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REDUCING CYCLE TIMES AT DENEL UAVS

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Executive Summary

One way of increasing productivity in manufacturing is to decrease the cycle times of processes. In terms of the manufacturing process at Denel UAVS this relates to the on time delivery of complete kits to the technicians for assembly, and decreasing the assembly time. This project will emphasise that by following a Lean methodology this needed decrease in cycle time can be achieved. The Lean methodology refers to a thinking process that incorporates any applicable technique to reduce waste (such as time, money, space etc.) in the value stream.

This document presents an improvement framework that management can use to reduce the waste in the manufacturing process. This framework will primarily consist of an improved facility layout to reduce wasted space and time during kit preparation, but will also explore other activities that promise waste reduction.

The benefits possible by implementing the improvement framework include:

- Reduce wasted facility space
- Reduce wasted material movement
- Reduce total assembly time with 10%
- Reduce material handling cost by 10%-30%
- Increase picking rates with 10%
- Reduce variance in pick-rates with 20%
- Reduce picking errors with 70%
- Increase material visibility
- Increase quality control

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1. Introduction and Background

Denel UAVS formally known as Kentron is situated in Irene Pretoria. Denel UAVS is a division of the Denel group and specializes in the design and manufacturing of military aircraft.
The Seeker II is a medium range UAV remote surveillance system (spy plane) used for reconnaissance, border patrol, policing and many other applications. The Skua is known as a High-Speed Target Drone which acts as a stand in for an aeroplane to be used as a shooting target in real life simulations for combat training and testing of weapon systems.

Figure 1: Seeker II UAV

Figure 2: Skua High-Speed Target Drone

Although Denel Dynamics offers world class products they are still experiencing problems with the building of the UAVs. Very long and variable cycle times constantly plague the production of UAVs. The variability in cycle times causes incomplete kits to delay production and result in a hold-up on the production schedule. In reaction to this the production manager authorises the issue of incomplete kits for sub-assembly attempting to stay on schedule, hoping that the there will be unused time later in the production to complete this kits. The system lacks control for incomplete kits, which may result in kits being categorised incorrectly, adding to the variability in cycle times.
The reason for the long cycle times can be assigned to the specialised nature of the production, with long lead times on custom-made parts and aviation quality requirements. However, the variability in cycle times for similar kits remains unknown at this moment.

Interventions are urgently required to pin-point and solve the variability in cycle times to reduce the cost of producing UAVs. UAVs are used for specialised tasks which make them more expensive than ordinary aeroplanes. Long cycle times result in extremely high Work In Progress (WIP) storage costs, which the company needs to carry until completion of the project when they will receive payment. Delays on the production schedule may result in late delivery of contracts, which results in a payment of a penalty as negotiated in the contract. WIP storage cost and penalties paid, equates to millions of Rands being wasted.
If shorter and standardised cycle times are achieved, payment on contracts can be received faster and more accurate information can be used in the negotiation of new contracts to reduce overall wasted money.

2. Project Aim

The aim of the project is to identify and eliminate all the waste in the manufacturing of UAVs. This waste includes the waste of money, time, unnecessary movement of material and others. By reducing the waste in the processes, the cycle times will be reduced resulting in a more standardised and streamlined manufacturing process that will ultimately save the company money. These improvements should then be implemented and incorporated into an improvement framework that can be used as a driver to implement the Lean principle throughout the company.

3. Project Plan

Value Stream Management will be the main management technique used to complete the project. This management technique is a storyboard type of management technique which enables all the stakeholders to give input, and gives the necessary guidance that enables all to know what exactly they should do next in the project.

The steps of the project are as follow:

1. Choose the value stream
2. Learn about Lean
3. Current state value stream map
4. Lean metrics
5. Recording data
6. Analysis of data
7. Ideal state map
8. Develop possible solutions for improvement framework
9. Choose and implement solutions contained in the improvement framework
10. Review process improvements

4. Choosing the Value Stream

The project will focus on the value stream that originates with the receiving of parts in the main store room to where subassemblies are requested for fitment on the UAV. This will exclude the procurement of parts and determination of optimal inventory levels.

Special attention will be given to the following:

- Inspection processes throughout manufacturing
- Binning process of parts
- Material handling
- Process design
- Facility planning
- Work in Process (WIP) Store functions
- Management of incomplete kits
- Communication techniques
- Production Scheduling

It is accepted that changes in a value stream may affect value steams further upstream or downstream. This is why a holistic approach will be taken to ensure that other value streams are taken into consideration.

5. Learn about Lean

Although the scope of the project is concerned with the value stream originating in the receiving of raw material to where subassemblies are ready for final assembly, any information regarding the reduction of cycle time and implementation of Lean in an aircraft facility will be investigated.

There exists a general consensus amongst low volume, high variability manufacturers that there is a need for the investigation and implementation of Lean principles in their operations. Currently little information is available on Lean in the aircraft industry due to the following reasons:

- The sensitivity of information
- The loss of competitive advantage over market competitors
- The fact that most of these companies are still busy with their pilot projects to evaluate the prospects of Lean
- The pilot projects are normally implemented on small scale, which usually focus on a single non-critical process

Lean is a way of thinking, thus all techniques showing potential to reduce waste will be considered as Lean techniques in this project. All material investigated will be analysed based on the applicability to the type of product manufactured by Denel UAVS. There is not an exact sequence in the presentation of the techniques, but it will be presented in a cohesive manner by grouping all information regarding a technique together. When all the techniques are presented they can be analysed and relevant techniques can be chosen to further pursue the project. Some literature regarding the specific topics will be left out, because it is beyond the scope of the project. The scope of the project can be adjusted in the future, if significant evidence supports this decision.

5.1 Lean Manufacturing

The Lean methodology is concerned with the reduction of waste. This waste can include wasted time, money, resources, inventory etc. Tapping, Shuker (2003:41) Lean manufacturing is a compilation of known techniques to form a powerful methodology Hobbs (2004:5). Lean has been applied across many disciplines, proving its success as a universal tool. (Poppedieck, 2002, *p*.1). According to Cook, Graser (2001:2) Lean manufacturing will enable significant savings and revolutionary changes in the way military aircraft are designed and built, where nearly all manufacturers surveyed as part of a research project had either implemented lean pilot projects or expressed their intention to do so. Moreover, all manufacturers who had initiated such projects reported that savings had already been derived from their efforts. A specific company such as NORDAM used Lean to reduce the lead times in assembling small components for their Cessna aircraft. Details of their success can be found at <http://www.bmgi.com/eNewsletter/June/Article2.html> The Lean Aircraft initiative shows that reduced cycle times were one of the results gained from using Lean manufacturing. Hobbs (2004:133).

5.2 Value Stream Management

A value stream can be thought of as a river. Each process in an organisation forms part of this river and products flow downstream to other departments/processes. The process furthest downstream is the customer who actually buys the product Tapping, Shuker (2003:33). A value stream can thus be any given size depending on the size of the section of river you choose to look at. The scope of the project determines the size of the Value Stream that is going to be investigated.

Value Stream Management (VSM) is a management tool that links all the Lean techniques and gives guidance to managers regarding their next step by representing the value stream in a story board fashion. This provides a structured process to follow and present a good form of visual communication which allows everyone to understand the Lean concepts.

5.3 Mapping the Current State

Before any improvements can be made the current baseline must be established. A common way to represent the current state is by a drawing. A drawing is easy to understand and also forms part of VSM. Value stream mapping and process mapping are great mapping techniques to use with Lean manufacturing. How each mapping technique works is beyond the scope of this document. What is important is the applicability of the technique to the current project environment.

Value stream mapping does not show the level of detail that is required in this scenario, due to the small size of the value stream chosen for investigation.
According to Quarterman Lee author of *The Strategos Guide to Value Stream Mapping*, the following factors ought to be considered before using Value Stream Mapping:

	Applies to	**May Not Apply to**
Volume	High Volumes	Low Volumes may be Problematic
Variety	Low Variety	High Variety
Equipment	Dedicated Equipment	Multiple Shared Equipment
Routing	Simple Routings	Complex Routings
Components	Few	Many Parts & Sub-assemblies

Table 1: *Applicability of value stream mapping to different environments*

It is clear that value stream mapping is not applicable to the current environment at Denel UAVS and process mapping should rather be used. Process mapping will give any desired level of detail because any activity can be seen as a process.
Lee (2006:25).

5.4 Six Sigma

Six Sigma is a methodology concerned with the elimination of defects to improve quality to near perfection, by driving standard deviations towards six standard deviations between the mean and the nearest specification limit. This will ensure that a process does not produce more than 3.4 defects per million opportunities. Six Sigma is implemented using the DMAIC process (define, measure, analyse, improve, control) which is based on incremental improvement. Issixsigma (2008).
Six Sigma projects generate an average of $250,000 in reduced cost or increased revenues due to the following benefits:

- Reduced cycle times
- Increased productivity
- Reduced total defects
- Decreased WIP
- Decreased unit cost

Gitlow et al. (2005:734)

5.5 The 5S Visual Management System

The 5S System is one of the many improvements techniques that can be used in the implementation of Lean. The 5S system stands for: Sort, Set in Order, Shine, Standardise and Sustain. During the sort phase all activities, tools and materials should be organised leaving only the necessary to make the relevant job possible. After the sorting process, what is left behind must be orderly arranged for easy accessibility for anyone. While the previous 2 steps are done, the area are also cleaned, this will make the employees more attentive to working neatly. The fourth step in 5S is to standardise the working procedures in this new layout to ensure that the workplace stay consistently neat. The last step is sustainability. This is the commitment to the whole 5S system where employees take pride in their work and maintain their own workplace.
IsSixSigma (2008).

Benefits of 5s:

- Decrease downtime
- Raise employee morale
- Identify problems more quickly
- Increase product and process quality
- Increased floor space by 20% to 40%
- Reduced lead time and cycle time by 10% to 25%

Burton, Boeder (2003:25)

5.6 Kanban

A kanban is a form of signal that will pull material from upstream operations in the quantity needed on the time it is needed. Takt time is an important element used to determine the rate at which product must be produced to satisfy downstream demand. It is determined by dividing the available production time by the rate of customer demand. Success for kanban is best achieved when a company has committed implementation for the lean tools of level mix model production, quick changeover, one-piece flow, mistake-proofing, 5S visual management, TPM, and point-of-use storage.

There is a use for Material Requirements Planning (MRP) in a pull scheduling system. MRP should be used for the purpose of planning to forecast material and capacity requirements within the enterprise and for suppliers. Burton, Boeder (2003:50). Currently Denel UAVS uses an MRP system, thus the integration of kanban suggest a small or little improvement gain in production times.

5.7 Facility Planning

Facility planning could be seen as a subset of Lean, because a good facility plan is also concerned with the reduction of wasted time, money, inventory, material handling etc. But it still is a subject matter on its own. Facility planning was primarily seen as a science, but in today's marketplace it is seen as a strategy. Between 20%-50% of the total operating expense within manufacturing is attributed to material handling. An effective facility plan can reduce this material handling cost with at least 10%-30%. By applying an effective facility plan US manufacturers can increase productivity 3 times more than it has over the last 15 years. Tompkins et al. (2003:9)

The following discussion will focus on areas or techniques within facility planning which shows promise for improvement.

5.7.1 Layout Planning

An effective facility layout will increase production and reduce wasted time and money on material handling. The facility layout sets the stage for order-picking, the most important activity in a warehouse. If material is staged for quick and easy retrieval and movement, customers downstream will receive good service at low cost Barthold, Hackan (2008:20).

5.7.2 Order Picking Operations

According to Carlsson and Hensvold's master's thesis done at Caterpillar, they depict kitting as beneficial in a high variety assembly line such as the one found at Denel UAVS. Order picking operations must thus be used to pick material or parts into kits for the technicians on the assembly line. Order picking is the most critical function in warehouse operations and forms the centre of material flow. Warehousing professionals identify order picking as the highest-priority in productivity improvement, because picking operations result in 55% of annual operating expense in a facility.

5.7.3 Automated Data Collection

Machine Readable Information (MRI) technology such as bar coding can be used to capture key data concerning the status of material. By doing this material will be more visible in the facility, reducing errors in picking and reducing wasted time in manually keeping track of kits and inventory. Lefebvre & Lefebvre (2005).

