only the processes within the roadmap which the Strategic Facility Planning Process owned and maintained but also the processes outside the control of the SFP system which interacted or depended on it. The process roadmap can be seen in Figure 12 while the strategic planning roadmap can be seen in Figure 13.

### 4.5. Verify phase results

The project was verified by repeating the measures undertaken in the Measure phase. Verifying the effectiveness of the new process design was a relatively simple undertaking – comparing the results of the measure phase with the results after the design phase.

The results speak for themselves. The site moved from being on target to having an overcommitment on space of 22,000 sq. ft. to having 16,000 sq. ft. of free space on the campus.

It must be noted that the Industrial Engineering and Facilities management arrived at the overcommitment

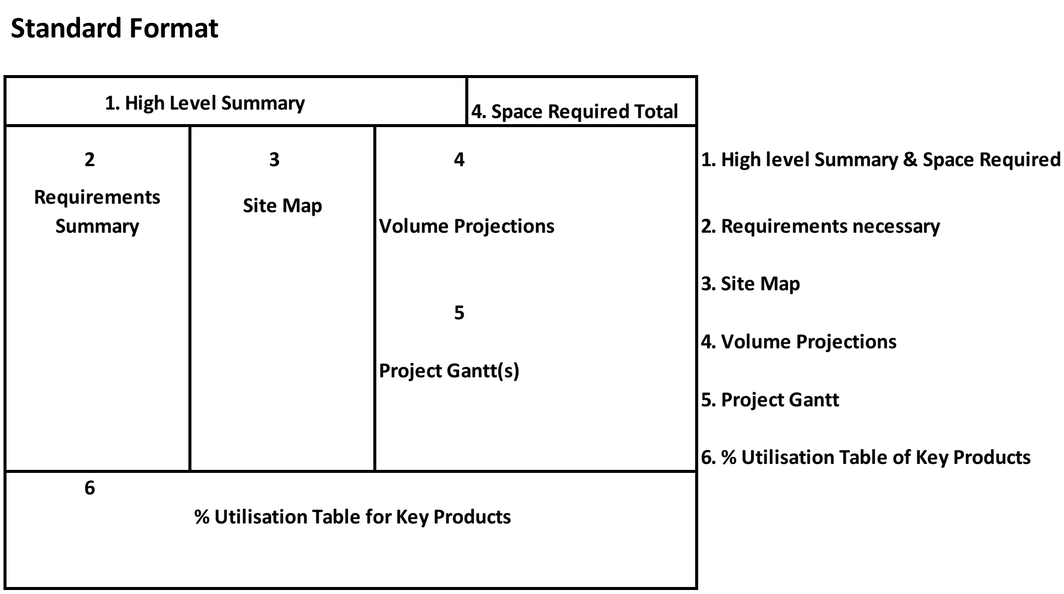


Figure 10. Space request process.

