Apex Valves
Facility Layout Optimization

by

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Submitted in partial fulfilment of the requirements for
the degree of

BACHELORS OF INDUSTRIAL ENGINEERING

in the

FACULTY OF ENGINEERING BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

UNIVERSITY OF
PRETORIA

October 2012

Executive Summary

The content of this report is centred upon Apex Valves (Pty) Ltd situated in Centurion, South Africa. Apex Valves is a supplier of plumbing and geyser valves. Their operations take place within four connected factory units and include receiving, storage shipment (warehousing aspects), as well as assembly, testing and packaging (assembly plant aspects).

Space utilisation is currently a challenge for Apex Valves; improved layout and material handling is required. The aim of this project is to generate and define the best solution for optimal layout and process organisation within Apex Valves. Methods to be used include thorough research of warehousing and assembly process objectives, principles and requirements, followed by a Systematic Layout Planning procedure and the appropriate algorithmic computation.

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1. Introduction & Background

Apex Valves South Africa (Pty) Ltd is a supplier of valves for the plumbing and geyser market. In 1997 Apex Valves South Africa was started as a joint venture with Apex Valves New Zealand. Since that time Apex Valves South Africa has shifted over to South African ownership completely. Apex Valves New Zealand no longer has any ownership ties but there is still a close supplier-customer relationship between the two companies.

The company utilizes four factory units situated in Lyttleton, Centurion. One unit is used for accepting deliveries and storing received parts. Two units contain the assembly, testing and selected packaging processes. The last unit is solely used for packaging.

The product range includes LVEV (Pressure Control Valve), VRV (Vacuum Breaker), TV (Tempering Valve), TP (Safety Valve), Drain Cock, LVC (Replaceable Cartridge), and Isotech Valves. All products require assembly, testing and packaging, except the Drain Cock. Drain Cocks are tested, repackaged and shipped to the customer without any assembly involved.

Apex Valves South Africa (Pty) Ltd functions as a warehouse, a packaging facility and an assembly line. Since its instigation, process- and facility layout has been organised by gut feeling and ownership judgement. These are both very valuable approaches to facility setups, since they bring intuition and insight that only experience can add to the operation. However, there is room for improvement through research and optimisation methods specifically aimed at effective material handling, layout and process setup.

2. Problem Statement & Project Aim

Storage and flow of materials within Apex Valves South Africa (Pty) Ltd are deemed inadequate and the cause of lowered efficiency. To measure a change, be it improvement or deterioration, a unit is required. Facility layout and material handling improvement is measured in time saving. Time saving irrefutably leads to cost savings. The aim of this project is to generate and define the best solution for optimal layout and process organisation within Apex Valves. Facility planning will be approached from an engineering solution design standpoint. Operation layout must be improved and material flow must be improved in terms of both warehousing aspects and process aspects within Apex Valves. To create an environment shaped by the rule of time saving is the goal of this project.

3. Project Scope

Apex Valves possesses both warehousing attributes and manufacturing plant attributes. Parts are received and stored. Some parts are simply inspected through sample testing, packaged, and shipped to customers. Other parts require assembly prior or subsequent to testing and then packaging and shipment. Both assembly and packaging requires workstations with personnel, materials and equipment.

The scope of this project begins with order-picking. For effective order-picking stock should be accessible and therefore the storage aspect within warehousing should be examined, improved alternatives should be planned and evaluated; material handling related to order-picking should be improved.

The scope continues to include the assembly, testing and packaging operations of five prominent Apex products. Improved alternatives for facility layout and the accompanying material handling system should be planned, evaluated and selected after thorough analysis of current conditions.

4. Literature Review

4.1 Research Aim

In order to supply an efficient and wholly suitable solution, a thorough exploration of the possible approaches to finding a solution must be done. All applicable elements must be identified, defined and then used to create a structure for the Literature Review to be built on. To fall short in this part of the research may lead to missed opportunity and an ineffectual solution. All available sources will be used to accumulate, compare and select the best method for finding a solution.

4.2 Facility Definition

4.2.1 The Macro View - A Warehouse in the Supply Chain

A comprehensive look at the facility and its improvement goal must start with the widest view. Every company with its facility, or facilities, occupy a niche in the supply chain. They have a defined role linked to the roles of those companies that precede it and those that follow it. The role of Apex Valves includes all elements relating to warehousing and added assembly. Warehouses are responsible for receiving products, storing products, repackaging products if required, and shipping products to the customer. According to Ecklund (2010) there are instances in which warehouses simply add cost or little to no value, to the supply chain; such as cases where products are bought in bulk and no time sensitivity is related to their use; or products are insensitive to transportation costs. For other products warehouses make the supply chain more effective and more efficient. It is more effective to have products in a position close to major markets and the customer; and efficiency is added by consolidation of products for shipment, a reduction in transportation costs and the value added services done by warehouses, such as branding, labelling, assembly, packaging, reverse logistics etc.
The suppliers for Apex Valves include Australia and Lesotho. Apex Valves facilities situated in Gauteng positions the product closer to a major market and their services include checking quality and quantity of items, assembly, packaging (with labelling and branding), consolidation of products and shipment.

TABLE [illegible] use Value-Adding Roles	
Value-Adding Roles	**Trade-Off Areas**
Consolidation	Transportation
Product mixing	Order filling
Service	Lead times, stockouts
Contingency protection	Stockouts
Smooth operation	Production

Table 1Warehouse Value-Adding Roles (Coyle et al, 2002)

4.2.2 Basic Operations

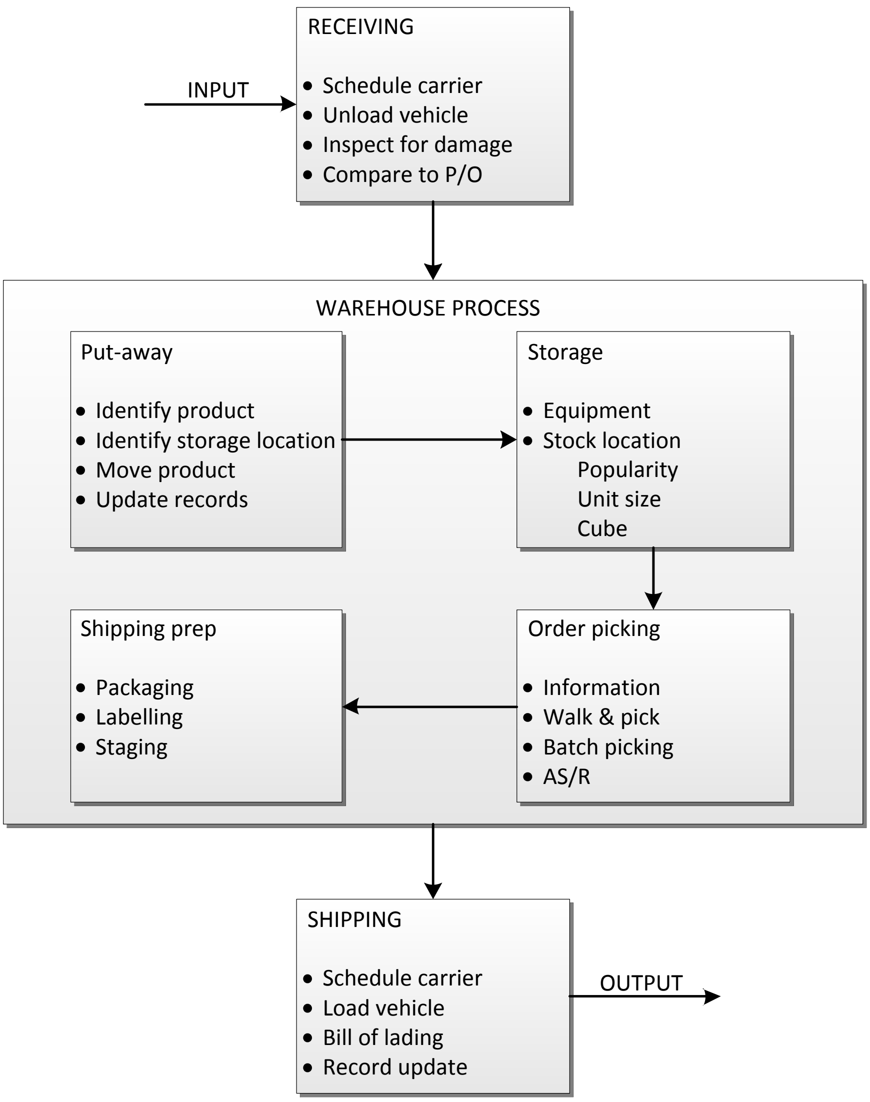


Figure 1Basic Warehouse Operations (Langley et al, 2008)

As maintained by Langley et al. (2008), there are two main operations in a warehouse; movement and storage. These operations are separated into six basic operations:

1. Receiving

   This includes scheduling delivery for maximum labour productivity, unloading goods from the truck to the dock, inspecting goods for damage and comparison to Purchase Order and signing the delivery note.

2. Put-away

   Once goods are delivered they are moved to storage. The product is identified, the allocated storage area for the specific product is identified and the product is moved. After which storage records are updated.

3. Storage

   Various types of material handling equipment is utilised in storage and also throughout the whole warehouse operation. This is a large and intricate facet of facility management that requires its own detailed description. Popularity, Unit size and Cube are the three stock location criteria. Popularity refers to products that are most frequently retrieved for added services and shipping situated closer the service area and shipping area; the Unit size and Cube criterions suggest that smaller items or items with smaller total cubic space requirements are kept closer to the shipping area.

4. Order picking

   Warehouse personnel are given a pick slip identifying the items required by manufacturing operations or customer orders, and use it to retrieve items from storage. Picking the total number of units of a product on all orders at one time it is called batch-picking.

5. Shipping preparation

   If goods are shipped in pallets they are placed on pallets, secured by strapping or plastic wrap, after which goods are placed on the ground or in storage racks (staged) ready for shipment.

6. Shipping

   Product is moved from the staging area to the loading dock and unto a waiting truck; the carrier signs a bill of lading to indicate receipt of goods; and records of inventory and shipments are updated.

Operations at Apex Valves predominantly conform to the basic warehouse operations set forth by Langley et al. (2008). However shipping preparations are a great deal more extensive at Apex Valves. Products are not only labelled and packaged but also assembled and tested at numerous workstations. This extends the Shipping Preparationoperation to encompass the process of packaging, labelling, staging, assembly and testing.

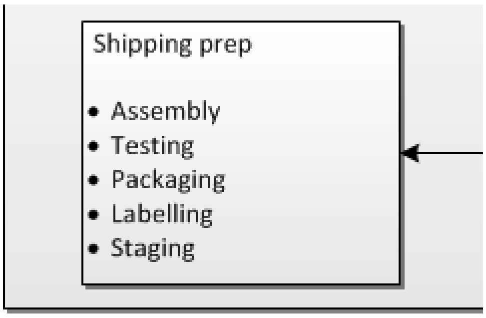


Figure 2 Apex Valves Adjusted Shipping Prep.

4.3 The Facility Planning Process

The Facility Planning Process is related to the facility life-cycle. Throughout the facility's existence it requires continuous improvement and constant adaptation to process and product changes.
Two Facility Planning Processes are set forth by Tompkins et al. (2010).

Winning Facility Planning Process

The winning facilities planning process is a novel method focussed on an organisation's model of success. As phase 1 it places emphasis on the definition of five elements prior to any physical facility planning related activities, namely;

1. Company Vision
2. Company Mission
3. Requirement of Success
4. Guiding Principles
5. Evidence of Success

The second phase of the winning facility planning process encompasses the assessment of the present status, the identification of specific goals, the identification of alternative approaches; the evaluation of alternative approaches and defining the improvement plans.

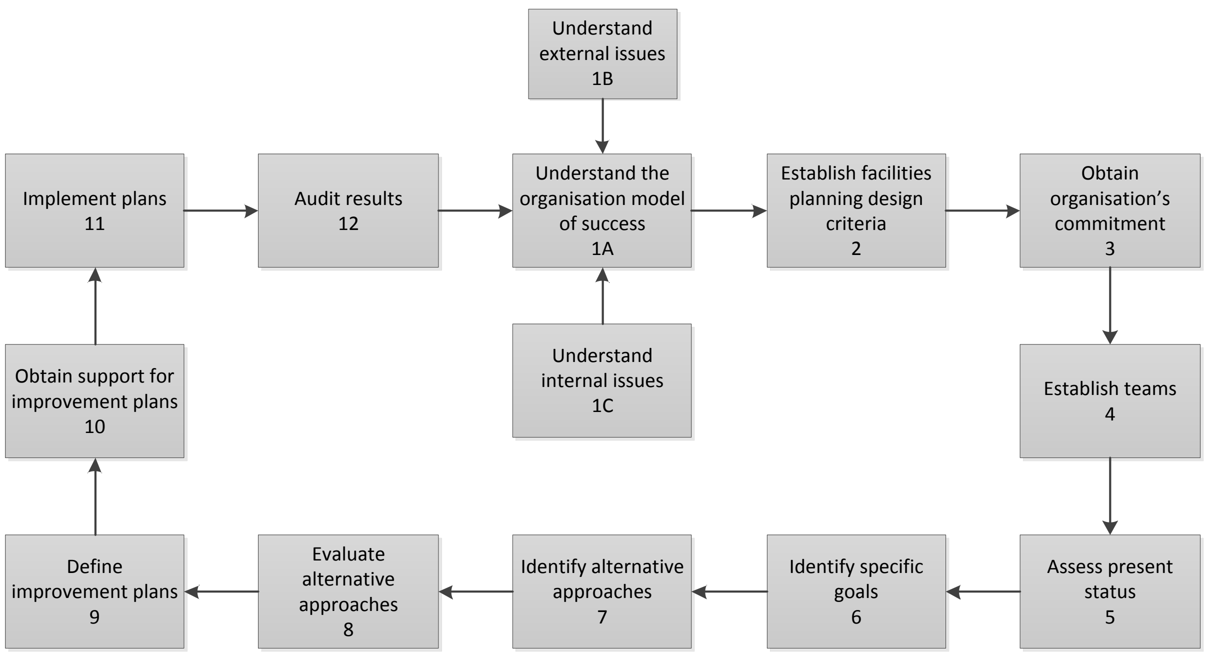


Figure 3 Winning facilities planning process (Tompkins et al, 2010)

Facility Planning Process - based on engineering design process

The facility planning process determined by the traditional engineering design process, as defined by Tompkins et al. (2010), will be used in this project:

Define the problem

1. Define (or redefine) the facility objective

   It is important to quantitatively define the products to be produced or services to be provided by the facility. The level of activity and volume of material related to these amounts should be identifiedand the whole objective should be the leading factor considered in all facility design concepts.

2. Specify both primary and supporting activities for accomplishing the facility objective

   These activities must be specified in terms of operations, equipment, personnel and material flow.

Analyse the problem

3. Determine interrelationships among all activities

   Once it has been determined that a relationship exist between activities the quantitative and qualitative nature of the relationship must be established and recorded. This must be done for all activities.

4. Determine the space requirements of all activities

   To obtain a sufficient space determination all equipment, flow of equipment, material, flow of material, personnel and flow personnel must be taken into account.

Generate alternative solutions

5. Generate alternative facility plans

   The alternative facility designs encompass alternative layout designs, structural designs and material handling system designs.

Evaluate alternative solutions

6. Evaluate alternative facility plans

   Appropriate criteria must be developed to compare and evaluate alternative facility plans. Factors such as cost, length of implementation time, advantages and disadvantages are used.