6. Current state maps

If you want to know where to go, you need to know where you are at the moment. The following current sate maps were constructed to form a base for improvement opportunities.

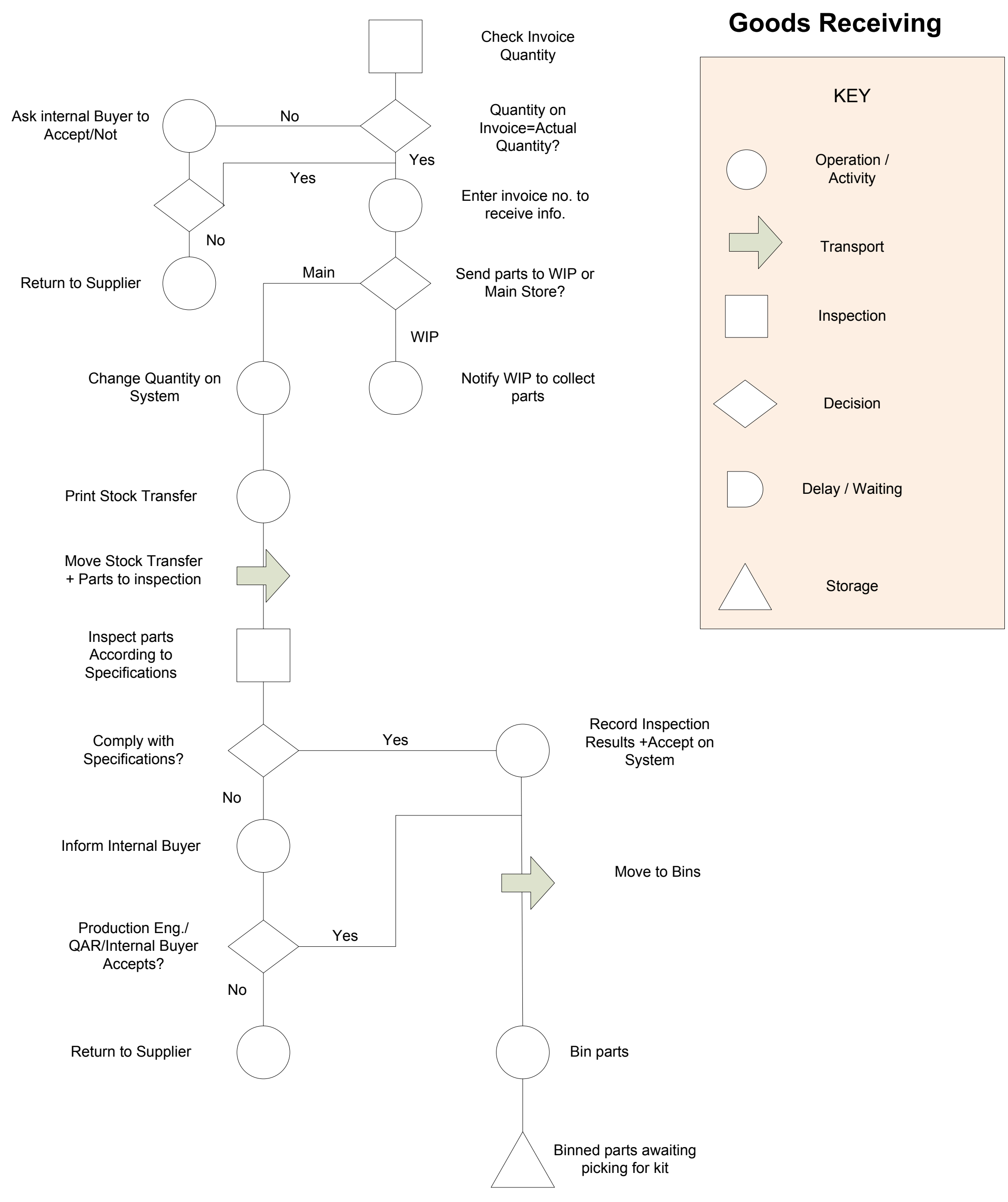

Figure 1: *Current state of the goods receiving operations*

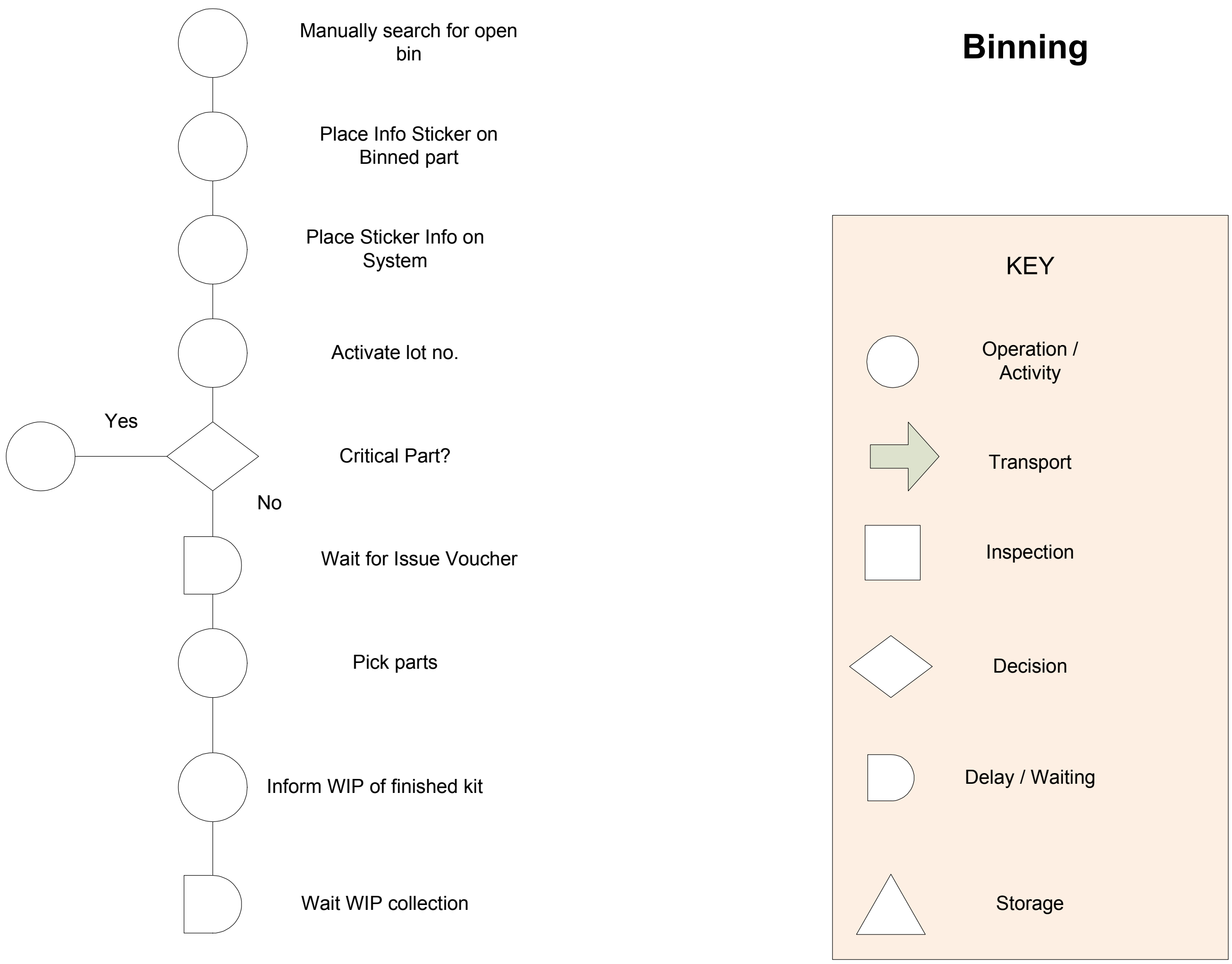

Figure 2: *Current state of binning operations*

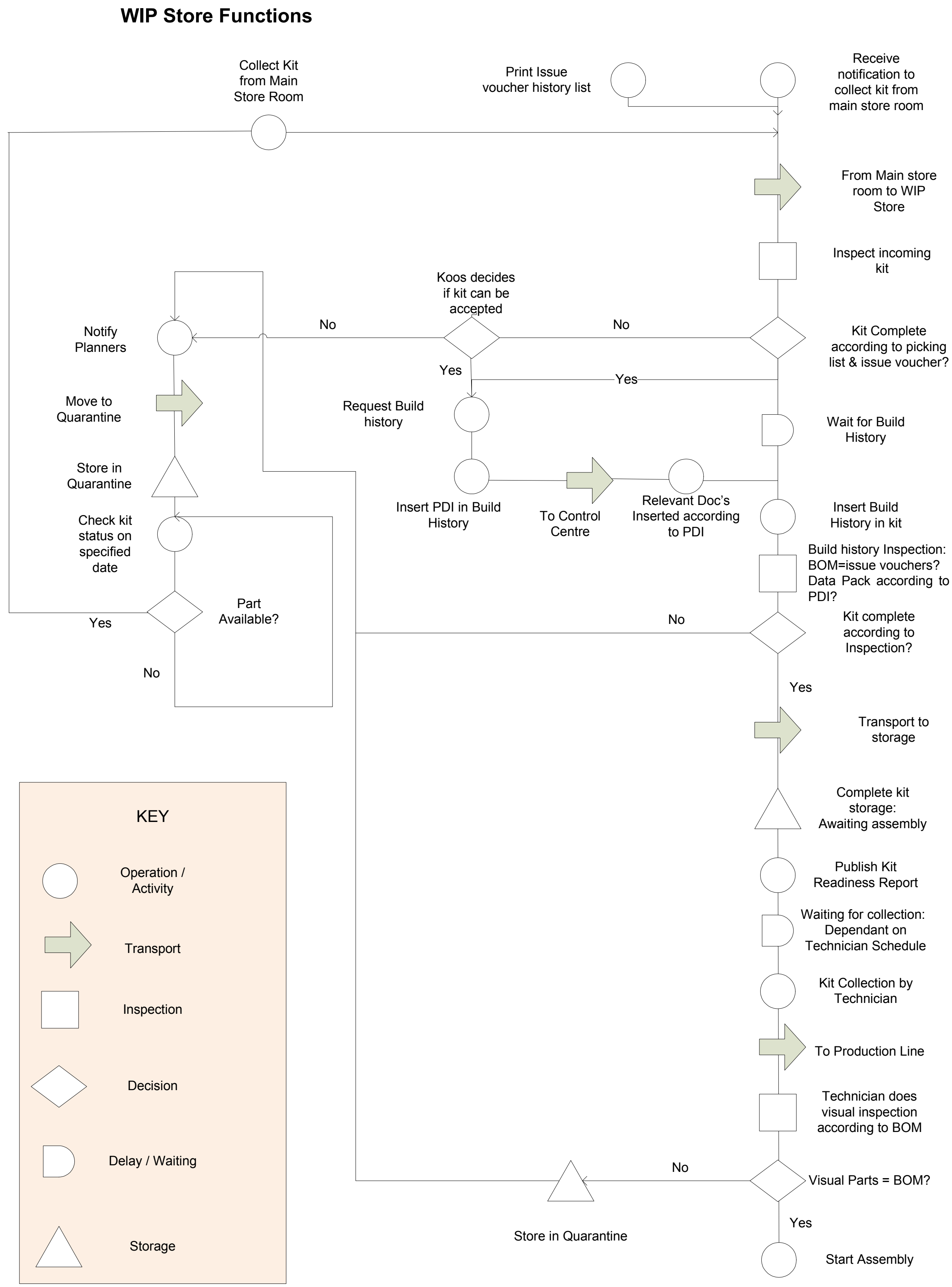

Figure 3: *Current state of WIP store operations*

7. Identify Lean Metrics

When one has a current state map in hand the identification of problems should start. Metrics will help to identify waste in the system while providing employees an understanding of the impact of their activities throughout the improvement cycle. Focus should not only be on what is going to be measured but also how. Typical measures are project completion milestones, lead time, cycle time, internal errors etc., but while some measures are generic to nearly all value streams, there will be some that is specific to one's specific value stream. It is important to collect data where it is most useful.
Due to the range of subassemblies made by Denel UAVS, it is difficult to use a common measurable. Important to this environment are the on-time delivery and completeness of kits delivered to the technicians for subassembly. The cycle times cannot be measured directly due to the once-of nature of the subassemblies. An upstream measure should be used to ensure that the cycle times in the subassembly will decrease. On-time delivery can be measured according to the production schedule, and the completeness of kits can be measured by Defective Parts per Million (DPPM). To calculate DPPM, the actual errors in the kit are divided by the total opportunities for errors in the kit multiplied by a million. One can then try to continuously improve this value stream until it is within satisfactory limits. A Pert, Pareto, or Fishbone diagram would be helpful to identify improvement opportunities, and see how they impact the Lean metrics. Tapping, Shuker (2003:75).