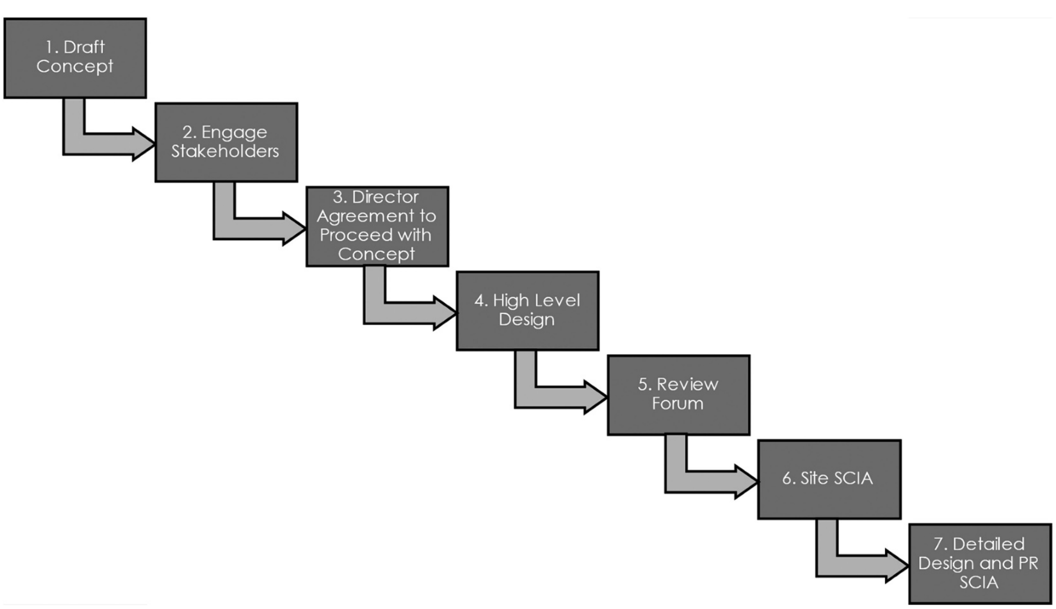


Figure 11. Space request process.

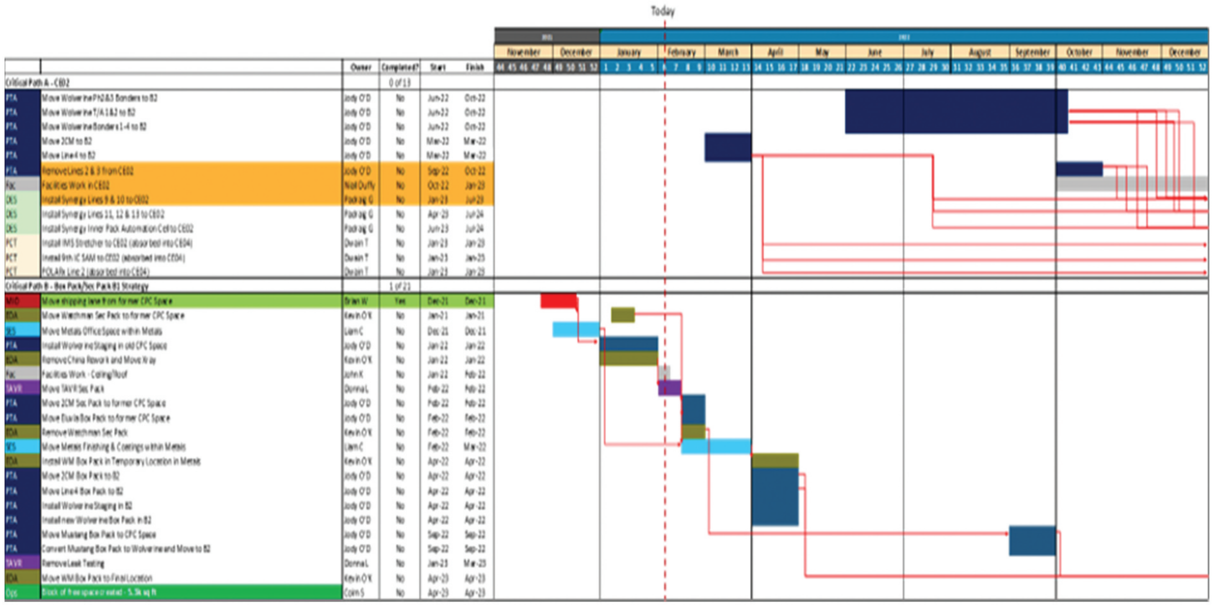

Figure 12. Strategic facility planning process roadmap.

figure based on mapping out the space requirements for new products to be introduced on-site and by looking at the shortfall in existing spec to increase capacity. CAD drawings and plans at a high level were created to visualise the space required. This comprised 9,000 sq. ft. of production area space and 7,000 sq. ft. of non-production area space. In addition, new or converted production area space was costed at ~$1,000 per sq. ft.