Select the best solution

7. Select a facility plan

   The best facility plan according to the evaluation results and the facility objective is chosen.

Implement the solution

8. Implement the facilities plan

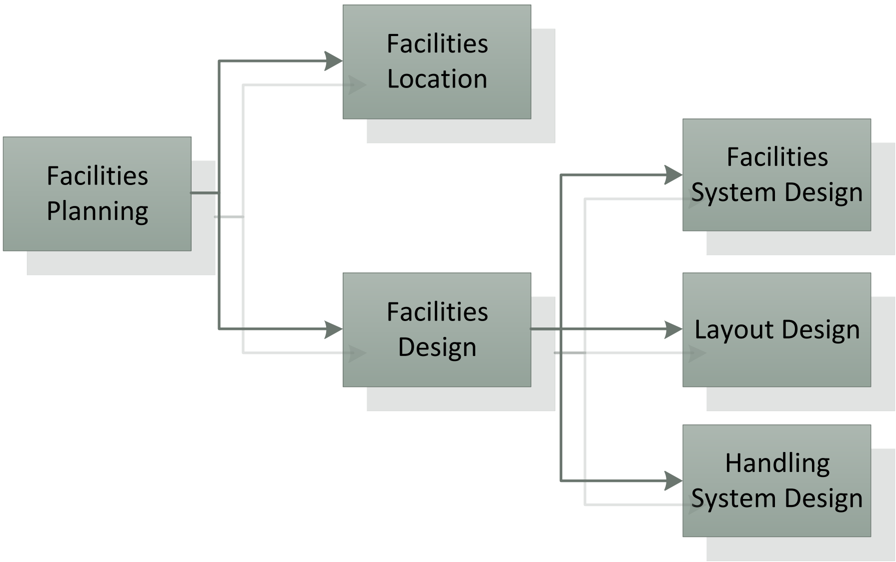


Figure 4 Facility Planning Hierarchy (Tompkins et al, 2010)

4.4 Facility Layout

As previously mentioned Apex Valves possess two areas of operation; warehousing, in terms of receiving, storage, unitising and shipment; and the assembly/packaging process. The following section will entail the objectives, principles and requirements for the two main aspects, Layout and Material Handling, within the scope of warehousing and assembly process constraints

4.4.1 Warehouse Facility Objectives

The basic objectives of layout optimization planning are defined by Slavendy (2001):

- Space efficiency
- Efficient material handling
- Cost efficiency
- Flexibility
- Good housekeeping

In addition to the objectives set forth by Slavendy (2001), ten warehouse layout objectives are provided by Mulcahy (1993):

- Maximising the space utilisation
- Efficient product flow
- Ease of access to positions and inventory rotation
- Reducing annual operation costs
- Improve employee productivity
- Maintain philosophy and direction of the corporate
- Protecting the inventory
- Providing expansion
- Providing safe work environment
- Customer satisfaction

4.4.2 Warehouse Layout & Design Principles

Langley et al. (2008) states the most commonly accepted warehouse design and layout principles:

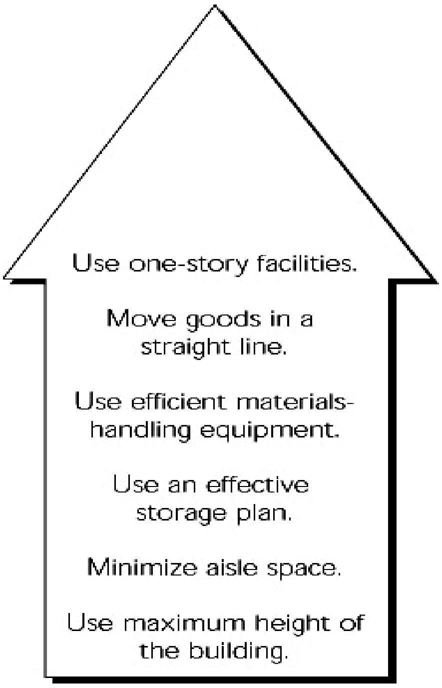


Figure 5 Principles of Warehouse Layout Design (Langley et al, 2008)

The first principle states that a one-story facility should be used wherever possible. This offers more usable space per investment rand and reduces complexity of travel and material handling equipment.Upper storeys may be effectively used for office space and other personnel requirements

The second principle maintains that a straight-line or direct flow of goods is most efficient in a warehouse.

Thirdly, it is important to use the best suited material handling equipment and operations for time and cost saving.

The fourth principle is to use the most effective storage plan, taking space utilisation, accessibility, product safety and travel into account.

According to the fifth principle aisle space should be minimised with due attention to size, type and turning space requirement of material handling equipment. Turnover should also be considered. If the turnover is high and better access is required for order-picking, suitable aisle space should be instigated.

The sixth principle is to make maximum use of the facility height, i.e. the building's cubic capacity. The costs of floor space occupation and the costs of equipment necessary for stacking greater heights should be weighed against each other.

4.4.3 Warehouse Layout Requirements

Space is required for receiving and shipment. It is possible to dedicate a single area to both operations, however, in most cases they are situated in separate areas for efficiency. These areas should consider space for equipmentmovements such as turning around, space for staging and space for inspection. Volume and frequency of throughput is key to determining receiving and shipping spatial needs.

According to Langley et al (2008) "another space requirement in physical distribution warehouses is for order picking and assembly", and the amount of space required depends on the nature of the product, order volumes and materials handling equipment. The layout of this area is critical in view of efficient operations and customer satisfaction. This warehouse requirement links directly to the following section of Process Layout Requirements considered with regards to the assembly, testing and packaging operations of Apex Valves.

In addition to these main areas of space requirements there are three less major considerations: recouping space, office space and miscellaneous space. Recouping space is set aside for the correction of parts that have been compromised, either in functionality, appearance or packaging. Office space and miscellaneous space is allocated to all administrative and personnel requirements.

4.4.4 Process Layout Objectives

The assembly, testing and packaging operations of Apex Valves can be compared to the operations of a manufacturing plant. Manufacturing in its simplest definition is "to make things, usually in large scale, with tools and either physical labour or machinery". At Apex Valves parts are moved from storage to numerous workstations where personnel using tools and machinery commence in a time consuming and value-adding process before packaged parts are moved to the staging area.

The operation layout at Apex Valves conforms to the Production Line Layout (Product Layout) as defined by Tompkins (2010). This layout is based on products moving through the process chain, from one workstation to the next adjacent one.

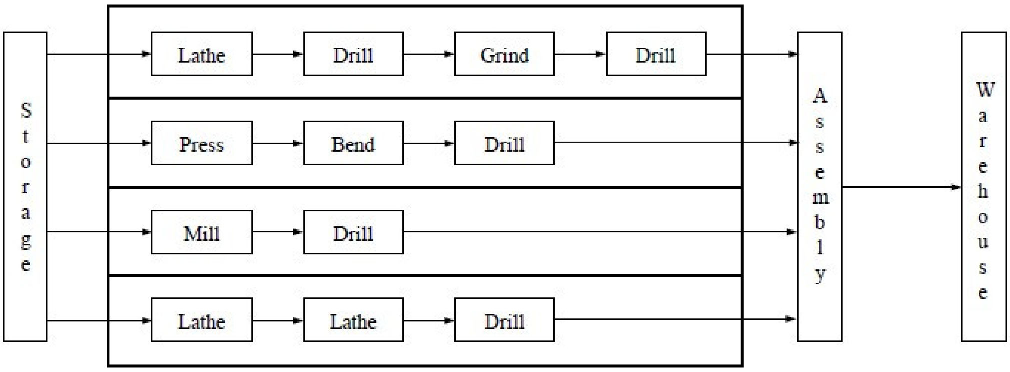


Figure 6Production line product layout (Tompkins et al, 2010)

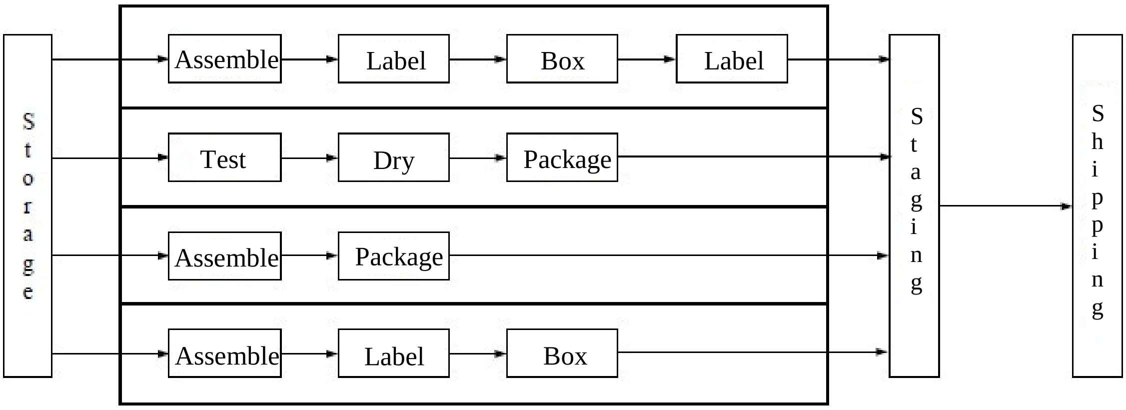


Figure 7 Apex Valves Product Layout

Viewing operations at Apex Valves as defined above leads us to the Plant Layout Objectives set forth by Kumar & Suresh (2009):

1. Streamline the flow of materials through the plant.
2. Facilitate the manufacturing process.
3. Maintain high turnover of in-process inventory.
4. Minimise materials handling and cost.
5. Effective utilisation of men, equipment and space.
6. Make effective utilisation of cubic space.
7. Flexibility of manufacturing operations and arrangements.
8. Provide for employee convenience, safety and comfort.
9. Minimise investment in equipment.
10. Minimise overall production time.
11. Maintain flexibility of arrangement and operation.
12. Facilitate the organisational structure.

4.4.5 Process Layout Principles

Kumar & Suresh (2009) plant layout guidelines with the following principles:

1. Principle of Integration
   The key to a good layout is the optimum utilisation of resources through integration of personnel, materials, machines and supporting services.
2. Principle of minimum distance
   A good layout should facilitate minimum travel or movement for material and personnel. Travel and movement should also, as far as possible, be in straight lines.
3. Principle of cubic space utilisation
   A good layout utilises both horizontal and vertical space.
4. Principle of flow
   Materials must move forward, one-directionally, toward completion, avoiding any backtracking.
5. Principle of maximum flexibility
   Future requirements are considered in designing a sufficient facility layout so that it may be altered with minimal cost and time.
6. Principle of safety, security and satisfaction
   The safety and satisfaction of the workers are always considered in a good layout, as well as the safeguarding of the plant, products and machinery.
7. Principle of minimum handling
   A good layout will keep material handling at a minimum.

4.4.6 Process Layout Requirements

The layout requirements for the assembly, testing and packaging operations are the requirements separate from warehouse layout requirements. These operations are done in separate workstations adhering to the "Product Layout" as defined in section 4.4.4 above.

Tompkins et al. (2010) continues in its layout requirements, characterising each workstation as a facility on its own, since "the broad definition of the term *facility* includes the fixed assets necessary to accomplish specific production objectives" and "a workstation consists of the fixed assets needed to perform specific operations". An effective layout for workstations is important; the productivity of the firm is strongly related to the productivity of each workstation.

According to Tompkins et al. (2010), space and layout requirements within a workstation must consider three elements; equipment, materials and personnel.

Equipment requirements in workstations consist of space for:

- Equipment
- Machine travel
- Machine maintenance
- Plant services

These aspects may be applied to the testing operations of Apex Valves. Space must be allowed for the testing equipment and water tanks, along with their maintenance and the necessary plant services.

Material requirements in workstations consist of space for:

- Receiving and storing inbound materials
- Holding in-process materials
- Storing outbound materials and shipping
- Storing and shipping waste and scrap
- Holding tools, fixtures, jigs, dies and maintenance materials

To determine space for receiving and storage of inbound materials, the size of the batches and the flow of the products through the workstation must be known. The working area size should accommodate in-process materials and space should be dedicated to the placement of finished products awaiting removal to staging and shipment area. Discrete space should be assigned to waste and scrap produced during the operation, as well as space for tools that is accessible but not obstructive.

Personnel requirements in workstations consist of space for:

- The operator work area
- Material handling
- Operator ingress and egress

The method used to perform the operation determines the space needed for the operator and the material handling. An aisle width of 0.75 m between a moving operator and a stationary object is desired. Five guidelines given by Tompkins et al. (2010) aide in designing a suitable workstation for personnel:

1. Workstations should be designed so the operator can pick up and discharge materials without walking or making long or awkward reaches.
2. Workstations should be designed for efficient and effective utilisation of the operator.
3. Workstations should be designed to minimise the time spent manually handling materials.
4. Workstations should be designed to maximise operator safety, comfort, and productivity.
5. Workstations should be designed to minimise hazards, fatigue, and eye strain.

4.5 Material Handling

4.5.1 Material Handling Objectives

Material Handling is comprehensively defined by Tompkins et al. (2010); "Material handling means providing the right amount of the right material, in the right condition, at the right place, in the right position, in the right sequence, and for the right cost, by the right method(s)."

Langley et al. (2008) lists the general objectives of Materials Handling:

- Increase effective capacity of warehouse

  As also mentioned in layout objectives, both horizontal and vertical facility space should be utilised. This minimises operating costs.
- Minimise aisle space

  Aisle width will be determined by the type of material handling equipment used.
- Reduce number of times product is handled

  There are several unavoidable product movements within a firm. Products are moved from delivery vehicles to receiving area, from receiving area to storage, from storage to value-added services, from value-added services to staging, and from staging to carrier vehicle. Products may however be moved numerous times at each area. A well designed material handling system must minimize the number of movements for an efficient flow of materials.
- Develop effective working conditions

  Effective working conditions promote safety of workers and enhance productivity.
- Reduce movements involving manual labour

  Depending on the level of automation of a company any product movement may be manual. As much of the monotonous, short distance movements involving manual labour should try to be eliminated. It is maintained that total automation of material handling is the optimal method; however many factors makes this solution difficult to attain. The best solution is to efficiently integrate manual material handling and automated material handling.
- Improve logistics service

  Effective material handling is vital to getting products to customers in the correct amounts and at the right time. Both inbound and outbound logistics benefit from the efficient movement of goods into the facility, locating stock easily, accurately filling orders and promptly preparing orders for shipment.
- Reduce cost

  Effective material handling increases productivity (more and faster throughput) and in that manner contributes to cost minimisation. Costs will also decrease by utilising space efficiently and misplacing items less of the time.

4.5.2 Material Handling Principles

Principles of Materials Handling

1. *Planning Principle.* Plan all materials-handling and storage activities to obtain maximum overall operating efficiency.
2. *Systems Principle.* Integrate as many handling activities as is practical into a coordinated operations system covering vendor, receiving, storage, production, inspection, packaging, warehousing, shipping, transportation, and customer.

*3. *Materials Flow Principle.* Provide an operation sequence and equipment layout that optimize materials flow.

*4. *Simplification Principle.* Simplify handling by reducing, eliminating, or combining unnecessary movements and/or equipment.

*5. *Gravity Principle.* Utilize gravity to move material wherever practical.

*6. *Space Utilization Principle.* Make optimum use of the building cube.

7. *Unit Size Principle.* Increase the quantity, size, or weight of unit loads or their flow rates.
8. *Mechanization Principle.* Mechanize handling operations.
9. *Automation Principle.* Provide automation that includes production, handling, and storage functions.