8. Recording of data

The metrics were used to collect data as far as possible downstream in the value stream to ensure that any upstream abnormalities will become visible in the data collection. Log book type forms were included into the kits to enable the technicians to indicate the shortages on kits or any other abnormalities that will inhibit them from completing the subassembly on time. All part shortages were recorded before the kit went for subassembly, thus the technician records shortages over and above the current shortages. Examples of the data collection sheets can be found in Addendum A.

9. Analysis of data

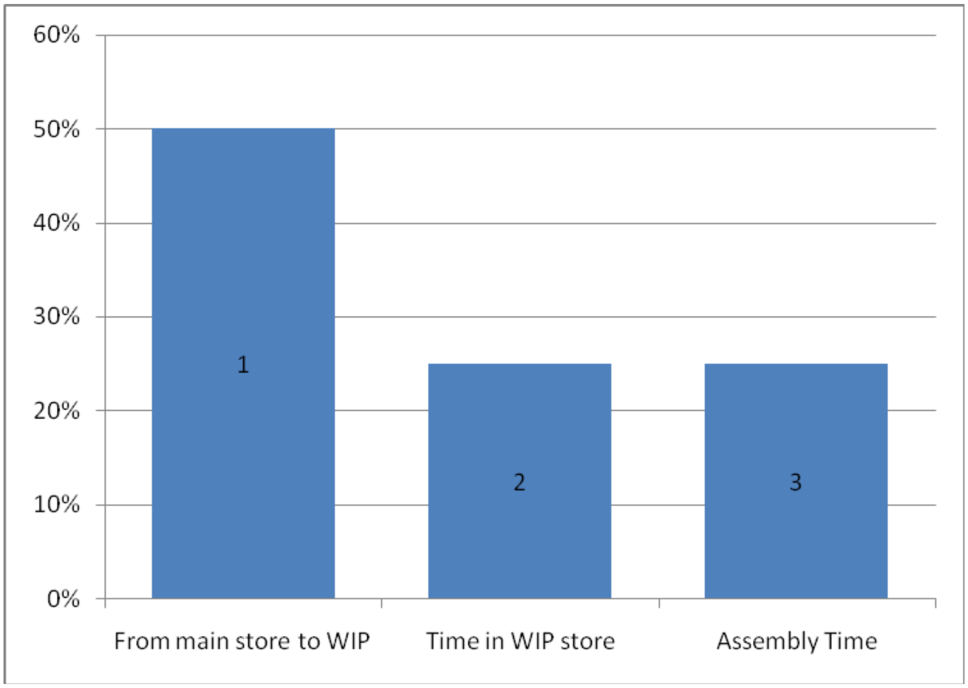

Figure 4: *Percentage of total time spent in each process*

Figure 4 shows the distribution of time during which the kits were tracked. Bar 1indicates the percentage of time that was spent waiting for the kit to be picked and delivered to the WIP store. Bar 2 indicates the percentage of time the kit spent in the WIP store, while bar 3 indicates the percentage of time that was spent to do the physical assembly of the parts in the kit. The time the kit spends in assembly is the only value adding time that was spent on the kit, because this is the only time that the client is willing to pay for.

The data gathered can be misleading and the following factors must be considered:

- The time the WIP store waits for kits is overstated due to delivery dates given to the main store to pick the kits. Thus the issue vouchers are issued well in advance of the actual date it is needed.
- The time spent in the WIP store is overstated, due to the kits waiting for assembly according to the production schedule.
- The time it takes to assemble the kit is understated, because the recorded data stops at the last part being assembled and not at the completion of the sub assembly.

It is clear from the data that the time a kit spends in a section is directly proportional to the size of the kit. Although the time indicated is not exact, it still shows where the waste is positioned in the process.

All the causes of the holdups in the process are not yet known but the following may play a role:

- Inefficient binning and order picking
- Inefficient WIP store layout
- WIP store is used as a "post office" to send non WIP related items between departments
- SAP is not fully utilised to keep track of quarantined kits due to lack of training
- WIP store does not have adequate access to production schedule

It is clear that the most waste incurs in the store, and must thus receive the most intention to investigate possible improvement opportunities.

10. Ideal state map

The ideal state map is a representation of the current process without any waste in the process. Although this is an idealistic approach, it guides the team towards looking for improvements that will get them as close to the ideal state as possible. It is accepted that certain waste reduction techniques will simply be too expensive to implement. In this case the value that the improvement will present must be weighed against the actual cost of implementing the improvement.

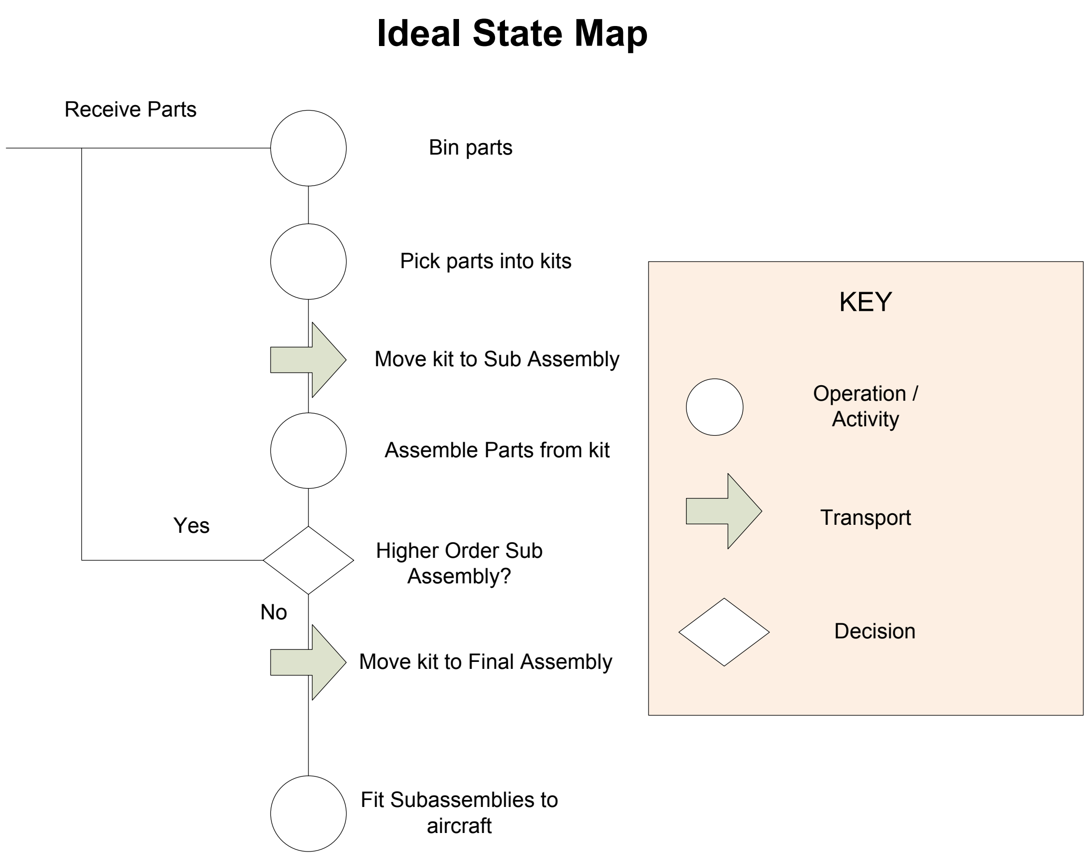

Figure 5: *Ideal State Map*

11. Proposed Solutions for Improvement Framework

Proposed solutions to the problems will be developed and incorporated in the improvement framework. The implementation of the solutions can be systematically done according to their perceived impact and duration of implementation each holds.

11.1 Improving WIP Layout

11.1.1 Analysis of Existing Layout

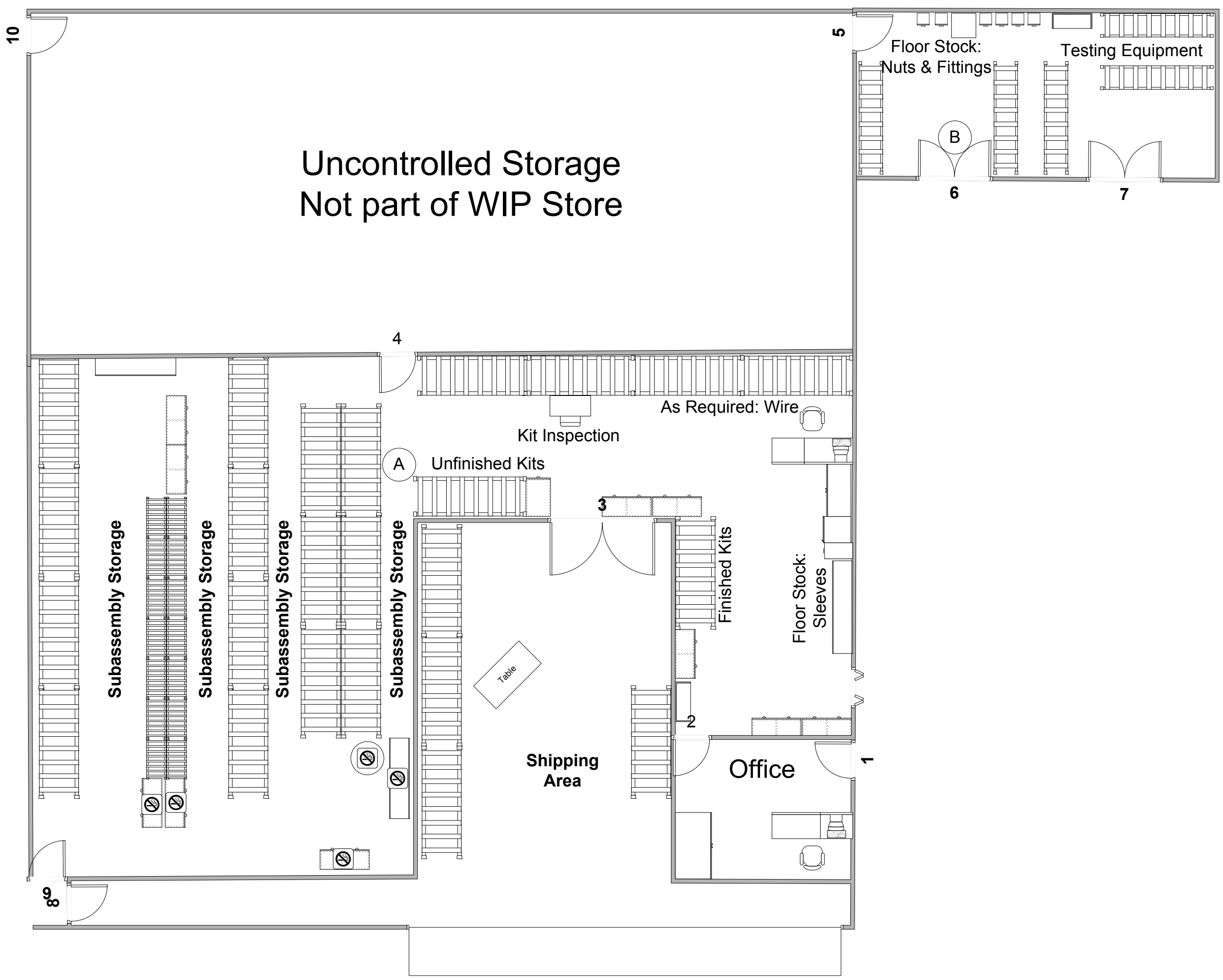

Figure 6: *Existing WIP Store Layout*

Figure 6 shows the current layout of the Work in Process (WIP) store. The layout is not drawn to scale but rather gives a bird's eye view of the facility. Circles A&B in figure 6 indicates uncontrolled storage on the floor, where figures labelled with a no smoking symbol indicate flammable material storage. The current layout makes provision for many products which is typical in a low volume environment.