In contrast, non-production space was costed at ~$600 per sq. ft. This led to an overall cost avoidance for the site of approx. $13.2 m as the site was no longer required to build or convert additional space to facilitate the provision of this 16,000 sq. ft. This cost avoidance was coupled with the additional revenue that the site would generate through the increase in production volumes to which the site was now able to commit (Table 4).

## 5. Discussion on findings

The results showed a significant change in the outlook for space usage in the site, with a 38,000 sq. ft. upswing in projected space usage. The manufacturing site could move from an imminent production space deficit to a surplus by creating and implementing the new process. There was no capital investment required to design and implement the process. This supported the claim from Tompkins *et al.* (2010) that efficient use of space can reduce operating costs. Following Trubetskaya *et al.* (2023), the ideas for improvements were all generated internally, meaning no expensive external consultation investment was required.

The process was carefully scoped to ensure success, with items of known complexity omitted from the scope, such as financial approval. All space moves on site would be subject to

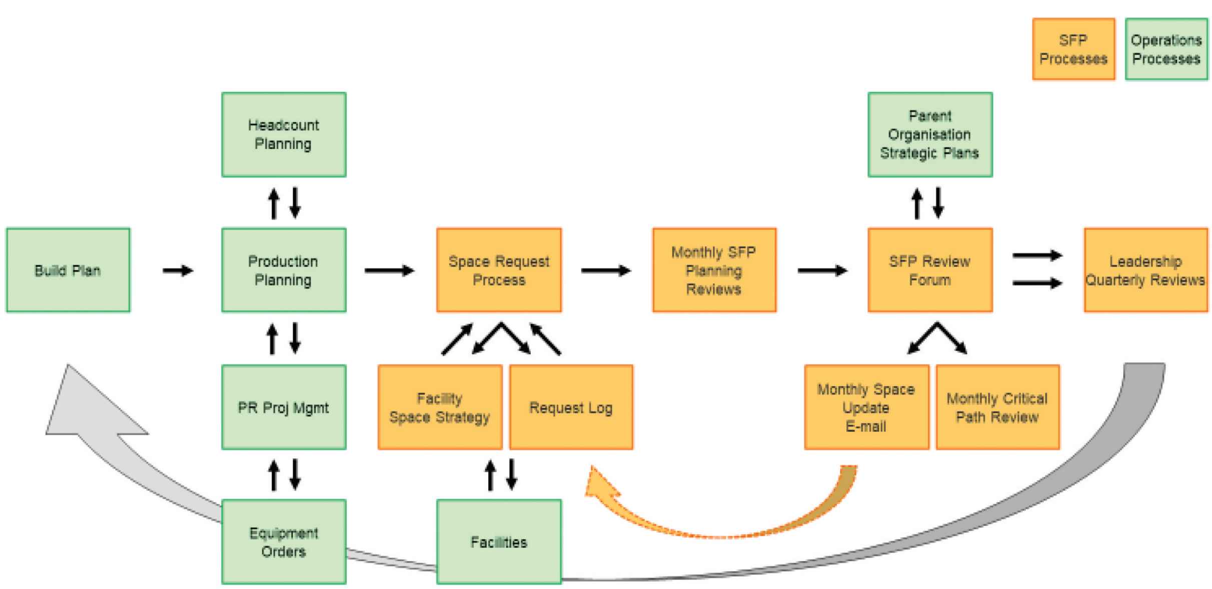


Figure 13. Strategic facility planning process Roadmap.

Table 4. Breakdown of cost savings.

| Before project | After project |
|---|---|
| 1) A requirement of 22,000 sq. foot in new facility space was needed. This was a cost of:22,000 sq. ft X $1,000/Sq. foot = **$22 Million** | 1) No new facility space or **zero sq. foot was required.** A cost avoidance of **$22 million** |
| 2) **Zero square foot space available** | 3) 16,000 sq ft of space freed up 9,000 sq ft production space at a cost of 1,000 sq./ft 7,000 sq./ft non-production space at a cost of $600 per sq. ft Total Savings of $**13,2000,000** |
| After Project Total Savings = **$22** million + **$13**.2 million = **$35.2 Million.** | |

the standard financial approval process after being approved for the use of space. A limitation of the study may be that should financial approval for the project not be forthcoming, the space request process would need to be re-started with an alternative location, with the original location becoming an option for other uses again. However, this process has, in turn, avoided space being tied up in the financial approval process, meaning no more than one use of the space would be planned for at any one time.