*10. *Equipment Selection Principle.* In selecting handling equipment, consider all aspects of the material handled—the movement and the method to be used.

*11. *Standardization Principle.* Standardize handling methods, as well as types and sizes of handling equipment.

*12. *Adaptability Principle.* Use methods and equipment that adapt to the widest variety of tasks and applications, except where special-purpose equipment is justified.

13. *Deadweight Principle.* Reduce ratio of mobile handling equipment deadweight to load carried.
14. *Utilization Principle.* Plan for optimum utilization of handling equipment and labor.
15. *Maintenance Principle.* Plan for preventive maintenance and scheduled repairs of all handling equipment.
16. *Obsolescence Principle.* Replace obsolete handling methods and equipment when more efficient methods or equipment will improve operations.
17. *Control Principle.* Use materials-handling activities to improve control of production, inventory, and order handling.
18. *Capacity Principle.* Use handling equipment to improve production capacity.
19. *Performance Principle.* Determine handling performance effectiveness in terms of expense per unit handled.
20. *Safety Principle.* Provide suitable methods and equipment for safe handling.

*Principles that deserve particular emphasis.

Source: Adapted from College-Industry Committee on Materials Handling (Pittsburgh, Pa.: Materials Handling Institute, 1990).

Table 2Principles of Materials Handling (Coyle et al, 2002)

4.6 Opportunities for Improvement

Observation of the operations within Apex Valves produced multiple opportunities for improvement through facility optimization. The four main categories of operation at Apex Valves were each considered in terms of space, material handling, equipment and personnel.

Receiving Area

- A stacking frame partially obstructs the receiving door. The frame is used as a part-time storing rack for pallets directly after receiving, prior to put-away. The frame has good utilisation potential and should be included in an improved storage or order-picking process.
- The equipment used for receiving consists of one manual stacker. Using the manual stacker is extremely time-consuming. Raising the fork to truck height takes a great deal of time and moving the stacker expends a large amount of effort. The difficult movement of the manual stacker is due to several factors:

  A huge grate extends from one side of the compound to the other, passing directly in front of the delivery area. The manual stacker cannot be moved over this grate because the wheels become trapped between the bars. This obstructs the manoeuvrability and turn-around space required by the stacker.

  The concrete surface of the entryway is uneven and inclining. These elements force personnel to pull the stacker backwards on entering the facility and turn the stacker around once entered. The area inside the facility dedicated for receiving is very limited, however, and this method of delivery handling is very inefficient.

  Research on acquiring improved material handling equipment should be done, as well as a more suitable, but cost-effective, drain coverage or grate.
- Depositing delivered units in receiving area is unstructured. Space is limited; it fills up fast and erratically resulting in greatly obstructed manoeuvrability and chaos. Both the space utilisation and receiving process can be improved.

Storage Area

- Current layout of storage area may benefit from redesign. More space for manoeuvrability is required; sections are too large in area, with not enough vertical space utilisation, and aisles are basically non-existent.
- Adequate equipment will be needed if more vertical space utilisation is pursued.
- The storage are contains an upper storey (balcony). Optimal use of such an aspect can be investigated and possibly included in improved facility plans.

Assembly & Packaging Area

- The aisles and areas around the workstations and even work surfaces are cluttered with leftover packaging parts and haphazard trolleys containing parts to be assembled/packaged. Trolleys and chairs are continuously obstacles to movement of other trolleys or personnel.
- Tables and parts are suddenly and haphazardly moved to any open space to accommodate an abrupt increase in order quantity for a certain product. It might be beneficial to include one vacant workstation in the improved facility plan, to be available whenever an increase in order quantity occurs. This will be part of the flexibility aspect.
- Apex Valves is spread over four factory units. Unit 1 contains the storage area and receiving bay. Assembly, testing and packaging workstations are contained within the other three. These workstations are spread out very unevenly with approximately 60 % of operations within unit 2, 30% within unit 3 and only 10% in unit 4. This indicates ineffective space utilisation.

Shipping Area

- This area should theoretically be situated in unit 4 so that the flow of products start at receiving in unit one, travel through the value-adding operations and end in staging at unit 4. Unit 4 is however not being used as such. One packaging operation takes place within the whole of unit 4 and products awaiting shipment are staged at the receiving bay.

4.7 Solution Methods

4.7.1 The Layout

Various procedures to aid in developing facility layout alternatives exist. They may be categorised into two groups; Construction Layout Methods & Improvement Layout Methods. Construction layout methods are used when there is no existing layout; whereas Improvement layout methods are used improve already existing facility layouts. Layout planning procedures at Apex Valves fall in the Improvement Layout Method category.

Tompkins et al. (2010) mentions different approaches to layout development, including Apple's Plant Layout Procedure (Apple, 1977), Reed's Plant Layout Procedure (Reed, 1961), and Muther's Systematic Layout Planning (SLP) Procedure (Muther, 1973). The layout approach to be used in this project follows the framework of Muther's SLP procedure:

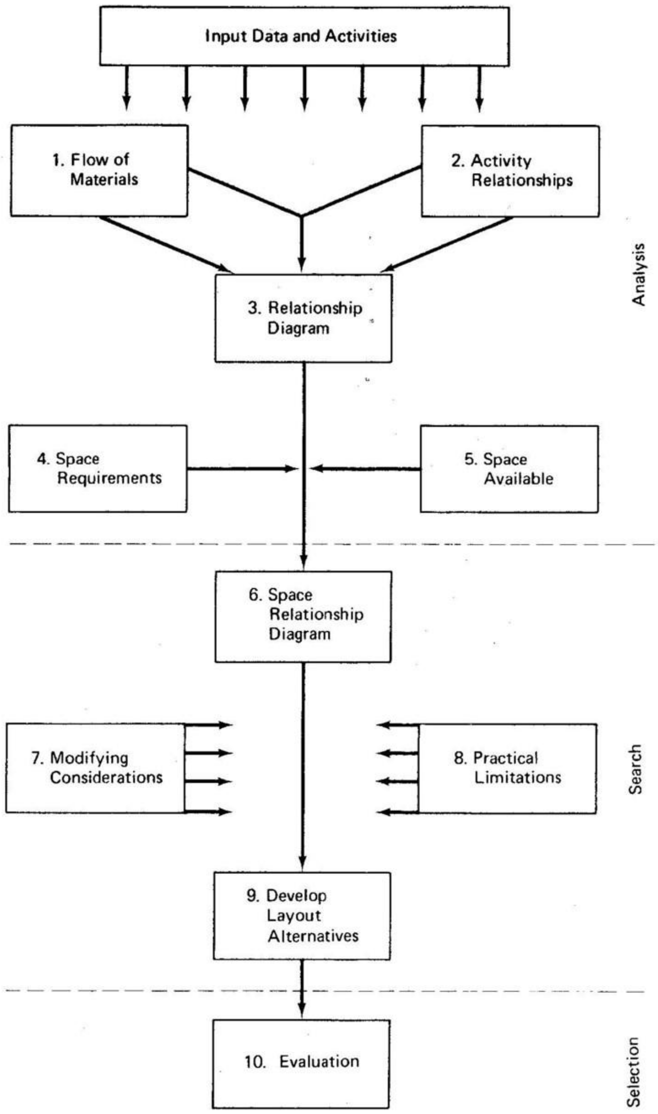
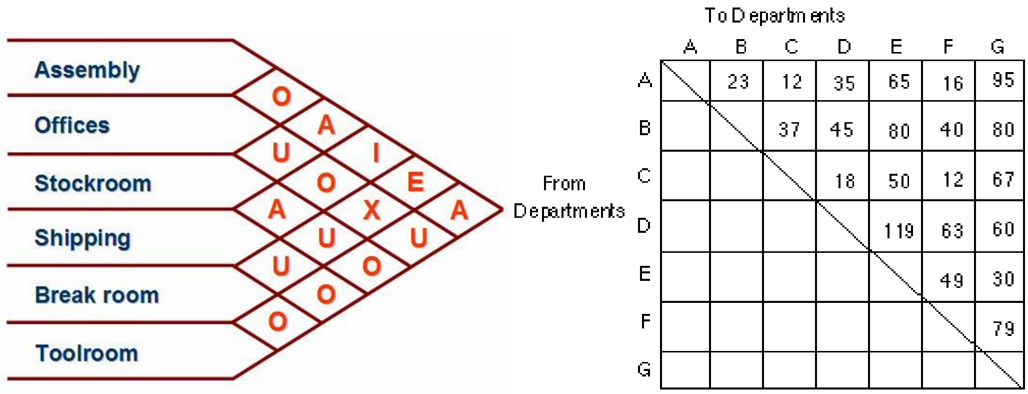


Figure 8 Systematic layout planning (SLP) procedure, (Tompkins et al, 2010)

The Systematic Layout Planning procedure is an excellent framework and overall process for improving a layout; however, as stated by Tompkins et al. (2010), in some cases the “closeness ratings” and “material flow intensities” can be reduced to an algorithmic approach since the mentioned procedures sometimes do “not provide a formal procedure or algorithm for some of the critical steps associated with layout design and evaluation”.

Looking at algorithms we find there are two classifications of algorithm depending on the input data used; qualitative “flow” data (such as a relationship chart) or a quantitative “flow” matrix (such as a from-to chart). The chart to be used depends on the number of departments that make up the facility to be planned. For less than 20 departments a relationship chart is appropriate and for more than 20 departments a from-to chart is preferred. Departments to be included in this project amount to less than 20, therefore a relationship chart would be sufficient.



(a) (b)

Figure 9Example of (a) relationship chart (Lean Sigma Supply Chain, 2012) and (b) a from-to chart (Riggs, 1987)

As explained by Tompkins et al (2010), another classification splits algorithms into (1) algorithms with the aim to minimise the sum of flows times distances, and (2) algorithms with the aim to maximise an adjacency score. Algorithms within classification (1) are suited to quantitative flow data (from-to chart) and those within classification (2) are used with qualitative flow data (relationship chart).

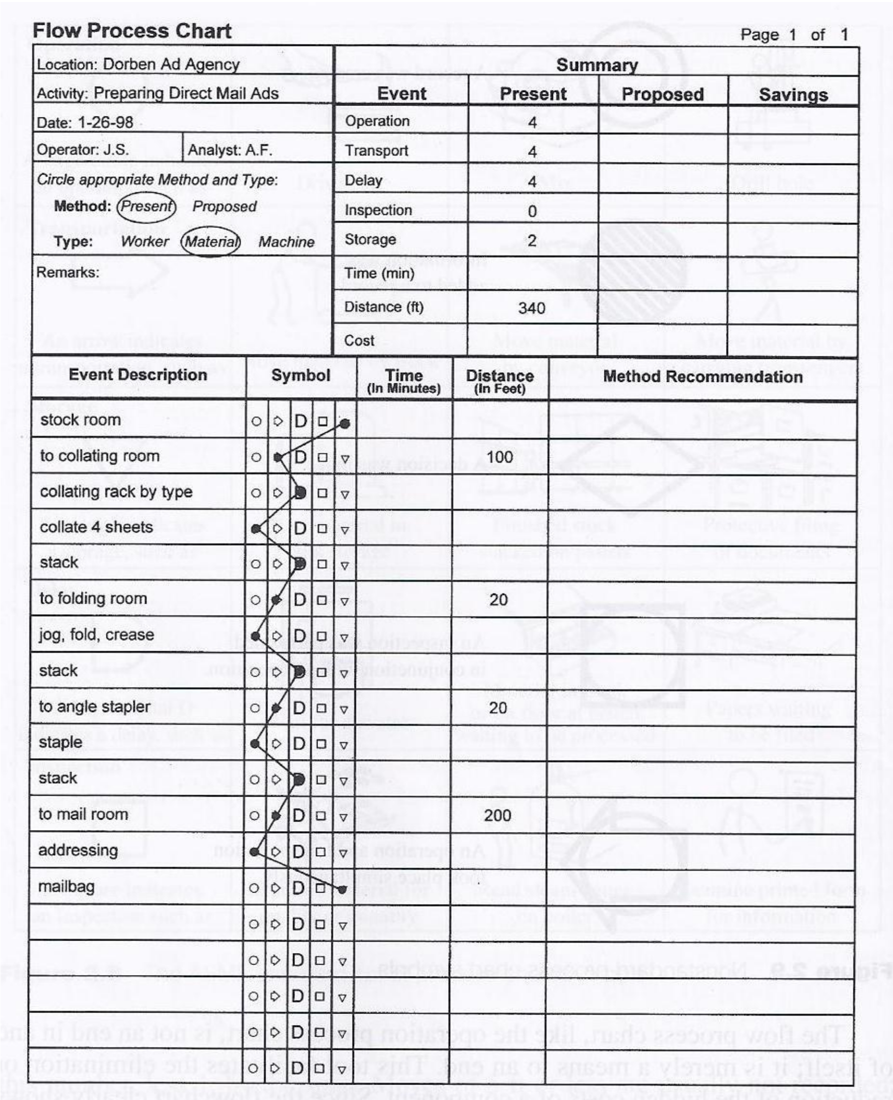
The adjacency-based objective has the following form:

$$\max z = \sum_{i=1}^{m} \sum_{f=1}^{m} f_{ij} x_{ij}$$

The adjacency score is calculated as the sum of all the flow values between those departments that are adjacent. $x_{ij} = 1$ If the departments i and j are adjacent and 0 otherwise.

4.7.2 Material Handling

Freivalds (2009) explains the Flow Process Chart. This chart records operations and inspections, as well as all the moves and storage delays encountered by material as it flows through the factory. This chart is particularly valuable for recording "nonproduction hidden costs" like that of temporary storage, distances travelled and delays; and with the identification of these nonproduction intervals they may be minimized along with their cost. With the recording of five elements, five symbols are utilised in a Flow Process Chart. A circle ◯ indicates an operation; an arrow ⇨ signifies transportation of an object form one area to another; a capital D denotes a delay, when parts are not moved to the next workstation immediately; a square □ indicates an inspection; and a triangle ▽ signifies storage, when parts are held and may not be removed without authorisation. A Flow Process Chart may be used to analyse operators or materials.



Flow Process Chart Page 1 of 1

	Event	Present	Proposed	Savings
Location: Dorben Ad Agency	Summary			
Activity: Preparing Direct Mail Ads				
Date: 1-26-98	Operation	4		
Operator: J.S. Analyst: A.F.	Transport	4		
Circle appropriate Method and Type:	Delay	4		
Method: *Present* (circled) *Proposed*	Inspection	0		
Type: *Worker* *Material* (circled) *Machine*	Storage	2		
Remarks:	Time (min)			
	Distance (ft)	340		
	Cost			

Event Description	Symbol	Time (In Minutes)	Distance (In Feet)	Method Recommendation
stock room	○ ◇ D □ ▽			
to collating room	○ ◇ D □ ▽		100	
collating rack by type	○ ◇ D □ ▽			
collate 4 sheets	○ ◇ D □ ▽			
stack	○ ◇ D □ ▽			
to folding room	○ ◇ D □ ▽		20	
jog, fold, crease	○ ◇ D □ ▽			
stack	○ ◇ D □ ▽			
to angle stapler	○ ◇ D □ ▽		20	
staple	○ ◇ D □ ▽			
stack	○ ◇ D □ ▽			
to mail room	○ ◇ D □ ▽		200	
addressing	○ ◇ D □ ▽			
mailbag	○ ◇ D □ ▽			
	○ ◇ D □ ▽			
	○ ◇ D □ ▽			
	○ ◇ D □ ▽			
	○ ◇ D □ ▽			
	○ ◇ D □ ▽			

Figure 10 Example of a material Flow Process Chart (Freivalds, 2009)

5. Problem Solving Approach

5.1 Current layout

The following illustration represents the current factory floor layout, drawn to scale. Each factory unit, sized 15.3m x 9m, is numbered 1-4. The built in rooms of 3.2m x 4m are visible in the corners of each factory unit along with assorted staircases. Lightly shaded rectangles show the work areas utilised for each product and testing operation.