Although no safety stock is carried and all projects are executed on a make-to-order basis, WIP stock can sometimes become excessive due to unmet production schedules. The production process is driven by Material Resource Planning (MRP), but the WIP store has little to no access to this information. Long lead and cycle times necessitate the incorporation of buffer times in the production schedule to ensure on time completion of the project.

The schedulers will issue kits from the main store to be picked when all the parts of the kits are in the main store (critical kits may be issued even if all the parts are not in the main store). Pickers at the main store get a date by which the kit must be completely picked. Some kits may be picked prematurely to balance the workload on the pickers; this also leads to the kits being pushed into the system rather than being pulled according to the production schedule. Premature kit issuing on the other hand gives more time to correct shortages in the kits and may help to get the kits completed on time.

Inefficient flow in the store is one of the main reasons to reconsider the layout of the store. Door 1 currently serves as the only access to any part of the WIP store from inside of the building. It is noted that WIP staff frequently struggle through door 1&2 due to the use of a bicycle or trolley to transport equipment. If technicians need floor stock or measuring equipment, they have to walk through door 1, 2, 4, (through the uncontrolled storage) and door 5, just to access the appropriate storage area. This storage area is equipped with two doors (doors 6 & 7), but door 1 remains the main access point. This lends itself to excessive control over the store and may hamper the productivity of the technicians and frustrate the WIP store personnel which have to manually open the door for each visitor.

Uncontrolled storage (circle A) and a flammable material cabinet blocks access to an entire length of racks. Even if these objects are moved, inadequate aisle space still exists to efficiently use the racks. There is also no separation of flammable material from stock and pose a major fire hazard. Overall, space is wasted by unused (and oversized) racks of which some are even used to store non WIP related material. Addendum B contains the material handling checklist done for the facility.

11.1.2 Developing New Layout Alternatives

Murther's Systematic Layout Planning (SLP) is the method used in this document to generate alternative layouts and plan for improvement.

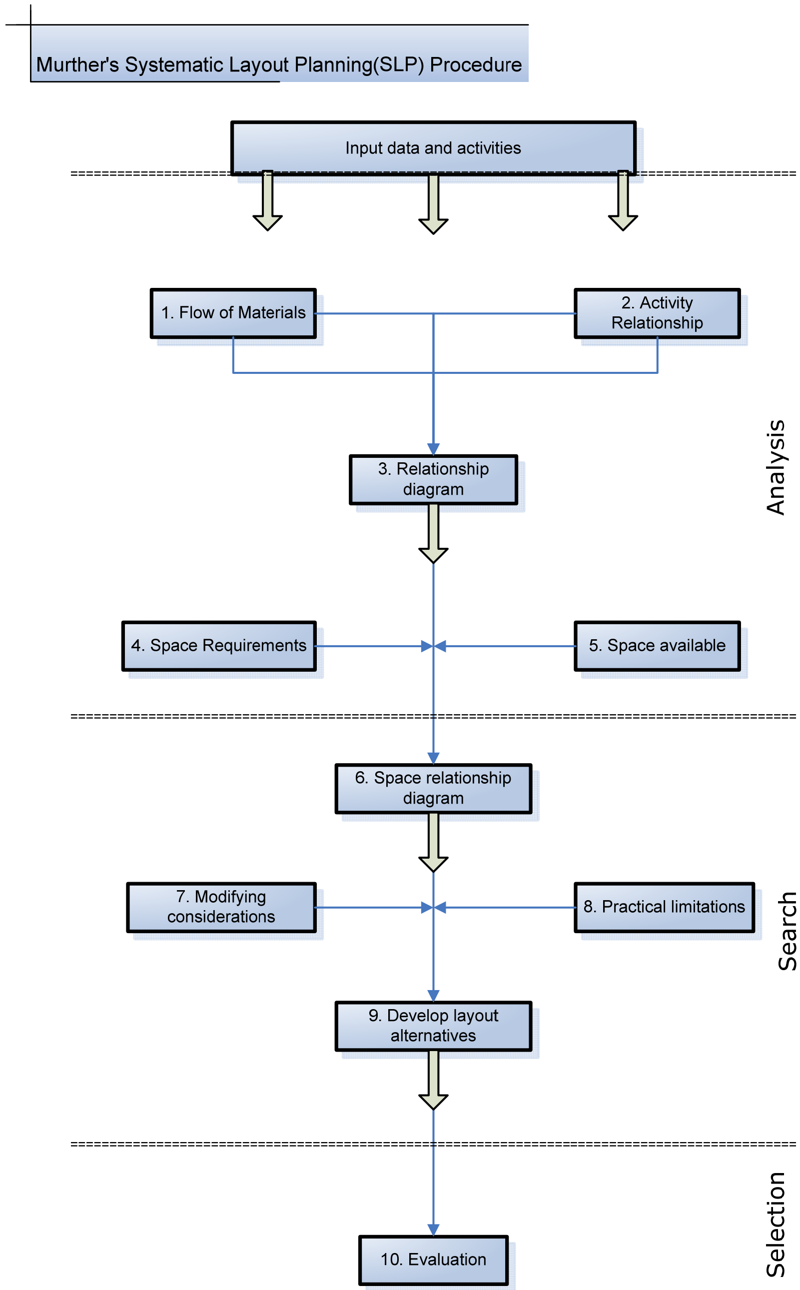

Figure 7: *Murther's Systematic Layout Planning Method*

11.1.3 Flow of materials

During the analysis of the existing layout the flow of material got a lot of attention. This flow did not include flow to and from the main store and assembly area. A From-To chart can be constructed to show the flow of material throughout the facility. All that this chart does is it shows the actual number of parts that flows from one part of the facility to the other. The From-To chart is a quantitative way of presenting the actual flows in the facility on a typical day. Due to the low volume nature of the production, a general representation of the actual flow of material will be used. A typical kit will be taken and a score of 0-3 will be assigned to the flow between the departments, where a zero score represents no flow and a score of 3 represents a high material flow.
Another scale of 1-7 will be used to indicate distance between the departments where 1 is near, and 7 extremely far. The kit flow score and distance scale will be multiplied to give weight to the number of parts flowing between departments, as well as the distance between the departments. (Another method can be to multiply the actual distance with the material flow score).

Number	Presenting
1	Main Store
2	Kit Inspection
3	Incomplete Kit Storage
4	Complete Kit Storage
5	Floor Stock
6	Assembly Area
7	WIP Office
8	Quarantine Store
9	Subassembly Storage
10	Composite Shop

		To									
		1	2	3	4	5	6	7	8	9	10
From	1		2	0	0	1	0	0	0	0	1
	2	0		1	1	1	1	0	0	0	1
	3	0	1		1	0	1	0	0	0	0
	4	0	0	0		0	1	0	0	0	1
	5	0	1	0	0		2	0	0	0	2
	6	0	1	0	0	0		0	1	1	0
	7	0	0	0	0	0	0		0	0	0
	8	0	1	0	1	0	1	0		1	0
	9	0	1	0	0	0	0	0	0		0
	10	0	1	0	0	0	1	0	0	0	

Table 2: *From-To Chart indicating flow between departments*

Although the main store, assembly area and composite shop are not part of the WIP store, these departments will be included to due to their relationship with the WIP store. This will give a holistic approach to the WIP store layout that will ensure that parts flow effortlessly between departments.

		To									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
From	**1**		14	0	0	7	0	0	0	0	5
	2	0		1	1	1	1	0	0	0	1
	3	0	1		1	0	1	0	0	0	0
	4	0	0	0		0	1	0	0	0	2
	5	0	1	0	0		2	0	0	0	2
	6	0	1	0	0	0		0	1	1	0
	7	0	0	0	0	0	0		0	0	0
	8	0	1	0	1	0	1	0		2	0
	9	0	1	0	0	0	0	0	0		0
	10	0	2	0	0	0	1	0	0	0	

Table 3: *From-To Chart weighted with distance scale*

Values concerning the main store where affected by giving weight to the distance between the departments. The other values mainly remained unchanged. The information gathered in the From-To chart will later be used in the development of alternative block layouts.

11.1.4 Activity Relationship

The activity relationship chart is used to indicate the need for closeness due to the dependence and interactions between the departments. Table 4 shows how close the department should be, and table 5 shows the reasoning behind the given rating.

Closeness Rating	
Value	**Closeness**
A	Absolutely Necessary
E	Especially Important
I	Important
O	Ordinary Closeness okay
U	Unimportant
X	Undesirable

Table 4: *Closeness Rating Index*

Reason behind closeness value	
Code	**Reason**
1	Flow of parts
2	Convenience
3	Inventory control
4	Communication
5	Same personnel
6	Cleanliness

Table 5*: Reason behind closeness rating*

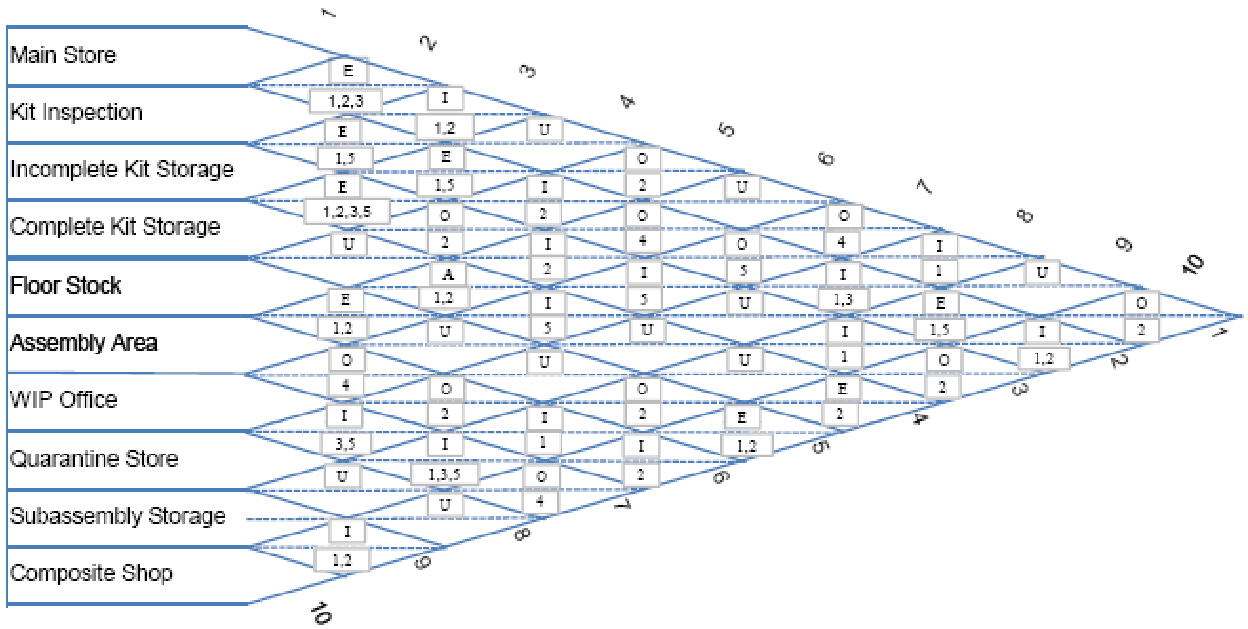

Figure 8: *Activity Relationship Chart*

This activity relationship chart will give guidance to make unbiased changes to the current facility layout to fulfil the needs of the production environment. This chart also shows the advantage of combining the main and WIP store. Since the activity relationship chart is based on subjective ratings, it is accepted that input is needed from more than one individual to obtain a more accurate relationship chart.