The manufacturing organisations' site leadership regarded the creation and documentation of the Strategic Facility Planning Process Roadmap as one of the single most impactful elements of the process. Thus, the defined DFLSS process with its structured DMADV methodology aided this new process creation (Thomas and Singh 2006). Rather than conjecture being used to explain the process, there is a single-page document that explains the process in simple terms, along with the links from each step to the next. Previously, the elements within this process were seen as standalone, with no understanding of the links between them. Now, the internal customer can easily see the links from the committed build plan through to the Space Request process and beyond. Further explanation of each element can be found in the

short explanatory documents, and any further clarity can be sought through contact with the Strategic Facility Planning Site Lead.

The development of the process has ensured that the organisation now has the required line of sight to satisfy all forecasted manufacturing space needs for the next two years. The process of identifying and prioritising space needs is planned to be undertaken again with a four-year window in mind. This will ensure the site is aware of potential shortfalls in the manufacturing space with enough time to react accordingly.

### 5.1. Managerial implications

Another novel element of this research was its use in a manufacturing site with significantly conflicting space needs. Each Production Room (P.R.) under the remit of the manufacturing organisation's campus was competing for the same manufacturing space in which they could expand their operations. An additional P.R. was also in the pipeline and need of manufacturing space. This shows that competing priorities are not a limiting factor for developing and implementing a successful space planning process. The fact that the site was able to generate a cost avoidance of $13.2 m in addition to facilitating the generation of additional revenue while meeting customer demands is a testament to the project. The utilisation of Lean within an organisational space design process can nullify or significantly reduce the need for costly additional space. Synergies were achieved through the open discussion forum of the Director and Manager's monthly reviews, namely around shared and flexible uses of spaces.

This research moved Space Planning from a position of reactive, transactional, and tactical planning to a truly proactive, transformational, strategic process that gives the site line of sight to the immediate future and beyond and can be replicated by many if not all, manufacturing sites.

### 5.2. Theoretical implications

This is the one of the few attempts in the literature to present a model for strategic space management using the DMADV framework in a highly regulated industry. While the process is limited to a single manufacturing site, it does provide a platform for further research into how strategic space management can be developed using the DMADV model.

This study has several significant implications for demonstrating how DMADV implementation can be successfully deployed in manufacturing organisations. First, this study was deployed in a manufacturing company in a highly regulated manufacturing environment where changes are cost prohibitive and can be difficult to implement or get concerns for because of regulatory requirements (McDermott, Antony, Sony and Healy, 2022; Trubetskaya, Manto, and McDermott 2022).

## 6. Conclusions

The novelty in this research lies in the fact that any manufacturing organisation could replicate the creation of a space planning process and apply it to any areas they deem necessary within their scope. The process followed the DMADV methodology, which has a large and varied toolset, making it quite adaptable to the needs of its users. The process designed via this project clearly outlines the roadmap from definition to verification of the success of the process and provides examples of process elements throughout, which can be replicated and modified to suit the organisation implementing them. Much of the literature has utilised DFLSS in SFP to design a once-off-site facility plan or change; this study provides a robust continuous process for future SFP. The study contributes to the organisation's sustainability agenda by eliminating unnecessary construction in building new production site areas and using existing resources and space to minimise waste.

### 6.1. Future work

The next developmental step for this research would be to investigate the creation of a software system or application to track and maintain the changes in footprint and space assignment within the site. Currently, the system is maintained through manual documents. This, in turn, has associated risks, particularly the potential for human error to impact plans. It also has a high time cost associated with it. With Lean being a key contributor to the improvements achieved to date, the next step would be to design a Lean system to reduce non-value add time associated with maintaining the process.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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