Unit 2 contains LVC (replaceable cartridge), LVEV (pressure control valve) and VRV (vacuum breaker) assembly, LVEV and LVC testing, as well as LVEV and LVC packaging.

Unit 3 is occupied by TP (safety valve) and TV (tempering valve) assembly, cut and press machining operations, as well as TP and TV testing.

Unit 4 accommodates packaging operations for TP and TV products as well as some outbound storage.

5.1.1 Layout Type

The layout type utilised at Apex Valves is the Product Layout. In a product layout materials flow follows a predetermined route from received raw materials, through the required operations, ending at inventory/shipment. Movement distance from one operation to the next is short, operations are repetitive and large quantities of standardised products are generated.

This layout type has many advantages, and as such it will remain the layout type of choice for Apex Valves. Advantages include:

1) Smooth flow of production

   With operations properly arranged in sequence, halting of work at different points in production can be reduced and a steady flow of production can be achieved.

2) Reduction in production time

   This layout can eliminate a great deal of loading, transportation and unloading time between operations.

3) Reduction in material handling costs

   Less material handling equipment is needed with each required operation next to each other and no back tracking of work.

4) Improved utilisation of space

   With less material handling there is less need for equipment space.

5) Less Work-in-Progress

   Work-in-Progress is minimal and in some cases negligible with production that is straightforward and uninterrupted.

Factors not connected to layout type that may interrupt production must however be considered; Apex Valves has a limited amount of labourers; some workers do more than one task, which causes interruptions in production.Another consideration in terms of production halting is the Process strategy.

5.1.2 Process Positioning Strategy

Apex Valves utilises Batch Production as its process structure. Production of each product is divided into operations and each operation must be completed for the whole batch before the next operation can be applied to the batch. Of course, with the correct batch sizes and correct amount of workers assigned to each operation a balancing of operations can be achieved where operations are done simultaneously and continuously, with batches moving through operations smoothly.
Disadvantages and dangers associated with this process strategy are; a high probability of reduced work flow, especially if there are major differences in productivity of each operation and/or incorrect batch sizes; and build-up of large amounts of work-in-progress.

5.2Production Processes

5.2.1Products

There are 6 products in high demand at Apex Valves; 5 of which requires assembly:

1. Pressure Control Valve - LVEV

The pressure control valve is a three port valve that can be used to mix or divert the liquid flowing through it. Three parts are used to create the "jump". The spring assembly consists of the spring housing, the 12EVADJ and the spring. The body and seat (5EVSA) make the base parts into which the others are inserted. Added parts are the cartridge, redcap and nuts.

2. Safety Valve & Safety Valve (Solar) - TP

Safety valves are used to prevent overpressure; if a predetermined maximum temperature is reached it releases a volume of fluid and lowers excess pressure. Safety valves consist of a bodies, jump retainers, jumps, probes, springs, caps and seals. After testing an adapter and nuts with rings are attached to complete a Solar safety valve or only the nuts with rings are attached to complete a standard safety valve.

3. Vacuum Breaker - VRV

When the pressure in a system drops below atmospheric pressure a vacuum breaker protects equipment and permits condensate to drain efficiently from storage vessels and pipe work by breaking the vacuum. Vacuum breakers consist of bodies, bonnets, o-rings, washers and red rings. After testing they are completed with a red cap.

4. Replaceable Cartridge - LVC

LVC cartridges are both attached to the LVEV pressure control valve and sold separately. They consist of 14 different parts, assembled, glued and tightened; after which they are measured to ensure correct tightening; a retainer, spring, cap and filter is then added to the assembly; after which they are sent to packaging or LVEV assembly.

5. Tempering Valve - TV

The tempering valve blends hot water and cold water. Unlike a static mixing valve, it prevents scalding and ensures a constant temperature for bath or shower water by using a thermostat.

6. Draincocks

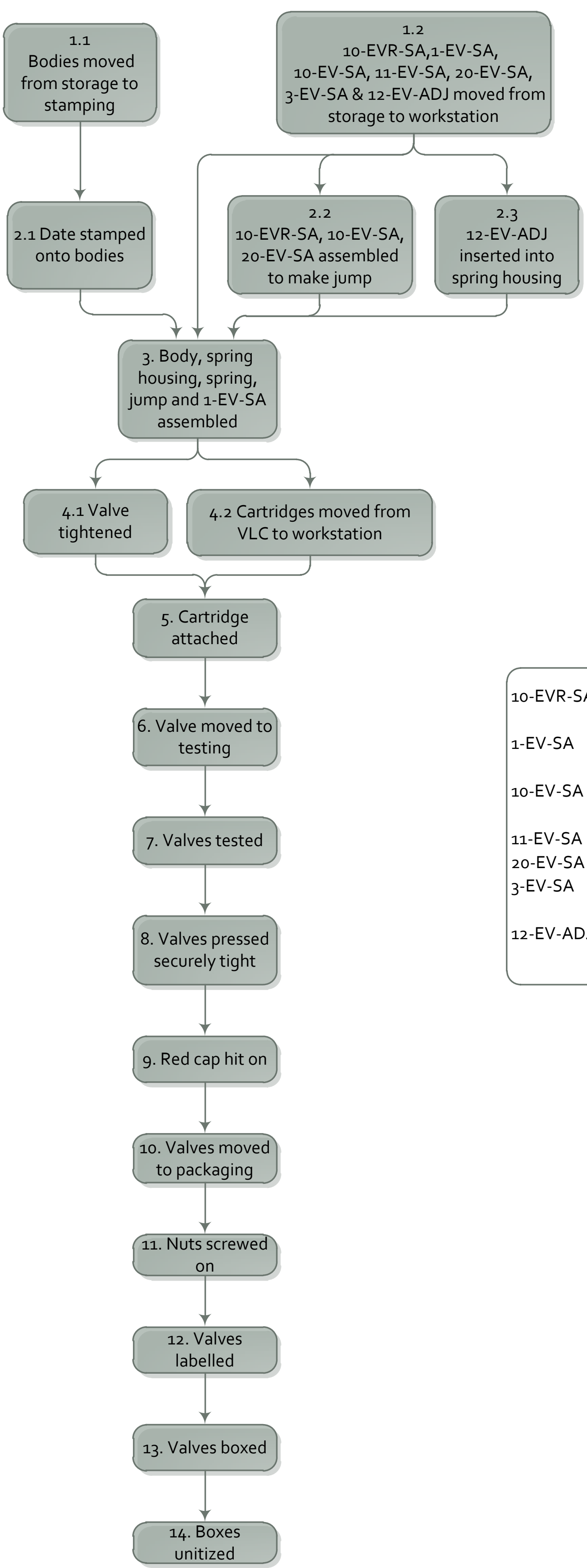
A drain cock can also be called a drain valve and acts as a drain tap inside a pipe system, a water heater, a water jacket, a pump, a vessel or a radiator to drain water, steam and/or air from a sealed water system.

5.2.2 Processes

Flow diagrams are used as an overview of the route that the products take through all the required processes. The diagrams show which parts are retrieved from storage, every subsequent assembly process that follows retrieval, the testing of assembled products and finally the packaging.
Product codes are used inside the flow diagram process blocks for compact and efficient representation; product names associated with the codes are provided alongside each flow diagram.

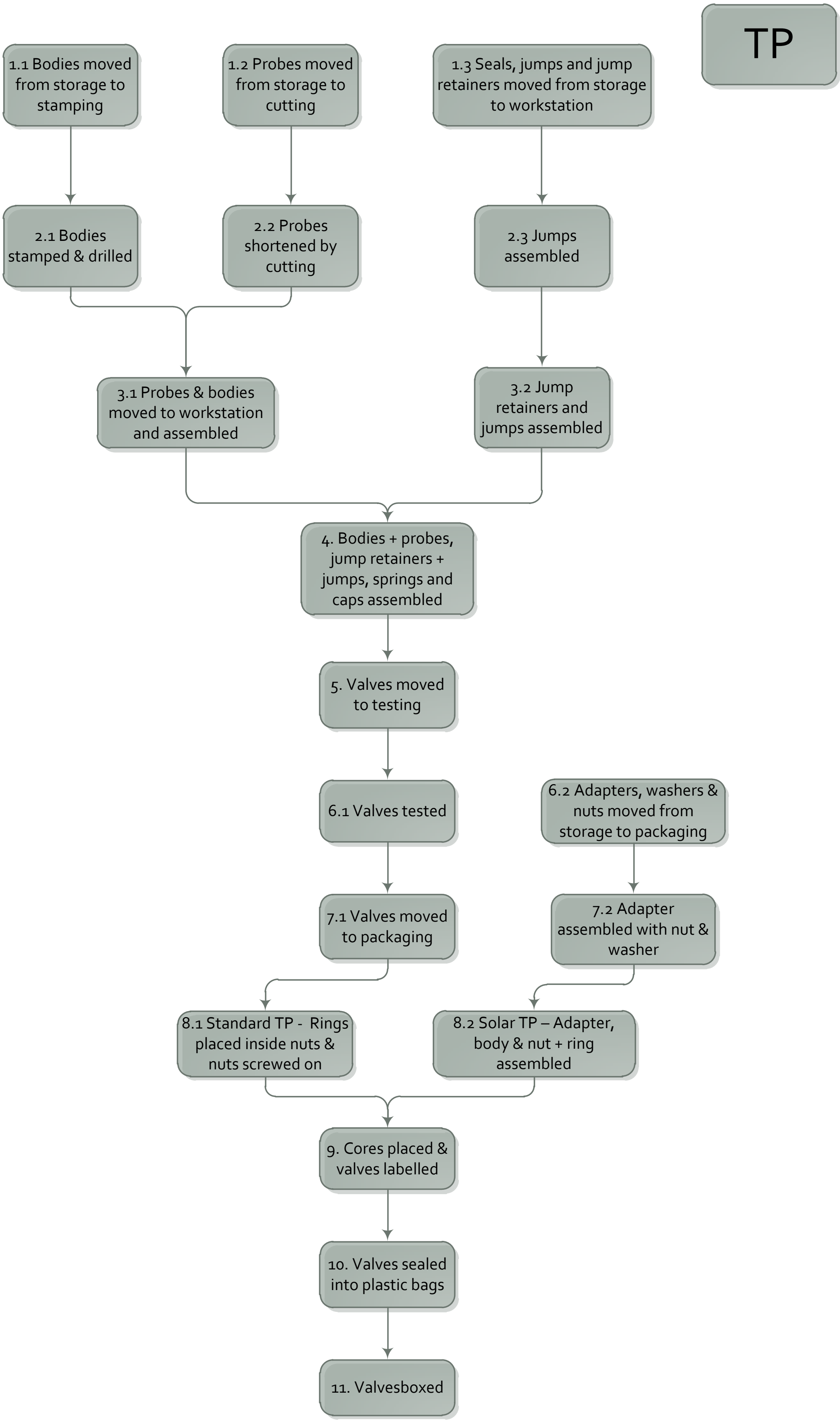
LVEV - Pressure Control Valve

LVEV

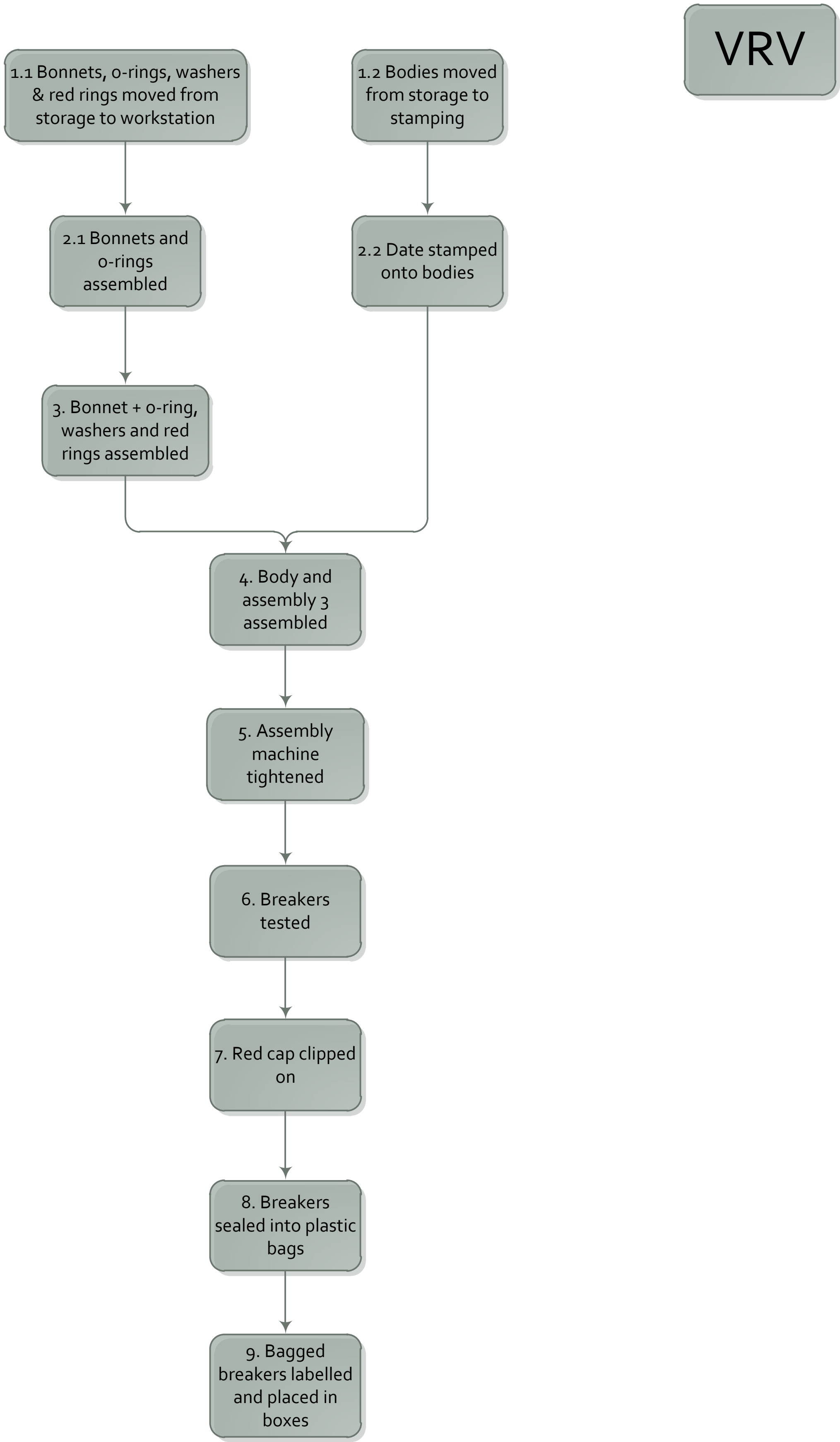


10-EVR-SA	Expansion Valve Jumper Retainer
1-EV-SA	Expansion Control Valve Body
10-EV-SA	Expansion Valve Jumper
11-EV-SA	Expansion Valve Spring
20-EV-SA	Expansion Valve Seal
3-EV-SA	Expansion Valve Spring Housing
12-EV-ADJ	Expansion Valve Adjuster