11.1.5 Space Requirements

A space relationship diagram was constructed to simulate the space requirements in each department and workstation. The lines represent the two way traffic between departments and areas. The frequency and material quantities could not be calculated accurately due to the make-to-order nature of the business, but the line thickness gives an indication of the observed traffic volume. This data was gathered using the current layout as a gauge for calculating the space requirements. The size of the blocks roughly represents the space requirement of each department; from which space templates can be obtain to determine alternative block layouts of the facility. The WIP office is indicated in the diagram but there is no flow of parts between the WIP office and the rest of the facility. It is included due to the convenience it holds for the staff.

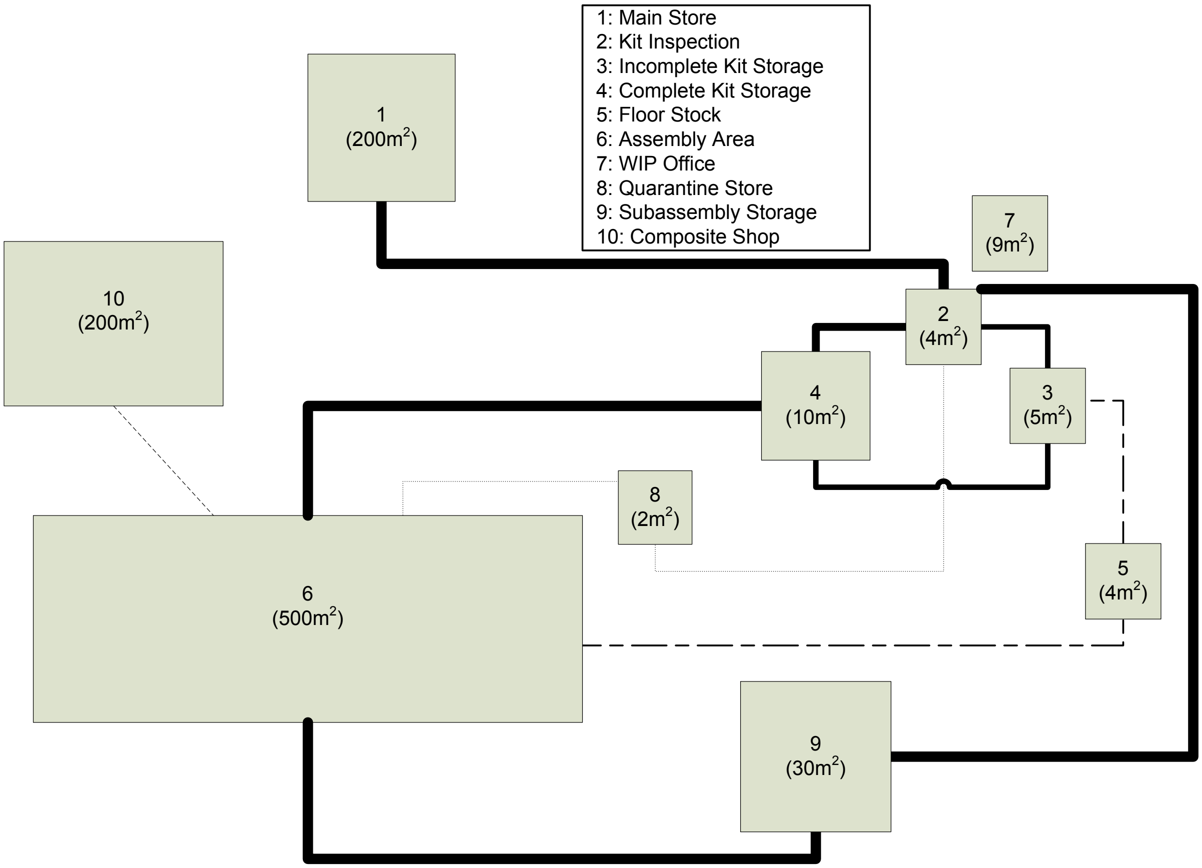

Figure 9: *Space Relationship Diagram*

Now that the flow of parts in the facility, the relationships between the activities and the space requirements are known, alternative block layouts can be constructed to improve the layout of the facility.

11.1.6 Alternative Block Layouts

To determine an optimal layout of a facility a number of alternatives must first be generated each with its own distinct advantage. The alternatives range from minor adjustments to the existing facility, to construction of a brand new facility. The alternatives are presented in block layouts which represent the space requirements of each department with attention given to the traffic between departments, existing stair cases, exits/entrances, logical flow of material and optimal use of existing space.

The process up to now describes a framework to construct or improve a layout manually, where experience and intuition gives the best results. An algorithmic approach will be followed to help to determine optimal block layouts. Algorithms will not only help to improve the layout but will also provide objective criteria to facilitate the evaluation of various layout alternatives that may emerge in the process. The computer generated outputs can then be massaged into practical layouts using the above mentioned intuition.

The type of algorithms used will be limited to those that use qualitative data obtained from a from-to chart. This approach is followed based on current trends that appears to be toward algorithms that use a from-to chart, which generally requires more time and effort to prepare but provides better information on part-flow. The way in which the algorithms calculate the optimal layout is beyond the scope of the document, only relevant information regarding the input data as well as some advantages or drawbacks will be discussed in the document.

The objection function of the algorithms will be limited to a distance based objective which is ideally suited to the input obtained from the from-to chart. This means that the objective of the algorithm is to minimize the cost per unit time for the movement of parts between the departments. The distances considered in the objection function may be altered between Euclidean or Rectilinear distances.

The first core algorithm that will be used is the Computerized Relative Allocation of Facility Technique (CRAFT) using a two-way (pair wise) department exchange method, relying heavily on its high path dependant heuristic to present an optimal layout. Its only weakness is that it rarely generates department shapes that result in straight uninterrupted aisles as desired in final layouts.

The second core algorithm that will be used is BLOCPLAN where the departments are arranged in bands. The number of bands will be changed to get optimal layouts, (typically 2-3 bands gives the best results) but the widths of the bands will be unrestricted and allowed to vary.

The third core algorithm will be Simulated Annealing (SA) which is a relatively new concept in optimization. This optimization technique was derived from the analogy between statistical mechanics and combinatorial optimization problems, where the analogous objective function is achieving the low-cost/energy point in the material annealing schedule. The primary strength of SA is that while trying to improve a layout it may accept a non-improving solution to allow the algorithm to explore other regions of the solution space.

The core algorithms mentioned above can be combined to get a more balanced optimal layout improvement.

Six simulations were run, each combining two types of algorithms. The following is the results obtained by these simulations:

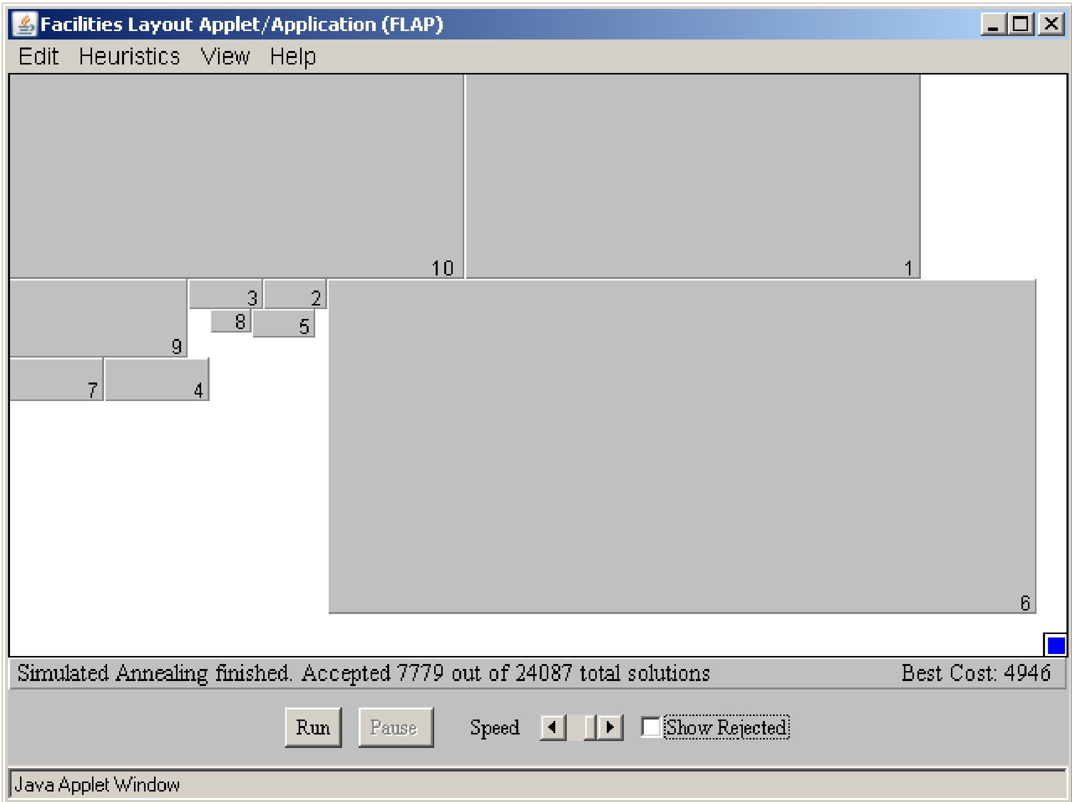

Figure 10: *Result from combining SA with Row-Fit (Alternative AA)*

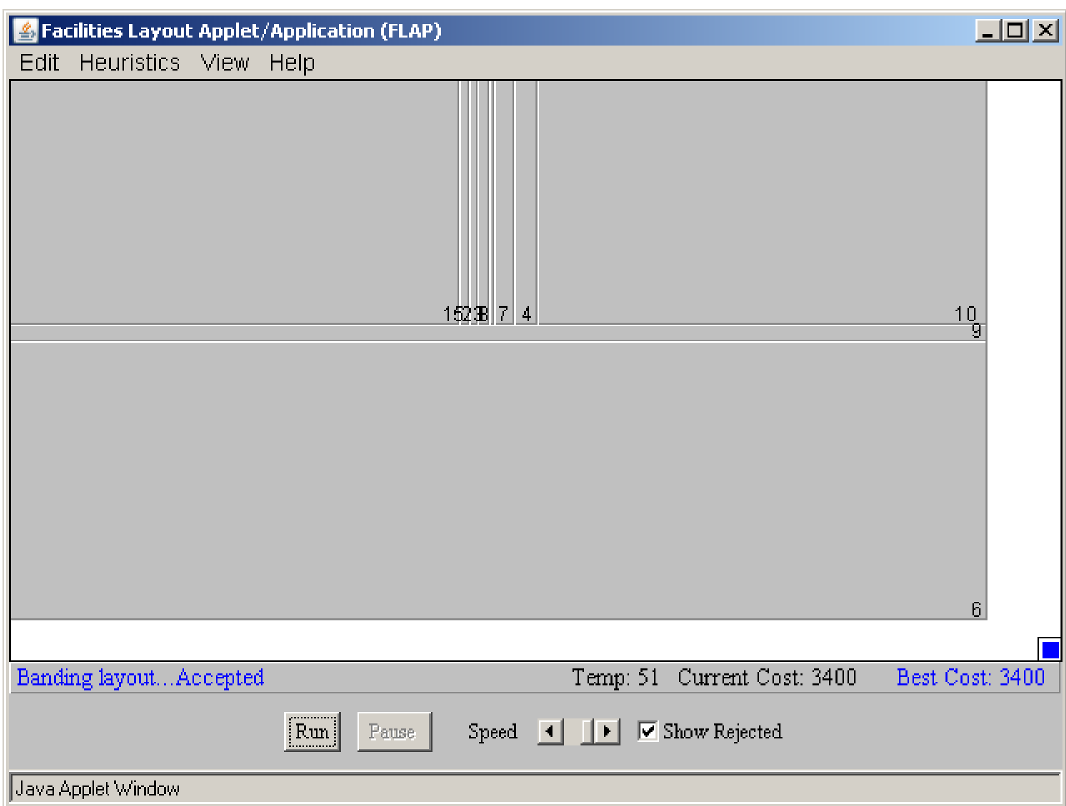

Figure 11: *Combining SA with a 3 band BLOCKPLAN (Alternative BB)*

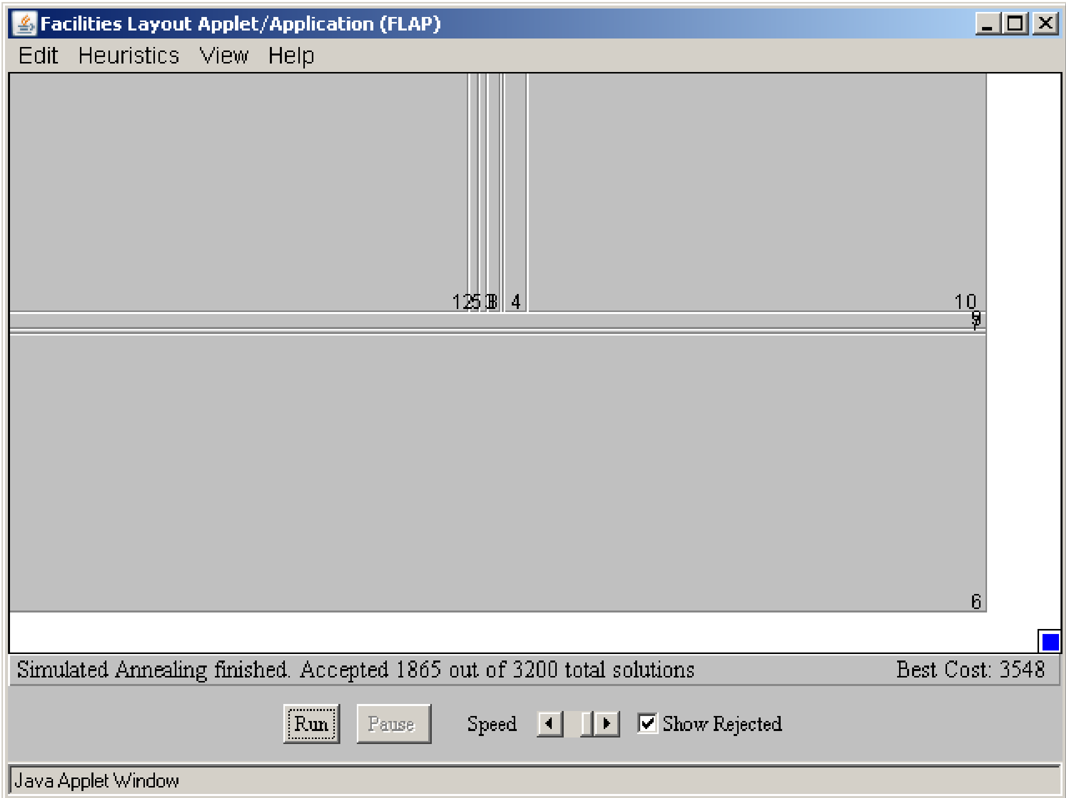

Figure 12: *Combining SA with a 4 band BLOCKPLAN (Alternative CC)*

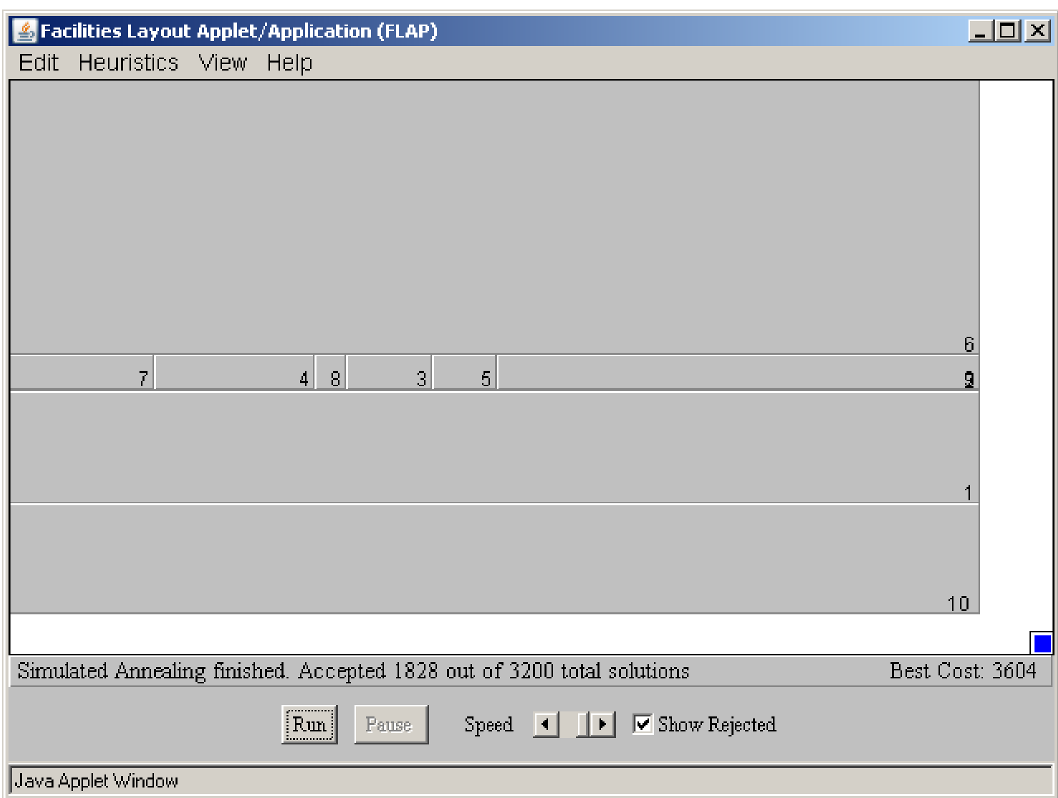

Figure 13: *Combining SA with a 5 band BLOCKPLAN (Alternative DD)*

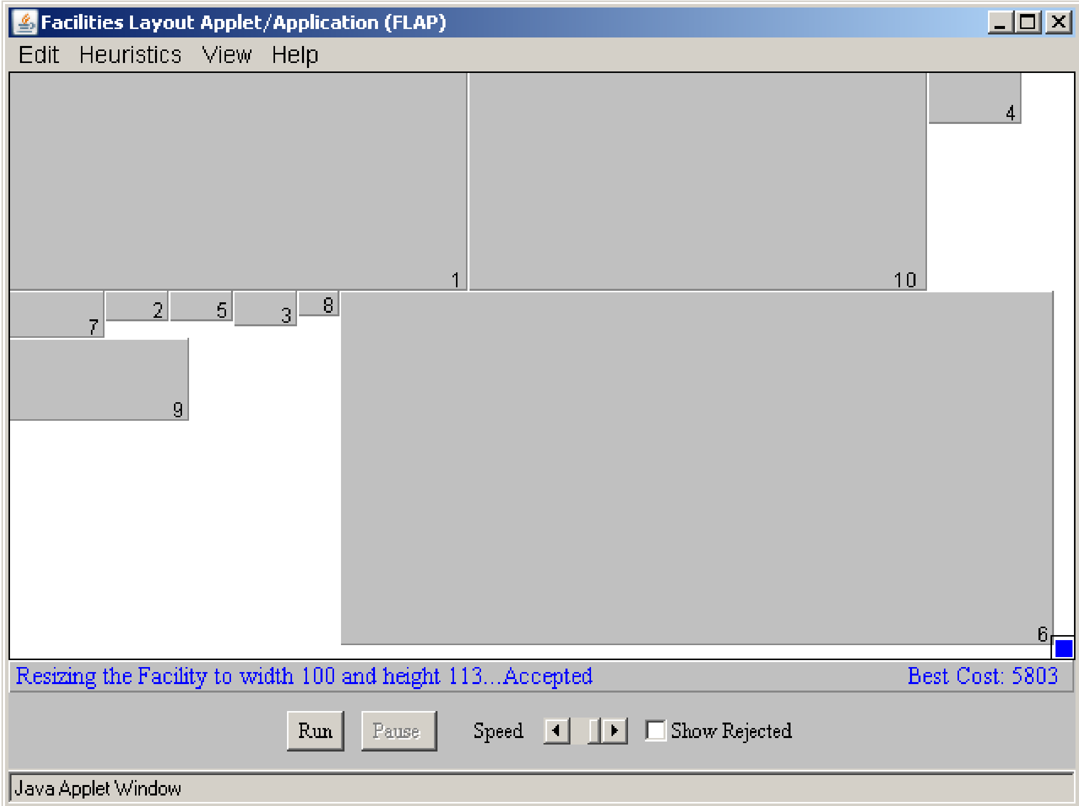

Figure 14: *Combining CRAFT with Row-Fit (Alternative EE)*

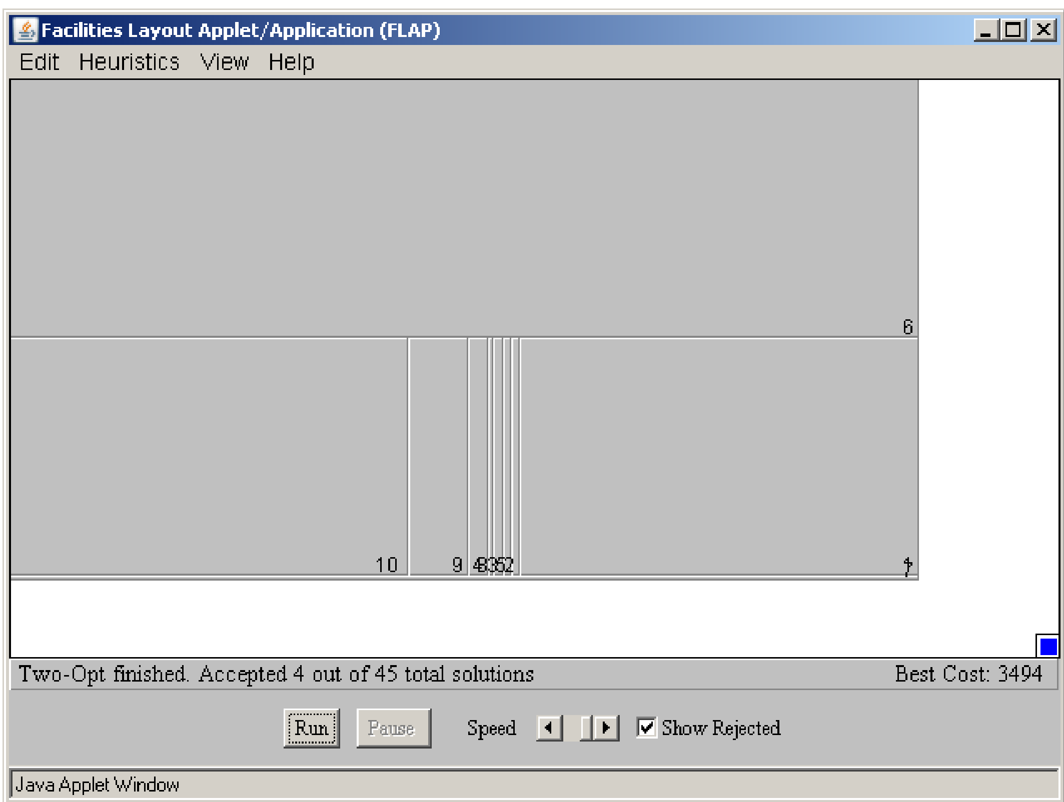

Figure 15: *Combing CRAFT with a 3 band BLOCKPLAN (Alternative FF)*

All of the simulations seem to cluster the main store, kit inspection, and incomplete kit storage together. This indicates that it is vital to group the activities regarding the kitting process together. This grouping is followed by placing the complete kit storage, floor stock, assembly area and WIP office nearby this grouping. The quarantine store, assembly area, and subassembly storage seems to get closeness preference in some of the simulations, where the composite shop rarely shows preference to any department.

11.1.7 Evaluation of Alternative Block Layouts

The Weighted Factor Comparison method can be used to scrutinize and investigate the different alternative block layouts and to select the best layout. Evaluation criteria were firstly generated and weight values assigned to them. The Economic Comparison was omitted from the analysis procedure because of the make-to-order nature of the business. There was unfortunately no accurate way to forecast the number of orders or the profit made, because order prediction would not be accurate with the use of historical data. The following table shows the evaluation criteria which will be used in the weighted factor comparison.