TP - SAFETY VALVE

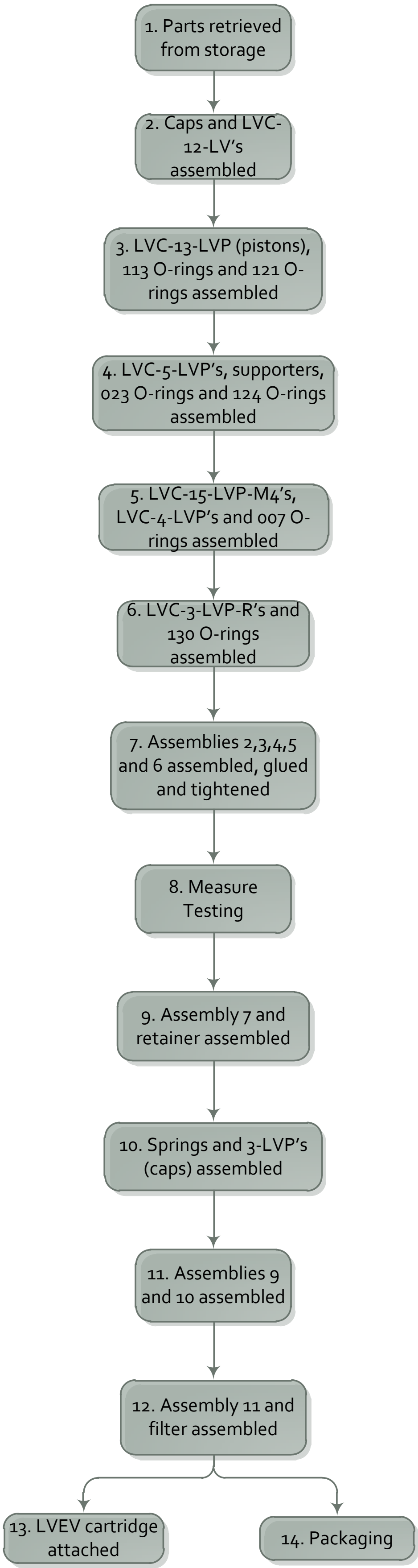


VRV - Vacuum Breaker



LVC - Replaceable Cartridge

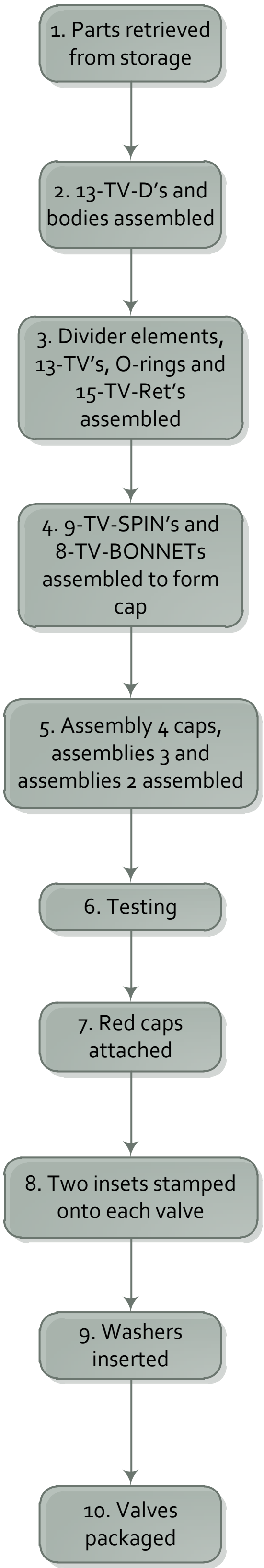
LVC



LVC-12-LV	Cartridge Adjuster
LVC-13-LVP	Cartridge Piston
LVC-5-LVP	Cartridge Seat
LVC-15-LVP-M4	Cartridge Stainless Cap Screw
LVC-4-LVP	Cartridge Pressure Plate
LVC-3-LVP-R	Cartridge Lock Ring
12-EV-ADJ	Expansion Valve Adjuster

TV - Tempering Valve

TV



13-TV-D	Tempering Valve Diverter
13-TV	Tempering Valve Control Piston
15-TV-Ret	Tempering Valve "O" Ring Retainer
9-TV-SPIN	Tempering Valve Spindle Sub Assembly
8-TV-BONNET	Tempering Valve Bonnet Sub Assembly

5.3 Analysis

In this section analysis of all those elements presented thus far, commences in the method set forth by Muther's Systematic Planning. First, in section 5.3.1, the material flow is dissected, separating each product's associated material handling into Inbound process and equipment, Holding processand equipment, and Outbound process and equipment.

The previously stated processes are then transformed into 26 activities by identifying whether material transport is required after each process, in section 5.3.2. This automatically groups those processes that are very closely connected and would be placed next to one another in any scenario, since separation would blatantly slow down progress.

The 26 activities obtained are arranged in a Relationship Chart (section 5.3.3) to show the relationships between them. In section 5.3.4 the Space Required by each activity is related in square meter after careful on-sight measuring along with Space Available (section 5.3.5) which shows the workshop floor and its measurements.

5.3.1 Flow of Materials

Point Legend:
1. Material handling process
1.1. Material handling equipment
1.1.1. Notes and extra information

Storage

Inbound
1. Unitized parts are delivered at Unit 1 entrance for storage as well as cross-docking.
1.1. Manual lifter is used to retrieve units from truck
1.1.1. Several inadequacies have been noted around the use of the manual lifter; material handling with the lifter in the receiving area is exceptionally slow due to unsuitable terrain, lack in space and excessive effort required.

Holding
1. Boxes containing smaller attachment parts are manually moved and placed on separate shelves dedicated to the storage of each products parts.
1.1. Large shelves of three different levels.
1.1.1. Moving from and to the shelves necessitates moving through a network of tight aisles.

2. Crates containing valve bodies, once received by manual lifter, are stacked on the floor in front of their respective dedicated shelves.
2.1. Large red metal crates
2.2. Small metal crates.
2.2.2. Stacked crates is good utilisation of vertical space in a warehouse.

Outbound
1. Crates of valve bodies are moved from storage to designated machining and assembly.
1.1. Manual pallet cart; small base, long upright support.
1.1.1. Can transport up to 9 stacked crates.
1.2. Small metal crates.

2. Smaller attachment parts are moved to respective assemblies.
2.1. Wide range of boxes and containers.
2.1.1. Workers use whichever empty boxes and containers at hand to fetch the parts they need.
2.2. Scales
2.2.1. Four scales of different sizes are used in measuring the correct amount of parts to send to the respective assemblies.

Date Stamping/Drilling

Inbound
1. Valve bodies moved from storage to Date Stamping/Drilling
1.1. Manual pallet cart
1.2. Small metal crates

In-process Holding
1. Valve bodies waiting to be stamped/drilled
1.1. Small metal crates
1.1.1. Crates with bodies stacked on one side of machine; stamping machine also has side crate holders attached.

Outbound
1. Stamped/Drilled valve bodies waiting to be transported to assembly
1.1. Black plastic containers.
1.1.1. One container is 0.3m x 0.3m.
1.2. Trolley
1.2.1. Trolley is 0.3m x 0.8m and can hold four black plastic containers.

LVEV Pre-test Assembly

Inbound
1. Stamped/Drilled valve bodies moved to LVEV assembly
1.1. Black plastic containers.
1.2. Trolley

2. Parts needed for assembly retrieved from storage.
2.1. Container and box assortment
2.1.1. Containers and boxes transported manually.

In-process Holding
1. Parts waiting to be assembled and tightened.
1.1. Table
1.1.1. Table surfaces are used to spread out assemblies and pick up parts with more ease.
1.2. Black plastic containers
1.3. Trolleys
1.3.1. Trolleys with containers remain until emptied during assembly process.

Outbound
1. Valves waiting to be transported to testing.
1.1. Black plastic containers.
1.2. Trolley

LVEV Testing

Inbound & In-process Holding
1. Valves moved to LVEV Testing & waiting to be tested.
1.1. Black plastic containers.
1.2. Trolley

LVEV Post-test Assembly

Inbound & In-process Holding
1. Tested valves waiting for post-test assembly.
1.1. Table
1.1.1. Table for post assembly situated next to testing, valves are placed on table after testing.

Outbound
1. Valves waiting to be moved to packaging.
1.1. Black plastic containers
1.2. Trolley

LVEV Packaging

Inbound
1. Valves moved to packaging for labelling, plastic insertion and boxing.
1.1. Black plastic containers
1.2. Trolley

In-process Holding
1. Valves being packaged.
1.1. Table

Outbound
1. Boxed valves moved to Unitising
1.1.1. Boxed valves are moved manually to the Unitising machine.

TP Pre-test Assembly

Inbound & In-process Holding
1. Valve bodies are moved to assembly & await assembly.
1.1. Black plastic containers
1.2. Trolleys

2. Parts are moved from storage & wait for assembly.
2.1. Container and box assortment.

Outbound
1. Assembled valves wait to be moved to TP Testing.
1.1. Black plastic containers.
1.2. Trolley

TP Testing

Inbound, In-process Holding & Outbound
1. Assembled valves arrive at testing, wait to be tested and wait to be moved to packaging afterwards.
1.1. Black plastic containers
1.2. Trolley

TP Packaging

Inbound
1. Tested valves are moved to Packaging.
1.1. Black plastic containers
1.2. Trolley

In-process Holding
1. Valves wait to be packaged.
1.1.1. Valves are spread out over table surfaces.

Outbound
1. Packaged valves wait to be moved to unitising.
1.1.1. Boxed products stacked on floor.

VRV Date Stamping

Inbound, In-process Holding & Outbound
1. Breaker bodies moved from storage to date stamping, waiting to be stamped and waiting to be moved to assembly.
1.1. Black plastic containers
1.2. Trolley

VRV Pre-test Assembly

Inbound

1. Parts are moved from storage to assembly.
1.1. Container and box assortment.

2. Stamped breaker bodies moved from VRV date stamping to assembly.
2.1. Black plastic containers
2.2. Trolley

In-process Holding
1. Parts being assembled and tightened.
1.1.1. Assemblies and parts are spread out and placed on table.

2. Breaker bodies being added to assemblies.
2.1. Black plastic containers
2.2. Trolley

Outbound
1. Assembled breakers waiting to be moved to testing.
1.1. Black plastic containers
1.2. Trolley

VRV Testing

Inbound, In-process Holding & Outbound
1. Breakers waiting to be tested and waiting to be moved to packaging after testing.
1.1. Black plastic containers
1.2. Trolley

VRV Packaging

Inbound
1. Breakers waiting for red cap attachment and packaging.
1.1. Black plastic containers
1.2. Trolley

In-process Holding
1. VRV breakers are packaged.
1.1.1. Operation spread out on table.

Outbound
1. Packaged VRV breakers waiting to be moved to inventory/shipment.
1.1.1. Boxes are moved manually.

LVC Pre-test Assembly

Inbound
1. Parts moved from storage to LVC assembly.
1.1. Container and box assortment.
1.2. Pallet cart.

In-process Holding
1. LVC cartridges are assembled.
1.1.1. Assemblies and parts spread out and placed on table.

Outbound
1. LVC cartridges waiting to be moved to LVEV assembly and/or testing.
1.1. Black plastic containers
1.2. Trolley

TV Pre-test Assembly

Inbound
1. Parts are moved from storage to assembly.
1.1. Container and box assortment

2. Valve bodies are moved to assembly.
2.1. Black plastic containers
2.2. Trolley

In-process Holding
1. TV's are assembled.
1.1.1.Assemblies and parts spread out and placed on table.

Outbound
1. Assembled TV's waiting to be moved to testing.
1.1. Black plastic containers
1.2. Trolley

TV Testing

Inbound & In-process Holding
1. Valves are moved to testing and then tested.
1.1. Black plastic containers
1.2. Trolleys

TV Post-test Assembly

Inbound & In-process Holding
1. Tested valves waiting for post-test assembly and assembled.
1.1.1. TV Post-test Assembly situated right next to testing; tested parts placed in box on table for post test assembly.

Outbound
1. TV's waiting to be moved to packaging.
1.1. Black plastic containers
1.2. Trolley

Unitising

Inbound
1. Packaged products moved to unitising station.
1.1.1. Packaged products are manually carried.

In-process Holding
1. Packaged products are unitised.
1.1.1. Unitised products are stacked on floor around unitising machine.

Outbound
1. Unitised product moved from unitising to inventory/shipment.
1.1. Pallet cart.

5.3.2 Activity Relationships

Product	Process	Transport Required After	Relationship Diagram Activity
LVEV	Retrieve from storage	Yes	Storage Retrieval
	Body stamping (large stamp)	Yes	Body Stamping (L)
	Jump assembly	No	
	Spring housing assembly	No	
	Jump, spring housing, spring & body assembly	No	
	Valve tightened	No	
	Cartridge attached	Yes	LVEV Pre-test Assembly
	Testing	Yes	LVEV Testing
	Valve pressed tight	No	
	Red cap attached	Yes	LVEV Post-test Assembly
	Nuts screwed on	No	
	Valve labeled	No	
	Valve boxed	Yes	LVEV Packaging
	Unitizing	Yes	Unitising
TP	Retrieve from storage	Yes	Storage Retrieval
	Body stamping (large stamp)	Yes	Body Stamping (L)
	Body drilling	Yes	Body Drilling
	Probe cutting	No (Possibly)	
	Jump assembly	No	
	Probe & body assembly	No	
	Jump retainer & jump assembly	No	
	Body & probe, jump & jump retainer, spring and cap assembly	Yes	TP Pre-test Assembly
	Testing	Yes	TP Testing
	Ring & Nut and valve assembly	No	
	Ring & Nut, adapter and valve assembly	No	
	Core placement	No	
	Valve labelled	No	
	Valve sealed into bag	No	
	Valve boxed	Yes	TP Packaging
	Unitising	Yes	Unitising
VRV	Retrieve form storage	Yes	Storage Retrieval
	Body stamping (small stamp)	Yes	Body Stamping (S)
	Bonnet and o-ring assembly	No	
	Bonnet &o-ring, washer and red ring assembly	No	
	Body assembly	No	
	Assembly machine	Yes	VRV Pre-test Assembly