Evaluation Factors	
A	Implementation Cost
B	Material Flow
C	Space Utilization
D	Duration of implementation
E	Layout Flexibility

Table 6: *Criteria used to evaluate alternative layouts*

Weights were assigned and calculated by the use of a Weight Factor Calculation Matrix as seen below. Basically the different factors are compared to each other and their importance represented by their presence in that specific block. For instance; material flow was compared to implementation cost. It was decided that the implementation cost is more important than material flow by a factor of 1, and thus the value of 1A was assigned to the specific block in the matrix. The time it takes to implement the proposed layout will bear the most weight of all the criteria, because production will be less influenced by a layout that implement fast.

Weight Factor Calculation Matrix						
Factor						
A	B	C	D	E		
	A	*2A*	*4D*	*A*	**A**	**Factor**
		B	*D*	*B*	**B**	
			4D	*2E*	**C**	
				2D	**D**	
					E	

Table 7: *Weight Factor Calculation Matrix*

After all the factors were compared, the total occurrence for each factor was counted across the matrix. The amount of occurrences of a factor indicates the weight that needs to be assigned to each evaluation factor. Next the weighted factor comparison table was filled in. All alternative layouts can now be evaluated and a rating out of 10 be given to each layout depending on how they met the evaluation criteria. A score can be generated by multiplying the rating with the weight of each factor.

WEIGHTED FACTOR COMPARISON FORM										
Company: Denel **UAVS** **Description of Investment: Improved UAV Facility Layout**										
			Layout Alternatives							
Factor		**Weight**	**AA**		**BB**		**CC**		**DD**	
			Rating	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
A	Implementation Cost	4	5	1	1	0.2	1	0.2	3	0.6
B	Material Flow	2	8	0.8	5	0.5	4	0.4	8	0.8
C	Space Utilization	1	9	0.45	0	0	0	0	8	0.4
D	Duration of implementation	11	7	3.85	1	0.55	1	0.55	4	2.2
E	Layout Flexibility	2	7	0.7	5	0.5	5	0.5	7	0.7
Total		**20**		**6.8**		**1.75**		**1.65**		**4.7**

** The score is calculated by multiplying the rating with the fraction obtained from dividing the factor weight with total weight.*

Company: Denel **UAVS** **Description of Investment: Improved UAV Facility Layout**								
			Layout Alternatives					
Factor		**Weight**	**EE**		**FF**		**Current Layout**	
			Rating	**Score**	**Rating**	**Score**	**Rating**	**Score**
A	Implementation Cost	4	1	0.2	3	0.6	10	2
B	Material Flow	2	6	0.6	5	0.5	3	0.3
C	Space Utilization	1	5	0.25	5	0.25	7	0.35
D	Duration of implementation	11	2	1.1	1	0.55	10	5.5
E	Layout Flexibility	2	8	0.8	5	0.5	5	0.5
								(1.15)
Total		**20**		**2.95**		**2.4**		**8.65**

Table 8: *Weighted Factor Comparison Table*

The layout(s) with the highest score together with the Activity Relationship chart and current layout can now be used as guidance to “massage” the current layout to form a realistic and implementable layout.

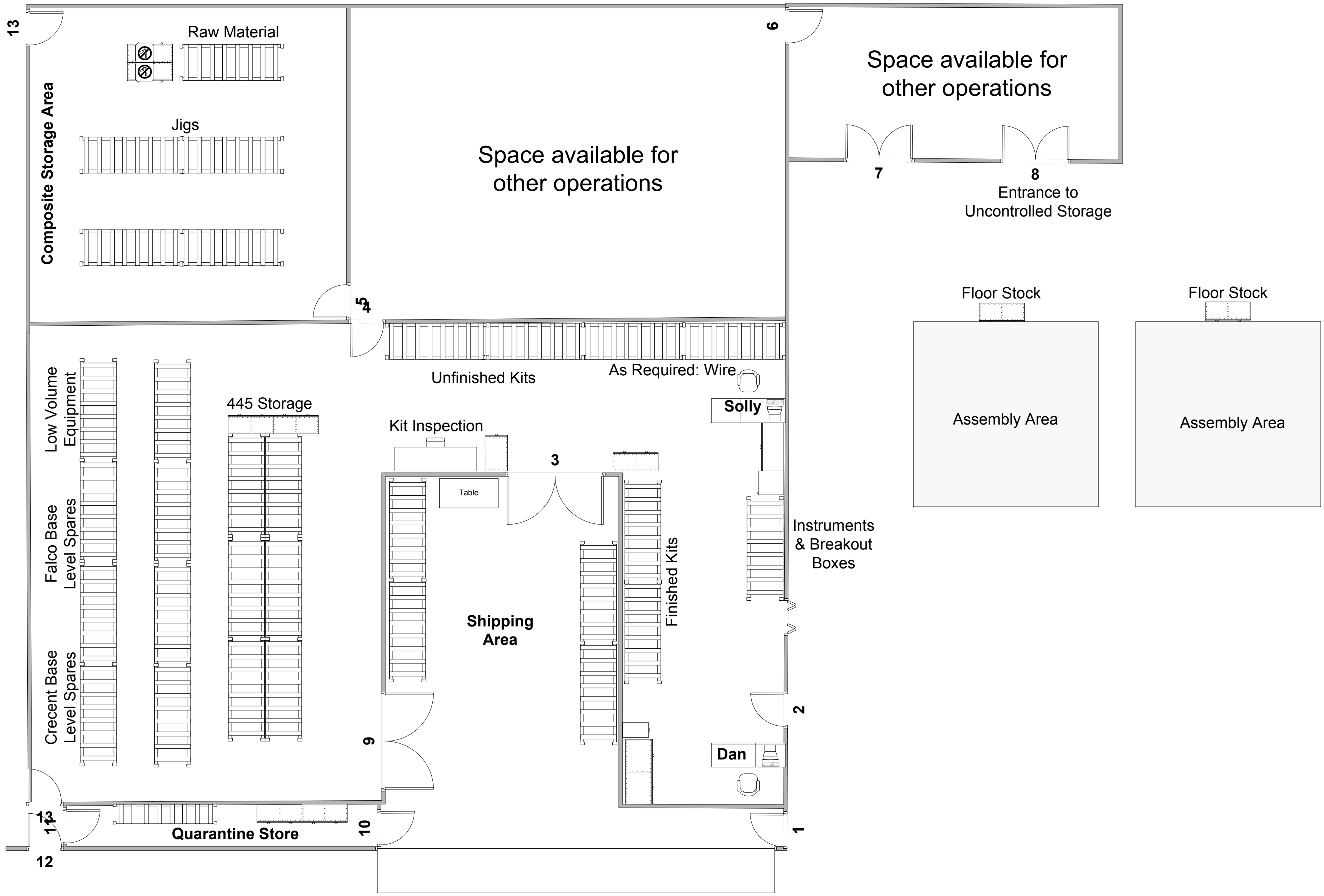

Figure 16: *Final Layout (Phase1) after "massaging"*

The new layout is referred to as the phase 1 layout. During phase 2 the main store's functions such as binning and goods receiving will be incorporated into the store to form a more optimal store layout. These functions can be implemented in the areas which are currently labelled as space available for other operations. When these functions are incorporated, the shipping area would also play the role of goods receiving.

Fortunately no major changes had to be made to achieve the goals for the new layout. Access to the store is through door 2, where there is no obstruction in material flow as was the case in the initial layout. There is no more need for technicians to enter the store, because instruments and breakout boxes are stored next to the service counter. Also floor stock was moved to mobile storage units on the line. This ensures that only the store personnel have access to the store and guarantees extreme control over the inventory. Areas in the store are now specifically assigned to certain needs and functions, and provision was made for storage of quarantined assemblies as well as composite storage. The space for finished kits was increased to cater for bigger kits and future increase in production. An increase in the kit inspection area will enable personnel to perform the inspection with greater ease and decrease the time required for inspection while decreasing errors in the kits. The new layout remains flexible enough to cater for future needs.

11.1.8 Managing Layout Change

Now that the layout is finalised it can be implemented, but this process must also be executed with care. The management of change already started in the investigation phase of the facility layout. Focus was given to give all stakeholders in the WIP store the freedom to raise their opinions regarding problems/improvements. When you get the buy in from all stakeholders from the beginning, the struggle for change is halfway won.

The 5S visual management system will play a prominent role in the transition towards the new layout. The clean up or sorting phase will be gradual to ensure no vital material is accidentally discarded. The WIP store manager will systematically work through the sections of the store to identify unnecessary material. This material will be placed in a transition area for a certain amount of time, where all stakeholders have access to it. Any stakeholder passing this material can make a judgement whether the material must be kept or discarded. Material that is judged to be kept can then be formally booked back into the store for further operations, otherwise the material is scrapped and discarded.

11.2 Improving SAP usage

Whether or not the suggested improvement in the WIP layout is done, there are still opportunities to eliminate waste by using SAP.

11.2.1 Create Virtual Quarantine Store

Currently kits are quarantined if they encounter problems on the line which cannot be fixed immediately. Typical cases are when a part shortage is detected (which can be a BOM or human error) on the line, or rework is needed on a part. If the kit is quarantined the technician who worked on it needs to manually track the kit's progress. If a virtual store is created for the quarantined kits, it will increase visibility of the kits and ensure that work on the kit can be resumed as soon as possible.

11.2.2 Identify Empty Bins

Currently the eye ball technique is used to look for empty bins to bin new material. The SAP system can be used to identify empty bins. This will reduce wasted time to search for empty bins.

11.2.3 Integrate Machine Readable Information Technology

The real time data processing function of SAP is currently under utilised and although most of the employees have access to the system, it is only used for referencing purposes. Machine Readable Information (MRI) technology such as bar coding can be implemented to capture key data concerning the status of material. By doing this material will be more visible in the facility, reducing picking errors, assembly errors and reducing wasted time in manually keeping track and marking of kits and inventory.

Due to ISO 9000 standards, MIL-STD-130L (US Department of Defence) and aerospace market adoption the best identification method to use is a 2D Data Matrix code. This code can store 25 to 100 times more information into a smaller area than conventional linear bar codes. This will make it possible to mark 99% of the parts with this technology. This bar code type also has the best accuracy, where it achieves a worst case accuracy of 1 error in 10.5 million readings. Parts such as the propeller receive a peen marking already applied by the supplier.

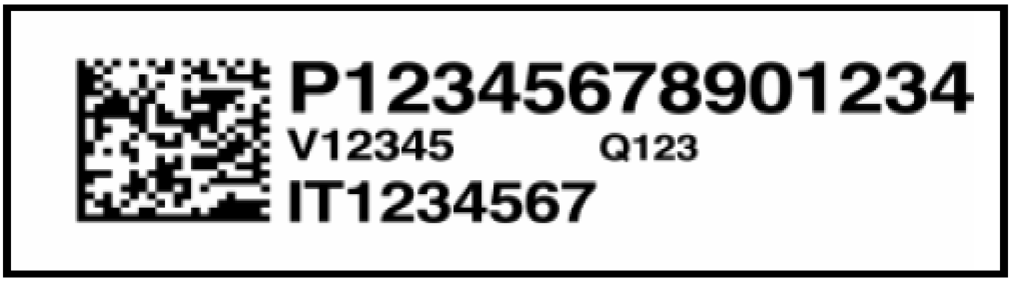

Figure 17: *A Data Matrix code with human readable code*

Requirements:

- The bar code must be printed on an adhesive label so that it can be applied and removed from sensitive parts.
- The system must implement portable marking and reading devices
- The chosen system must be compatible with SAP
- The label must contain both machine and human readable code

Further investigation is needed on the details of such a system when the solution is to be pursued due to technology enhancements and variety of products on offer.

11.3 Improving Binning & Order Picking Operations

When binning new material in empty bins as stated above, the old material associated to that bin are released and associated with the new material. By doing this the capacity of the bins are utilised more efficiently. Once a bin is empty it is reasonable to assume that no more of that material will be ordered, because only the material required for a contract is ordered. It will thus be a waste to allocate that bin to that material until the next contract is received.

The use of bucket brigades will increase the pick rate, and reduce errors in picking. Bucket brigades are a way of organising workers in an assembly line fashion so that the line balances itself. The way bucket brigades work is by letting each worker picking the list to completion. When the last worker finishes his pick list he does not start at the beginning, but moves upstream to take over his predecessors work. The predecessor then takes over his predecessor's work and so on until the first picker's work is taken over and he can then begin to pick a new kit. Thus workers maintain their sequence in a line without passing each other. The fastest workers are placed at the end of the line to ensure that the work is pulled through the system. At first some upstream workers might get held up by downstream workers, but they must just simply wait for their successor to move so he can resume his work. This waiting must not be feared, seeing as this is the way the line balances itself by moving workers to their optimal position in the lines.

Benefits of bucket brigades:

- Reduced planning is needed, the line balances itself
- Production becomes flexible and agile, without any motion study
- Increased throughput due to spontaneous optimal division of work

Anderson Merchandising implemented a two week trial and achieved a 20% increase in pick-rates and a 90% reduction in the variance of pick-rates by picking orders from paper. At Readers Digest picking errors dropped 35% by using bucket brigades under a pick-to-light system. And Ford Customer Service Division recorded a pick rate increase almost weekly and the last measurement was over 50% faster than the original pick rate without bucket brigades. Details are available from the Warehouse & Distribution Science website < www.warehouse-science.com/>.

11.4 Improving Production Scheduling

Currently the production works as follow. Let's assume a new order is placed for 5 aircrafts. The procurement will order exactly the right amount of parts needed to assemble the 5 aircrafts, but it will also include operational spares that were negotiated in the contract.

When the production schedule is set up, a technician is assigned to assemble the entire batch of a particular subassembly. This includes the 5 subassemblies plus the operational subassemblies. If only the 5 needed subassemblies are schedule first and the operational subassemblies scheduled when the load on the technicians are low, one can level or smooth the production. Typically the workload on the technicians is very low during the last stages of a contract when the aircrafts are being flight tested etc.

If you go one step further and schedule each of the 5 subassemblies individually one can then reach a better fit to the final assembly that takes place. One must keep in mind that the aircrafts in the final assembly bays are not in the same state of completion, and this fact can be used to pull the subassemblies. The process of production levelling is known as Heijunka.

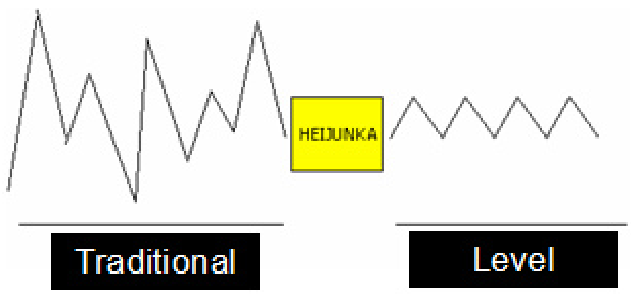

Figure 18: *Heijunka stabilises production*

By following this approach the right assemblies are done at the right time. If you schedule the subassemblies individually one can then operate on a *make one, check one, move one on* basis (MO-CO-MOO). This is in accordance with lean manufacturing and increases the quality control of the products. This also reduces the risk to incur penalties due to late delivery, because the important subassemblies take place first. If a schedule slip occurs the chances are that it will be on spares which are not immediately needed when the system is delivered to the customer.

11.5 Other possible improvements

- Making extensive use of Microsoft Project to make all facets of the production process more visible. If the UAV store uses this information, they can give priority to kits as well as acquiring the data packs in advance while waiting for the kits to be picked. The planners can use the production schedule to monitor the rate at which they issue the kits.

- Production readiness reviews can be considered to reduce the number of errors on the Bill of Materials (BOM) to acceptable levels. A correct

BOM will minimise the possibility of any defects keeping the technicians from successfully completing their assemblies.

- Banning all non value adding activities such as the “post office” activities from the WIP store.
- Each employee can be trained in quality control and given the permission to take corrective action on perceived errors. This will result in the need for less dedicated quality control staff and increase the chances of detecting an error high up in the value stream. This also increases the quality control chances which are needed in such a specialised field of manufacturing. Depending on the type of operation extensive use must be made of the 7 tools of quality control namely: flow diagrams, histograms, Pareto charts, scatter diagrams, fishbone diagrams, run charts and control charts.

12. Review process improvements

After every suggested improvement is implemented, the changes must be reviewed to evaluate their actual impact versus the planned impact. This will aid in the Lean thinking of continual improvement.

13. Conclusion

It is clear from the investigation and development of proposed solutions that the biggest gain would be from implementing a new store layout. This is due to the non value adding nature of a store environment. By implementing the new layout, lower inventory levels can be achieved while wasted time will significantly be reduced. This layout will also decrease wasted space and material movement and increase the space utilisation and material flow.

The possible benefit to gain by implementing the entire improvement framework includes:

- Reduce material handling cost by 10%-30%
- Increase picking rates with 10%
- Reduce variance in pick-rates with 20%
- Reduce picking errors with 70%
- Increase material visibility
- Increase quality control

Due to the reduction of waste in the system, production and cycle times will improve. This will result in faster completion of contracts which will automatically result in receiving payment sooner. This will reduce the time Denel UAVS has to carry the large inventory cost of the expensive aircrafts.

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Addendum A:

Part No.: LCE-43000/5			**Kit Description:** Engine Int. Box	
Order No.:	1000 62146		**Serial no.:** 410-413	
Date	**Time**	**Person Commenting**	**Comment/Kit status**	**Defects on Line**
2008/04/23	12:00	Solly	Kit received from main store	
2008/04/25	13:50	Solly	Kit from production store	
2008/05/19	10:30	Solly	Kit inspection not complete	
2008/05/21	09:00	Naphtali	Kit to production + inspection	
2008/05/21	10:00	Naphtali	Signal + ignition PCB build/assemble	
2008/05/22	08:00	Naphtali	Coating of signal + ignition interface PCB	
2008/05/22	13:00	Naphtali	Need to update BOM, add 1 of item 8 (LCE-43019/12)	1
			, i.e. we must have QTY=5 of spacer 9.1mm	
2008/05/22	14:00	Naphtali	Modify 10mm to be +- 9.1mm	Assume 1
2008/06/06	12:00	Naphtali	Signal PCB assembly	
2008/06/10	14:50	Naphtali	Heat sink assembly + power PCB assembly	
2008/06/11	08:00	Naphtali	Assemble EIB 410-413	
2008/06/12	08:00	Naphtali	PCB test	

Table 9: *Kit Tracking*

Shortages to Line			
Part No.	LCE-43000/5	**Description**	Engine Int. Box
Order No.	100062147	**Serial No.**	529-533
Part No.	**Description**	**Quantity**	**Remarks**
LCE-43012/1	Support	6	Issued on 490481798 (received 17/06/2008)
LCE-43002/5	PCB, EIB signal	5	Issued on 490482538 (received)
07-021116-C	Connector 3-Way	5	At Quality (received 19/05/2008)
LCE-43018/3	Heat sink	5	Delivery date 31/05/2008 received 10/06/08)
	Total shortage	26	

Table 10: *Shortages in kits due to WIP store problems*

Addendum B:

Material handling Checklist

			To correct this we need:				
		Condition exists here	Supervisor attention	Management attention	Analytical study	Capital investment	Comments
1	Delays in material moving	x		x			
2	Excessive material on hand	x		x	x		Mostly in-process materials that build up
3	Production equipment idle for material shortage						
4	Long hauls	x			x		Main to WIP
5	Cross traffic						
6	Manual handling	x					Almost all handling done by hand
7	Outmoded handling equipment						
8	Inadequate handling equipment						
9	Insufficient handling equipment						
10	Unbalanced sequence of operations	x			x		Main push kits
11	Idle handling equipment						
12	Obstacles to material flow						
13	Material piled directly onto floor	x	x				
14	Poor workplace layout for material						
15	Disorderly storage	x					Absolute material between new
16	Cluttered isles	x				x	
17	Cluttered workspace						
18	Crowded dock space						
19	Motor truck and Railroad car tie-up						
20	Manual loading techniques	x					Almost everything is done by hand
21	Excessive waste in "cube" storage						
22	Excessive isles						

23	Operations unduly scattered	x		x			Main & WIP store far apart
24	Poor location of service areas						
25	Lack of in-plant container standardisation	x	x				Material too big to be containerised
26	Lack of unit load technique						Material too big to be unitised
27	Excessive MH equipment maintenance cost						
28	Rehandling	x			x	x	All kits are rehandled
29	Handling done by direct labour	x		x			All handling
30	Operators travelling for supplies, material						
31	Supplies moved by poor techniques						
32	High indirect payroll						
33	Material waiting for papers	x		x			Build history docs
34	Excessive demurrage						
35	Unexplained delays						
36	Idle labour						
37	Inspection not properly located	x			x	x	No inspection at main, only at WIP
38	Excessive scrap						
39	Hazardous lifting by hand						
40	Misdirected material						
41	Clumsy, dangerous, home-made handling rigs						
42	Lack of standardisation on handling equipment						
43	Long travel distance for material, equipment, personnel	x		x			Main & WIP store
44	Backtracking of material						
45	Non-standard process routing						
46	Opportunity for group technology layout						
47	Opportunity for product layout						
48	Opportunity for process layout						
49	No real time dispatching of equipment						
50	No modular MH system						
51	No modular workstations						
52	Automatic identification system not used	x			x		
53	No one way isles	x					This is not a problem no forklift traffic
54	MH equipment running empty						
55	Different things treated the same						
56	Excessive trash removal						
57	Centralised storage						

58	Decentralised storage	x				x	Main store in different building then WIP& production
59	No incentive for MH labour						
60	Low usage of automated MH equipment	x					Production volume to low
61	Variable path equipment used for fixed path handling						
62	System not capable of expansion and change						
63	Low usage of industry						
64	No parts preparation performed prior to manufacturing						
65	No prekitting of work						
66	Lack of automated loading/unloading trailers						
67	Poor MH at workstation						
68	Lack of industrialised truck attachments and below hook lifters						
69	Equipment not matched to load requirement						
70	Manual palletising/depalletising						
71	Lack of equipment for unitising and stabilising loads						
72	Lack of long range MH plan						
73	No short-interval scheduling of MH equipment						
74	Lack of narrow isle and very narrow isle storage equipment						
75	Low bay storage areas						
76	Poor utilisation of overhead space	x				x	Rack to big
77	Single-sized pallet rack openings						
78	No palettes handling of unit loads						
79	Storage in part number series						
80	Randomised storage						
81	Dedicated storage						
82	Crushed loads in block stacking						
83	No ABC storage classification						
84	Obsolete and inactive material						
85	Floor stacked material in receiving, QC, shipping						
86	Isles and storage locations clearly marked						
87	Manual stock locator system						
88	Lack of standardisation in part numbers						
89	Cycle counting of physical inventory						
90	No formal audit program in use						
91	No guards to protect racks and columns						
92	Guided aisles without guiderail entry						
93	Loads overhanging pallet						
94	Excessive floor, rack, and structured loading						

95	Equipment operating at excessive speed						
96	Front-to-back rack members not provided						
97	MH equipment does not fit through doors						
98	No sprinklers and smoke detectors						
99	Hazardous and flammable material not segregated and identified						
100	Lack of ventilation in battery charging area						
101	Entrances and exits not secured						
102	Waste and trash containers located near docks						
103	Inadequate number of fire extinguishers						
104	No contingency plan for fire loss						
105	Sagging load beams and bent trusses on racks						
106	No formal training for MH equipment operators						
107	No preventative maintenance program						
108	No equipment replacement program						
109	No dock levellers						
110	Unscheduled arrival of outbound and inbound carriers						
111	Decentralised receiving and shipping						
112	Inbound material not unitised						
113	Inadequate number of dock doors						
114	Receiving numbers not preassigned						
115	Picking lists not printed in picking sequence						
116	Orders picked one at a time						
117	Aisle lengths unplanned						
118	Excessive honeycombing is storage						
119	Poor quality pallets, not standardised						
120	Manual sorting in order accumulation						
121	Poor work-in-process control						
122	Energy-inefficient lighting						
123	Lights, heaters and fans poorly located						
124	No dock enclosure						
125	Excessive heating, ventilation, and air conditioning for material stored						
126	Poorly insulated walls and roof						
127	Poorly designed enclosures for environmentally controlled areas						
128	Lack of scheduled energy use to reduce peak loads						
129	Unclean Floors						
130	Battery Charging too frequently						
131	Other						