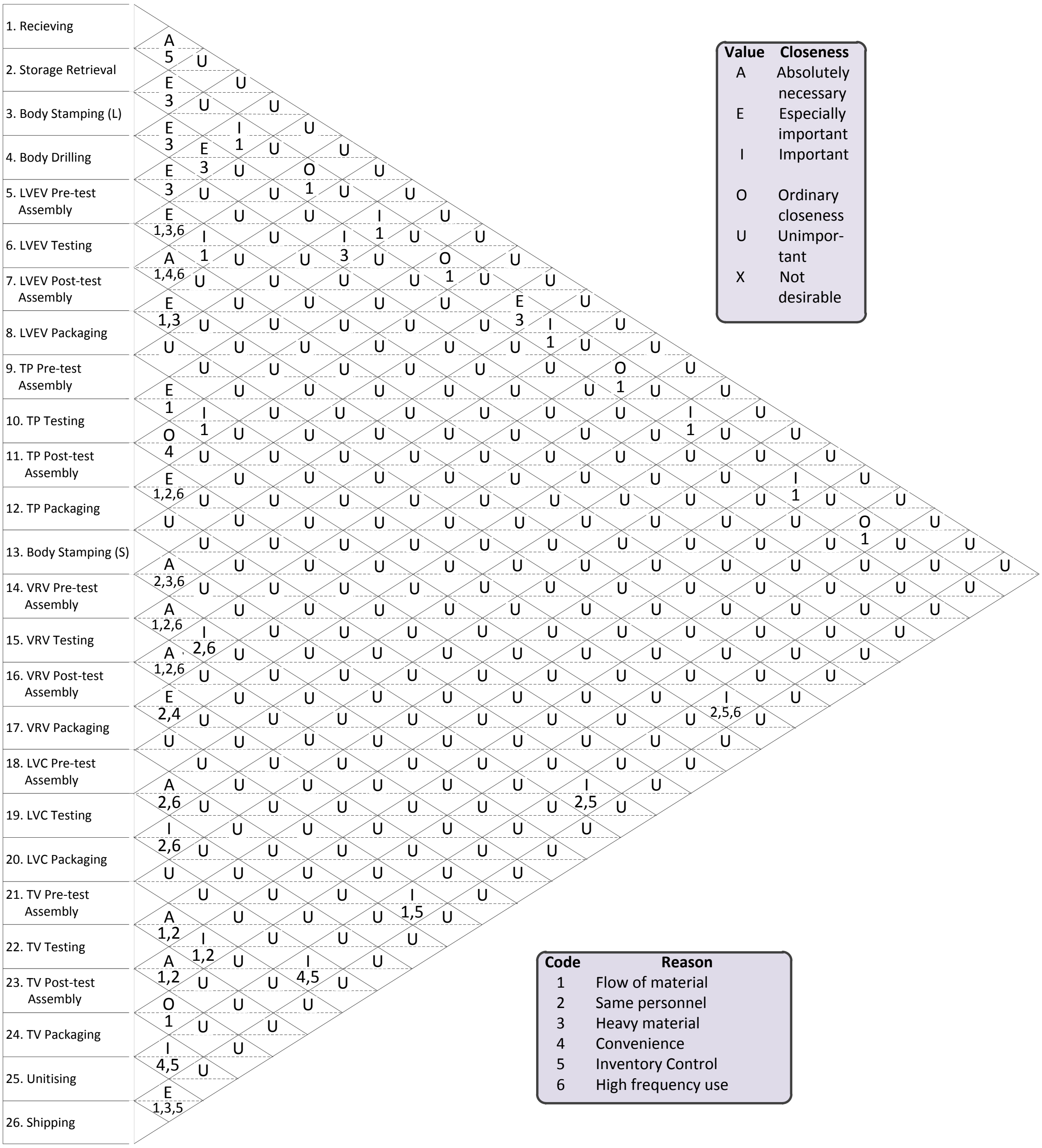
	tightened		
	Testing	Yes	VRV Testing
	Red cap attached	Yes	VRV Post-test Assembly
	Breaker sealed into bag	No	
	Bagged breakers boxed	Yes	VRV Packaging
LVC	Retrieve from storage	Yes	Storage Retrieval
	Cap and 12-LV assembly	No	
	13-LV, 113 O-ring and 121 O-ring assembly	No	
	5-LVP, supporter, 023 O-ring and 124 O-ring assembly	No	
	15-LVP, 4-LVP and 007 O-ring assembly	No	
	3-LVP-R and 130 O-ring assembly	No	
	Total-assembly-1 gluing and tightening	No	
	Measure testing	No	
	Total-assembly-2: Total-assembly-1 and retainer assembly	No	
	Spring and 3-LVP assembly	No	
	Total-assembly-3: Total-assembly-2 and spring & 3-LVP assembly	No	
	Total-assembly-3 and filter assembly	Yes	LVC Pre-test Assembly
	Testing	Yes	LVC Testing
		Yes	LVC Packaging
TV	Retrieve from storage	Yes	Storage Retrieval
	Body and 13TVD assembly	No	
	Divider element, 13TV, O-ring and 15TV Red assembly	No	
	9-TV-SPM and 8TV bonnet assembly	No	
	Cumulative assembly	Yes	TV Pre-test Assembly
	Testing	Yes	TV Testing
	Red cap attachment	No	
	Double inset stamping	No	
	Washer inserting	Yes	TV Post-test Assembly
		Yes	TV Packaging

Activities

1. Receiving
2. Storage Retrieval
3. Body Stamping (L)
4. Body Drilling
5. LVEV Pre-test Assembly
6. LVEV Testing
7. LVEV Post-test Assembly
8. LVEV Packaging
9. TP Pre-test Assembly
10. TP Testing
11. TP Post-test Assembly
12. TP Packaging
13. Body Stamping (S)
14. VRV Pre-test Assembly
15. VRV Testing
16. VRV Post-test Assembly
17. VRV Packaging
18. LVC Pre-test Assembly
19. LVC Testing
20. LVC Packaging
21. TV Pre-test Assembly
22. TV Testing
23. TV Post-test Assembly
24. TV Packaging
25. Unitising
26. Shipping

5.3.3 Relationship Chart

The Relationship Chart ascertains the necessity for closeness between each activity using a qualitative measure, and is compiled by the collective opinions of workers and overseers, and objective observation. For some activities closeness is absolutely necessary, such as Receiving and Storage Retrieval, and LVEV Testing and LVEV Post-test Assembly. For other activities closeness is Especially Important, like Storage Retrieval and Body Stamping (L), or only Important, like Storage Retrieval and LVEV Pre-test Assembly. The closeness options range from 'Absolutely necessary' to 'Not desirable' and different reasons form the basis of each allocation; the flow of material, assignment of same personnel, heavy materials involved, convenience, inventory control, or high frequency use. Reasons associated with each closeness measure are represented by an assigned number (1-6).



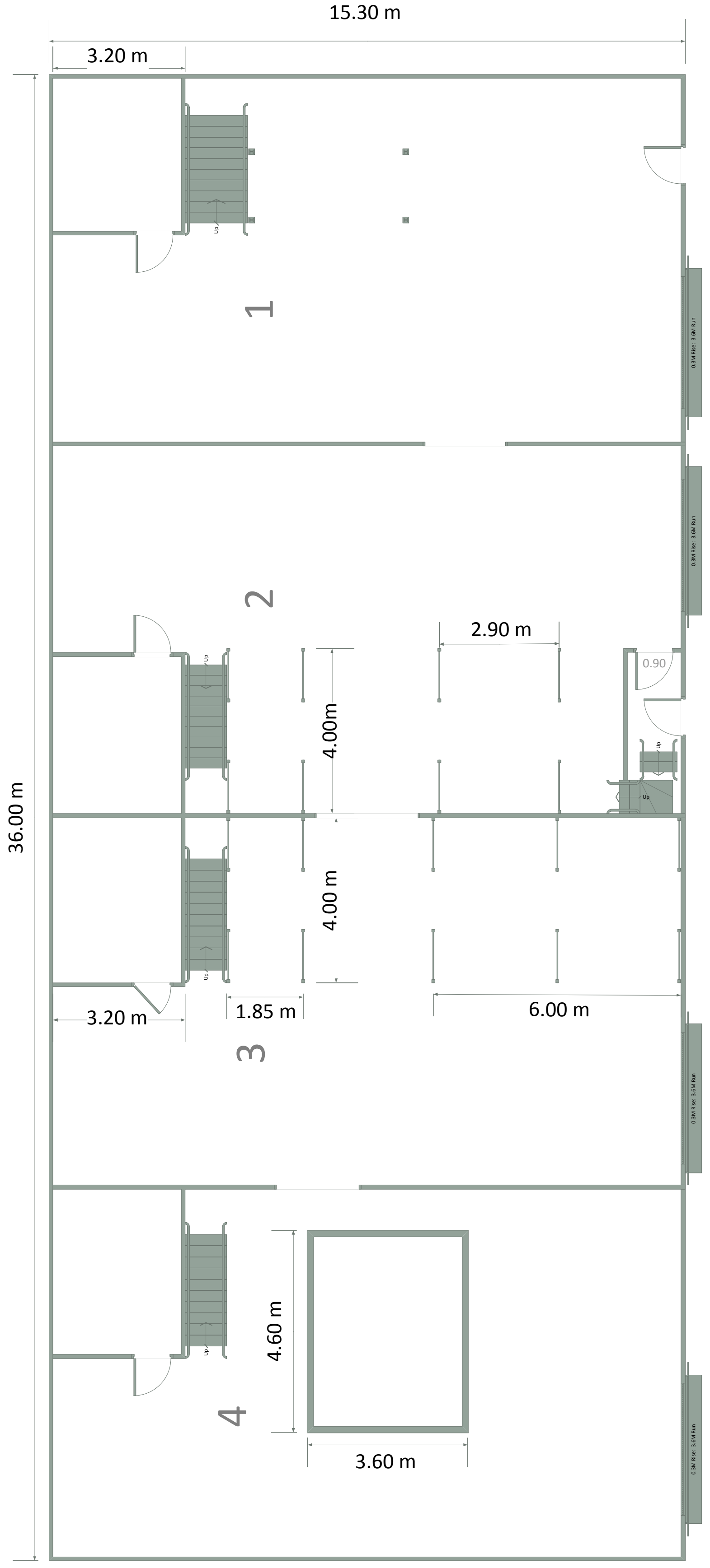
5.3.4 Space Requirements

On-sight measuring of activity areas was done with measuring tape and a Bosch PLR50 laser measuring device. As per Tompkins et al. (2010) Workstation Specification; space requirement was considered in terms of equipment, personnel and materials.

Department	Activity	Area	Notes
1. Receiving	1. Receiving	3.2m x 7.7m	Receiving area begins at the roller door in unit 1 and ends approximately 7.7m into unit 1. Area is right between storage and shop floor and causes obstruction because of cross-docking units waiting in receiving area.
2. Storage	2. Storage	94.3 m^2	Storage of raw materials utilises most of unit 1, with most of the receiving bay used as a cross-docking area.
3. Manufacturing Adjustments	3.1 Body Stamping (L)	1.6m x 1.3m	Area contains stamping mechanism (0.6mx1.45m), one trolley and one person (seated)
	3.2 Body drilling	1.1m x 1.1m	Small drill; two trolleys; and one person
4. LVEV Department	4.1 LVEV Pre-test assembly	1.9m x 2.3m	Area contains two tables (0.76mx1.5m each) in L shape, for boxes containing various parts and spreading out of assemblies; 1-2 people; and multiple crated trolleys containing valve bodies.
	4.2 LVEV tightening & Cartridge attachment	2m x 1.2m	Space provides for valves waiting to be tightened and attached to cartridges; box of cartridges; person assembling; and crate trolley for valves headed to testing.
	4.3 LVEV Testing	2m x 3m	Water tank is the main consideration, utilising the most space. Space also includes basin and pipes connected to water; crate trolley with valves waiting to be tested; and tester.
	4.4 LVEV post-test assembly	1.1m x1.6m	Space entails table with surface for tested valves waiting for post-test assembly, a press machine and the tool used for hitting caps on; crate trolley with finished valves next to table; and person assembling.
5. LVEV Packaging Department	5.1 LVEV Nuts & Labeling	2m x 1.7m	Area contains two tables (0.74mx1.5m each) placed next to each other; one trolley; two chairs; and two people.
	5.2 LVEV boxing	2.8m x 1.5m	Entails two tables (0.76mx1.5m each) placed next to one another; a cage with folded boxes; and one person standing.
6. TP Department	6.1 TP Probe cutting	1m x 1.2m	Area contains one table, the cutter and one person.
	6.2TP Jump assembly	1.2m x 1.2m	Area consists of press machine (0.78mx1.7m) and one person.
	6.3 TP Probe & body assembly	1.2m x 1.5m	One table with two silver crates and cut probes on top; and one person.

	6.4 TP Body & probe, jump & jump retainer, spring and cap assembly	1.7m x 1.5m	One table for holding crates, boxes and spread out assemblies; one trolley; and two - three people.
	6.5 TP Testing	0.9mx2m + 2m x 3.5m	Area contains bench & basin (0.45mx2m); two small crates; one person; and a water tank.
7. TP Packaging Department	7.1 TP Ring & Nut and packaging	2.5m x 2.9m	Area consists of four tables moved together to make one big surface (1.5mx2.9m); large box with toilet rolls; and 3 people.
	7.2 TP Boxing	1.9m x 1.5m	Space for two tables and 1 person
8. VRV Department	8.1 Body stamping (small stamp)	1m x 1.2m	Space provides for stamp press; box with new bodies on one side of the press; box with stamped bodies on the other side of the press; and worker using press.
	8.2 VRV pre-test assembly	1m x 1.4m	Space provides for table carrying permanently placed tightening equipment, boxes for parts and surface for spreading out parts being assembled; and person assembling.
	8.3 VRV Assembly machine tightened	0.7m x 1.2m	Tightening machine takes up half a tables space and one person is required
	8.4 VRV Testing	0.9m x 1.3m	Area consists of a bench & basin (0.45mx1.27m) and one person standing.
	8.5 VRV Red cap attachment	0.8m x 1.2m	Requires space equal to half a table and one person
9. VRV Packaging Department	9. VRV Packaging	0.8m x 1.2m	Requires space equal to half a table and one person
10. LVC Department	10.1LVC Pre-test assembly	2m x 1.5m	Area allows for one table; two - three boxes; and one - two people.
	10.2 LVC Testing		Tested at LVEV Testing
11. LVC Packaging Department	11. LVC Packaging		Packaged at LVEV Packaging
12. TV Department	12.1 TV Pre-test assembly	1.5m x 1.3m	Area allows for one table; one person; and on trolley.
	12.2 TV Testing	1.2m x 1.1m	Area consists of one basin (1.2mx0.5m); on trolley; one crate; and one person
	12.3 TV post-test assembly	0.6m x 1.3m	Small surface required; one person; and one trolley.
13. TV Packaging Department	13. TV Packaging		Packaged at TP Packaging
14. Unitising	14. Unitising	1.3m x 5m	Unitising machine is 1.5mx0.7m; unitised boxes are stacked all around unitising machine taking up more surface area.
15. Shipping	15. Shipping	3.6m x 4.6m + 10m x 3.4m	Large shelves in unit 4 as well as the vault in unit 4 are used to store inventory prior to shipment.

5.3.5 Space Available



Industrial Unit 1

The 4m x 3.2m room in unit 1 is reserved for the storage of returned defective products which need to be analysed and potentially fixed. A staircase of 1.5m width occupies a piece of the area and four columns holding a second storey area causes obstruction.
The complete surface area available in unit 1 is:
118.9m^2

Industrial Unit 2

The front door entrance area detracts space from unit 2; the underside of the stairway leading up from the entrance also impedes on unit 2 space, obstructing square spacing and vertical space utilisation. Eight columns are used to hold a second storey; the column structures are 0.1m in width and 1.3m in length, creating obstruction and limitation for spacing. A 4m x 3.2m room in unit 2 is used for general purposes and a staircase next to it is closed up and dead ended serving no purpose.
The surface area available in unit 2 is:
115.3m^2

Industrial Unit 3

The 4m x 3.2m room in unit 3 is used as locker/tea room by the workers; another staircase occupies space in unit 3 with the underside of the staircase obstructing square spacing and vertical space utilisation. Unit 3 also contains supporting structure of size 0.1m x 1.3m; ten of the structures are placed intermittently from the front wall of the unit to the staircase, causing spacing limitations and obstructions.
The surface area available in unit 3 is:
120.9m^2

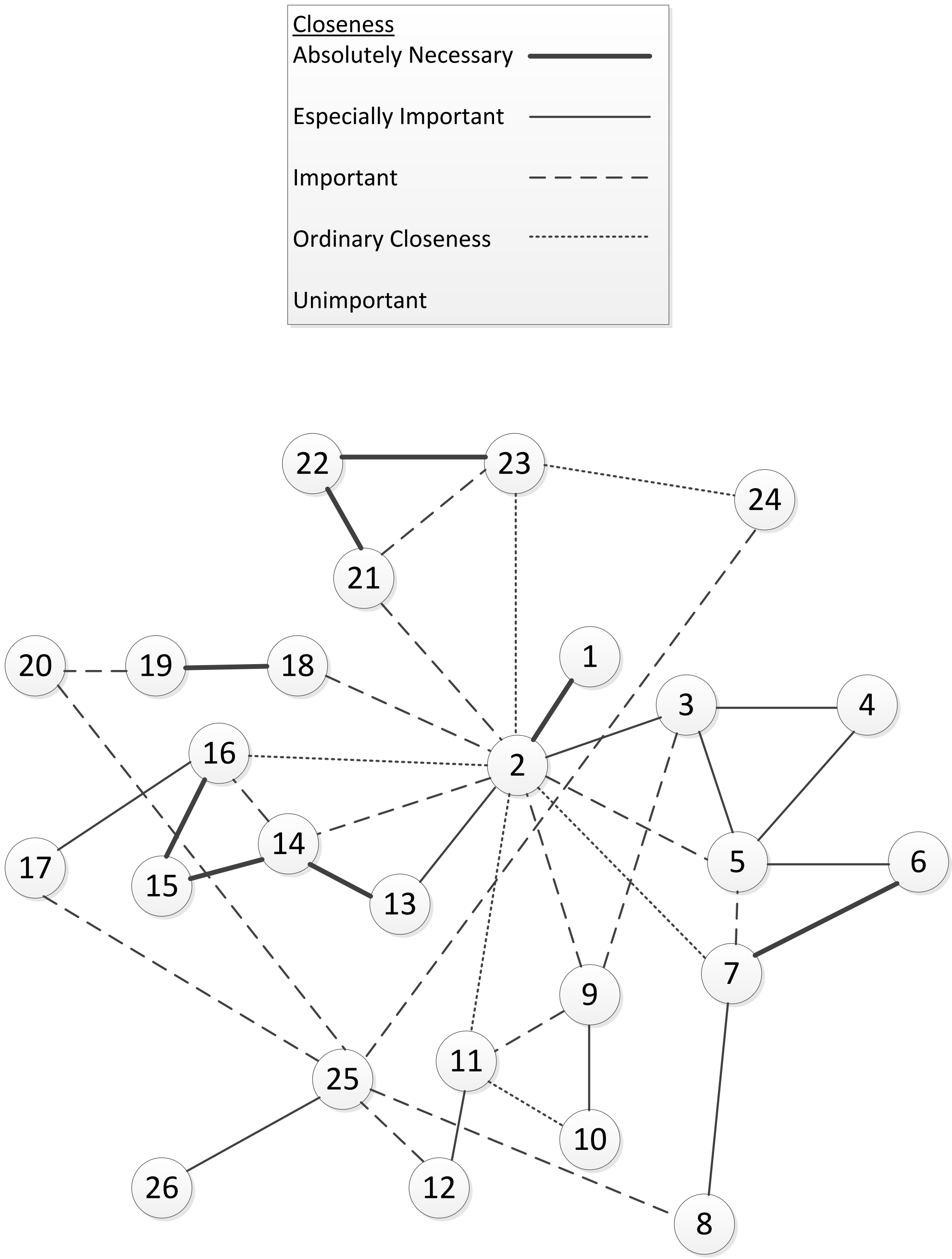
Industrial Unit 4

The greatest flow obstruction in unit 4 is the built-in vault; it limits entering unit 4 (narrow entries to the left and right), it limits movement of materials to and from units 4, it decreases effective space utilisation and it obstructs observation of work being done inside unit 4.
The surface area for operation and other in unit 4 is:
104.3m^2
Storage area in unit 4 is:
16m^2

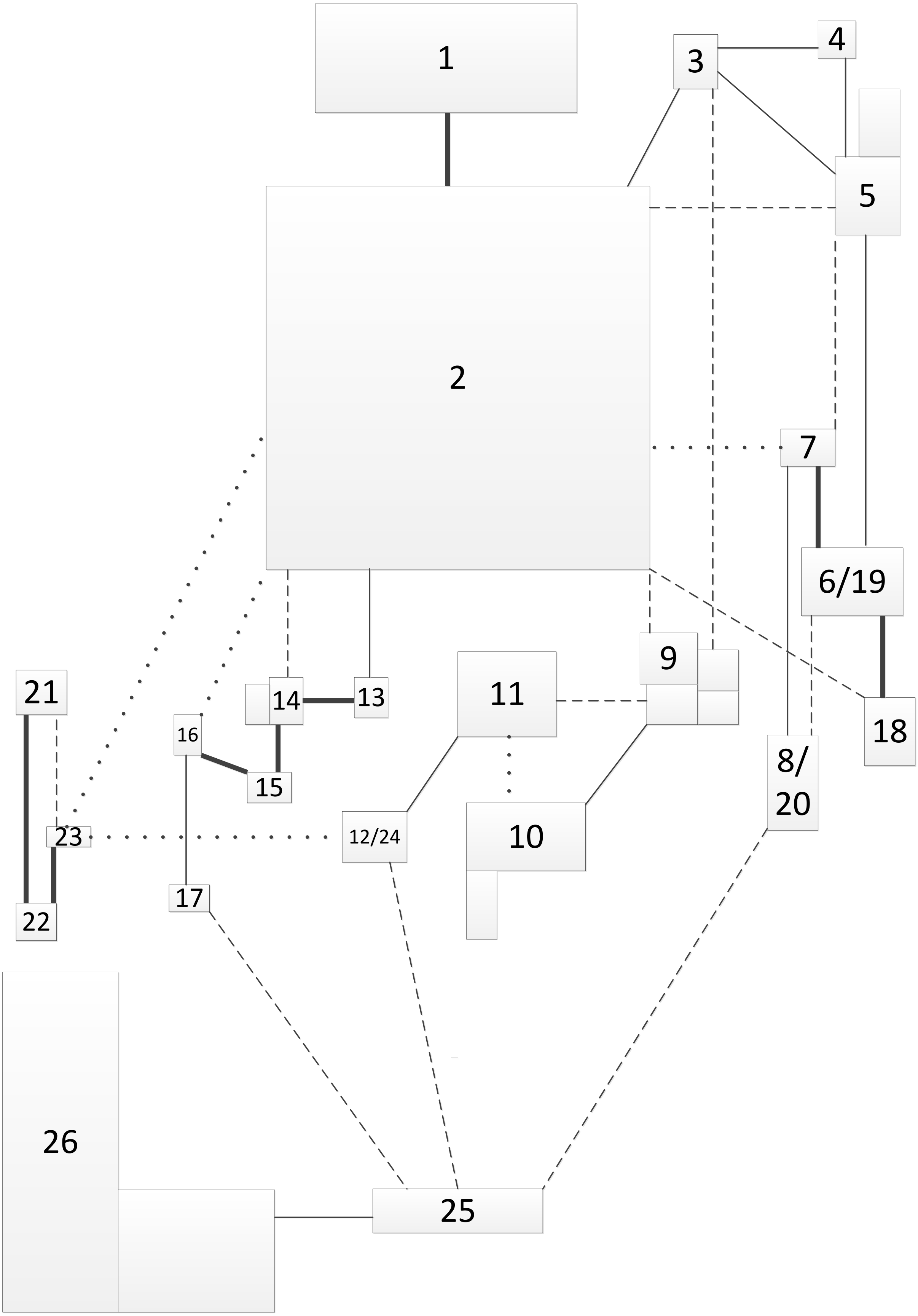
5.4 Search

In line with the Systematic Layout Planning Procedure 'Search' follows 'Analysis' with a Relationship Diagram that illustrates the closeness needs identified in the Relationship Chart previously (section 5.4.1); a Space Relationship Diagram which illustrates both closeness relationships and space requirements of activities (section 5.4.2); and Practical Limitations that should be considered (section 5.4.3). The 'Search' segment ends with several proposed layout alternativesderived from the Space Relationship Diagram,drawn in Microsoft Visio (section 5.4.4).

5.4.1 Relationship Diagram



5.4.2 Space Relationship Diagram



5.4.3 Practical Limitations

Apex Valves resides in a four unit factory with set dimension and structures; all activities must be laid out within these four units.

Each unit has a 3.2m x 4m room, with adjacent staircases to each. Currently these rooms are used for storage of defective product waiting for analysis and repair, ablutions and worker eating areas. As entrances to these rooms are single door sized and inadequate for sizable material movement these functions are well suited and would optimally remain as they are. In respect to shop floor they are practical limitations to be considered in the layout.

The fourth unit has a vault, sized 3.6m x 4.6m. This limits pace utilisation and material movement severely and would optimally be removed. Removal of the vault would however be an expensive solution and will be resorted to after all other solutions have been considered.

The main entrance limits space in unit 2.

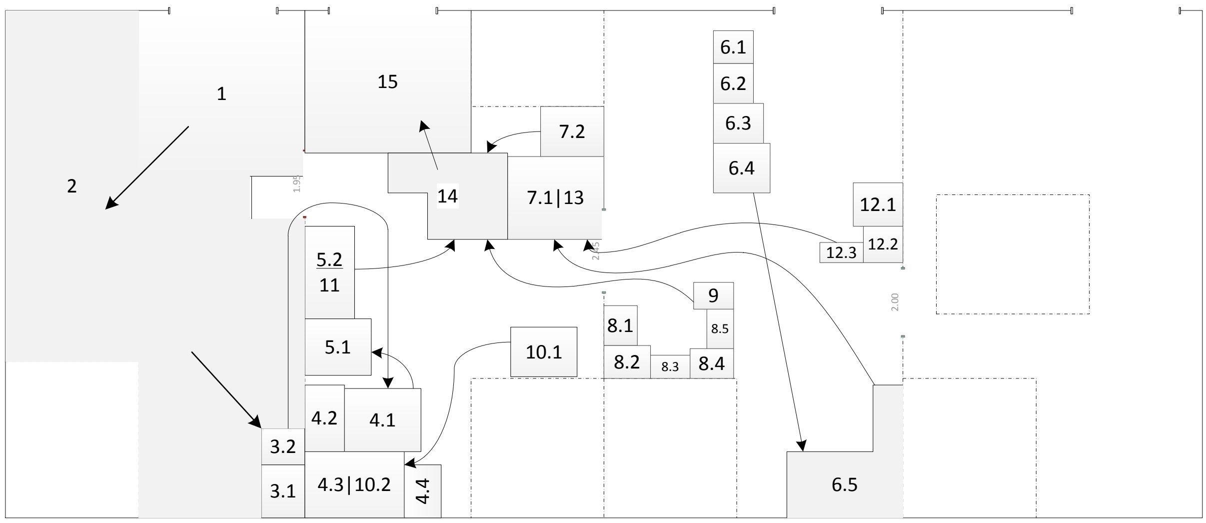
Three activities require water tanks and testing basins of permanent placement; activity 4.3 (LVEV & LVC Testing), activity 6.5 (TP Testing), and activity 12.2 (TV Testing). VRV testing also requires a basin and pressure; however without a water tank it has more possibility of movement.

The position of roller doors at each unit will also cause certain limitations with respect to receiving, dispatch and storage.

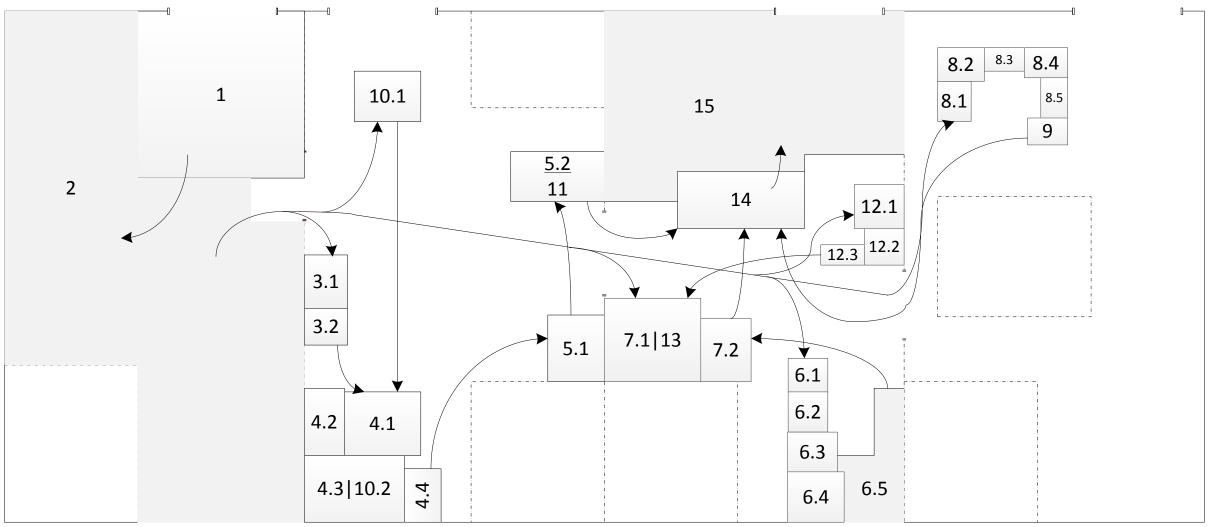
5.4.4 Block Layout Alternatives

Each activity is represented by a number as designated in Space Requirements Section 5.3.4. The activities are placed on a skeletal structure of the factory layout drawn to scale and flow lines show the movement of workers and material through the facility.

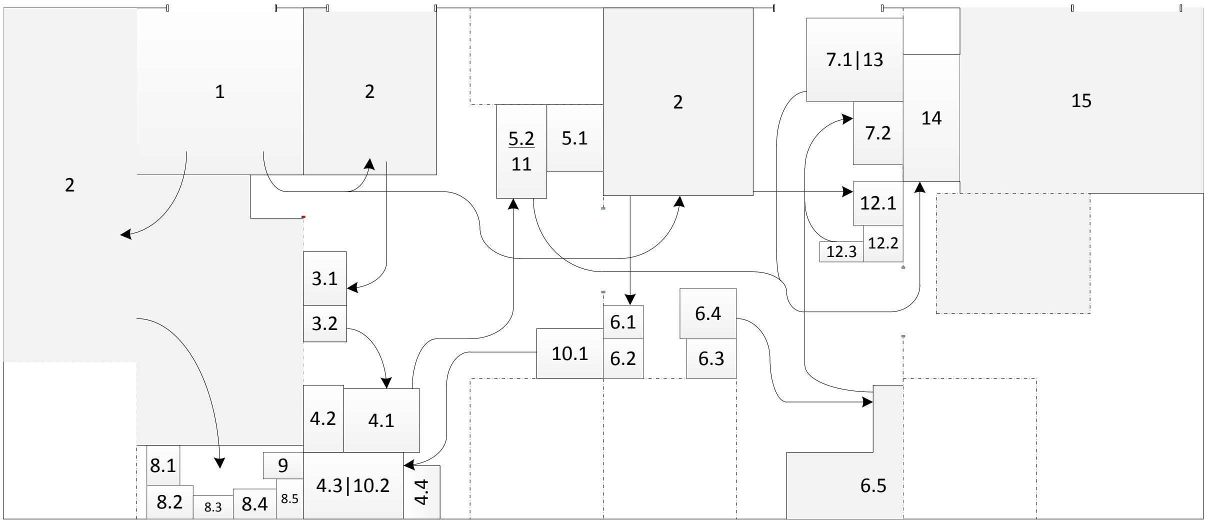
Block Layout 1



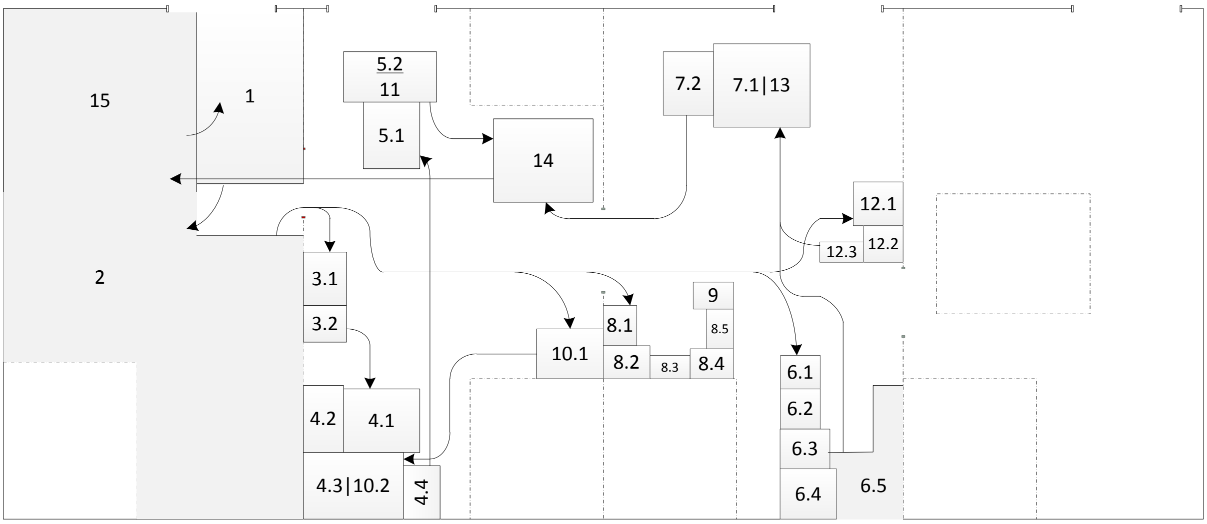
Block Layout 2



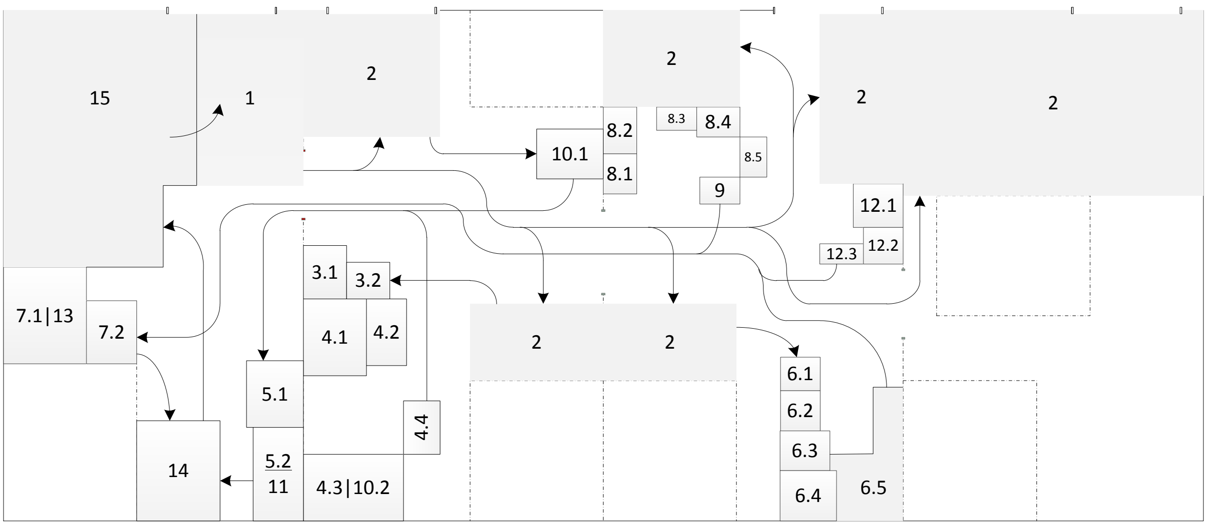
Block Layout 3



Block Layout 4



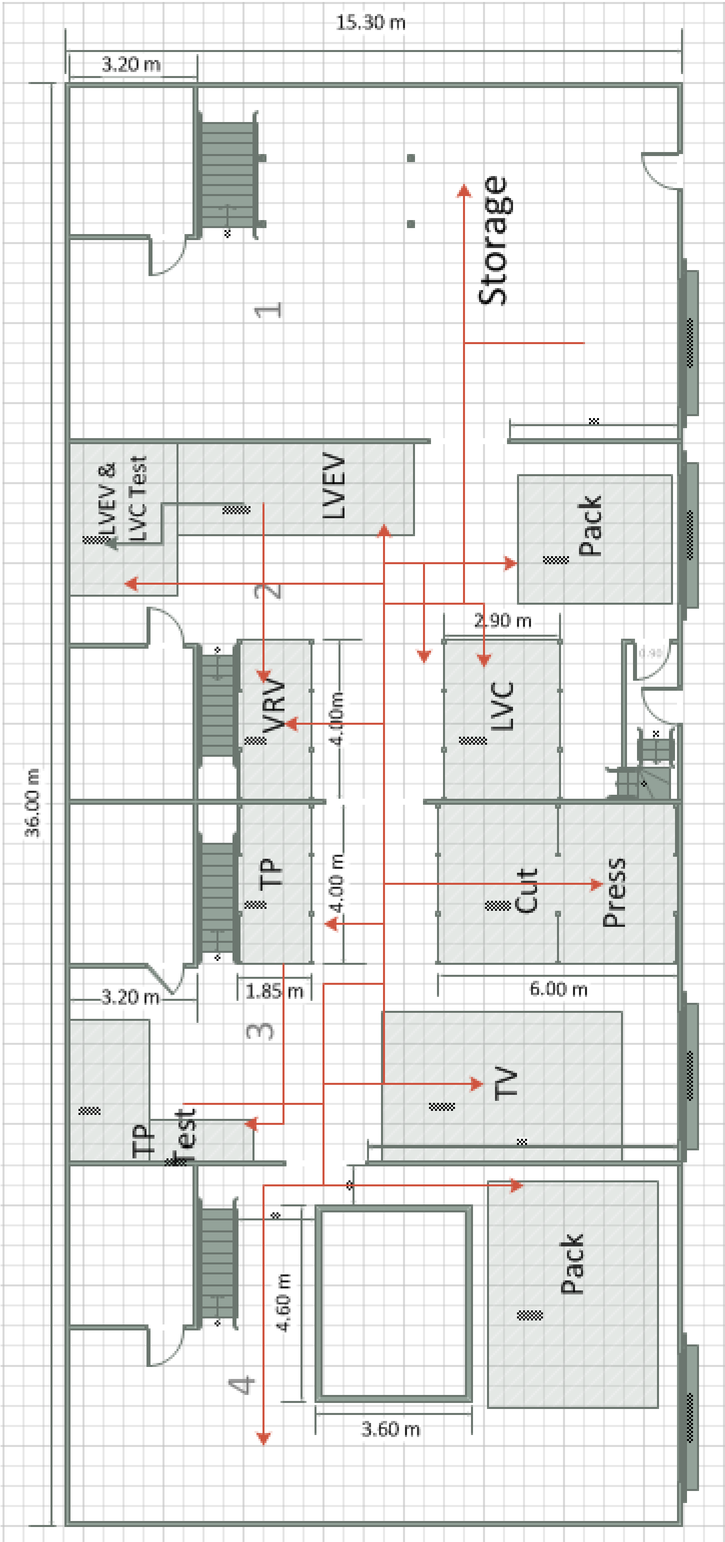
Block Layout 5



5.5 Evaluation& Selection

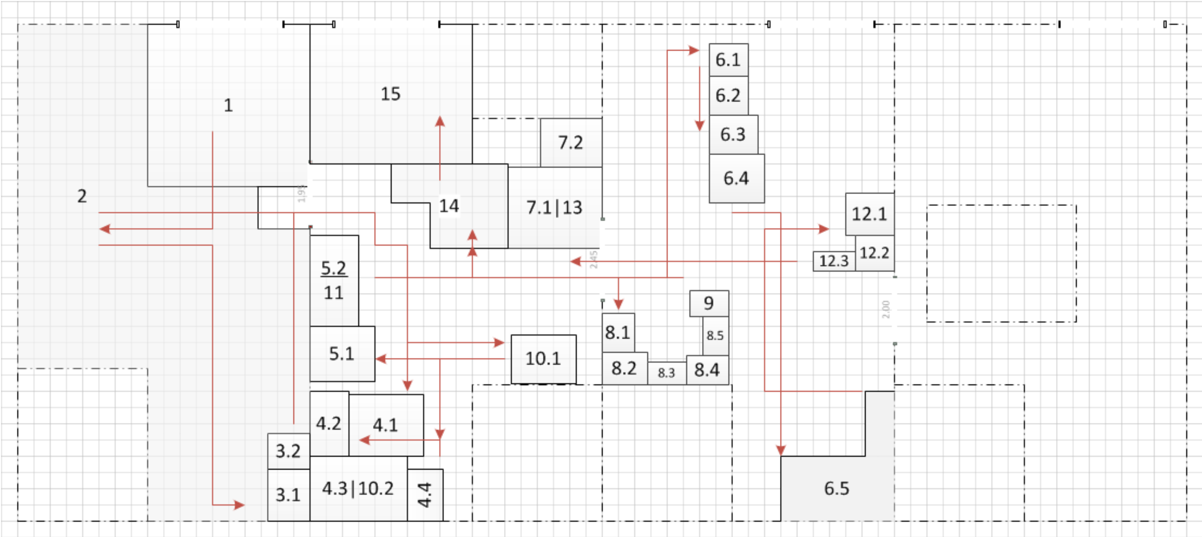
A modified Flow Process Chart is used to show the evaluation of each alternative. A Flow Process chart illustrates all the operations, moves, delays, inspections and storage delays that an item encounters as it goes through the factory. The modified version presented here shows the operations, inspections, storage instances and delays but it focuses mainly on moves, i.e. the transport of the items. This is so a clear idea of the flow of parts through the factory is obtained and made available for evaluation.

The five alternative layouts as well as the current layout were drawn to scale on Microsoft Visio. Each drawing possesses the dimensions of the actual factory to within approximately 10 centimetres; and each layout drawing contains square blocks representing determined activities with exact sizes to match dimensions ascertained in 'Space Requirements'. These drawings were placed on a grid where each block represents a 0.5m x 0.5m area in the actual factory. Flow lines of items were then drawn utilising the grid and measurements of these lines were able to give the distance travelled by items, with a possible ± 1 meter deviation from actual or real world travel.

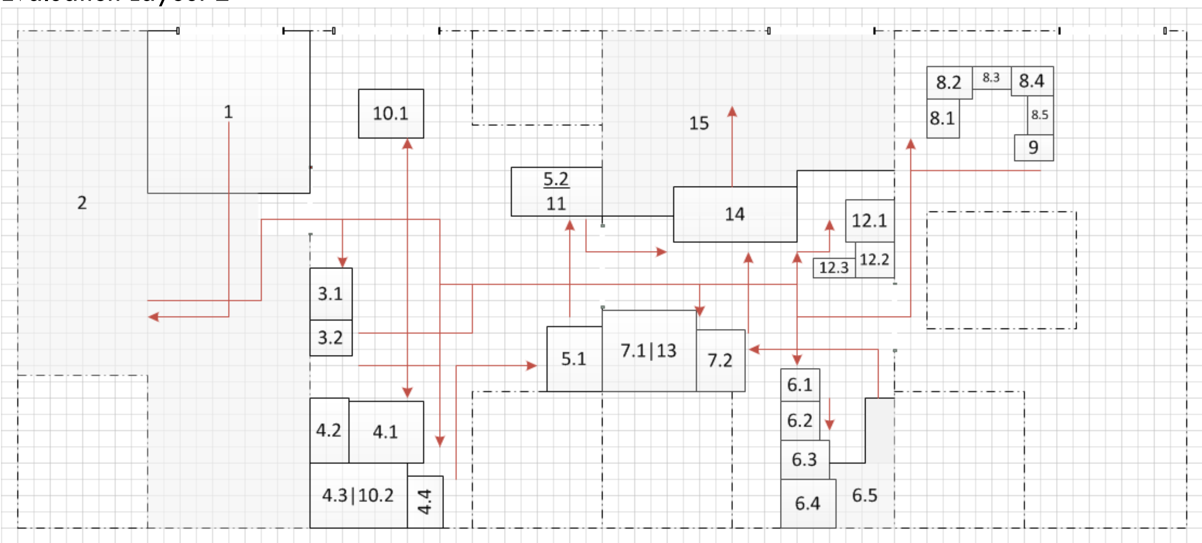


5.5.1 Alternative Evaluation Layouts

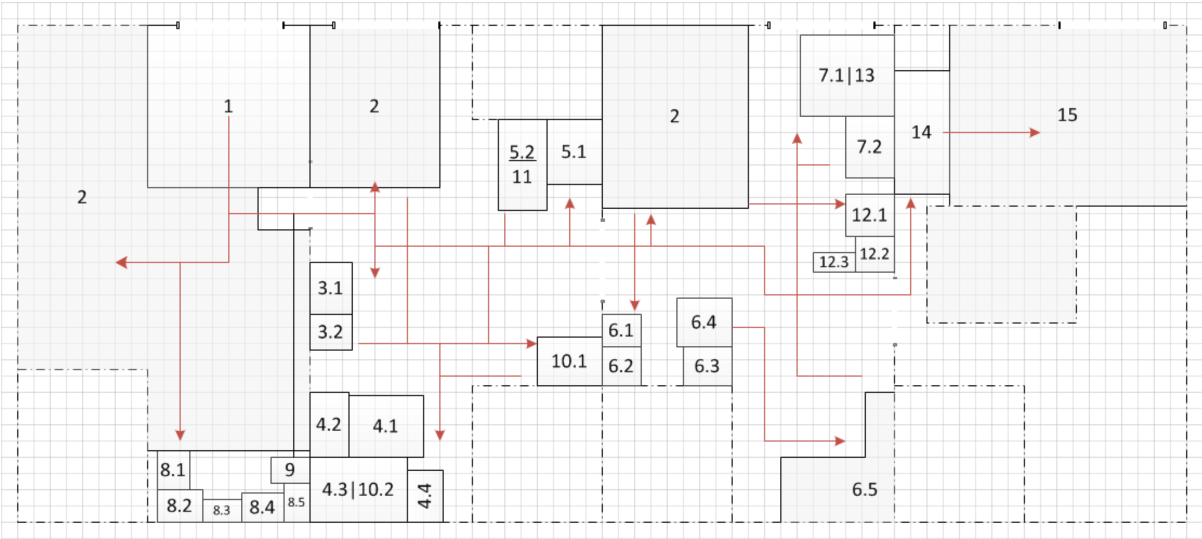
Evaluation Layout 1



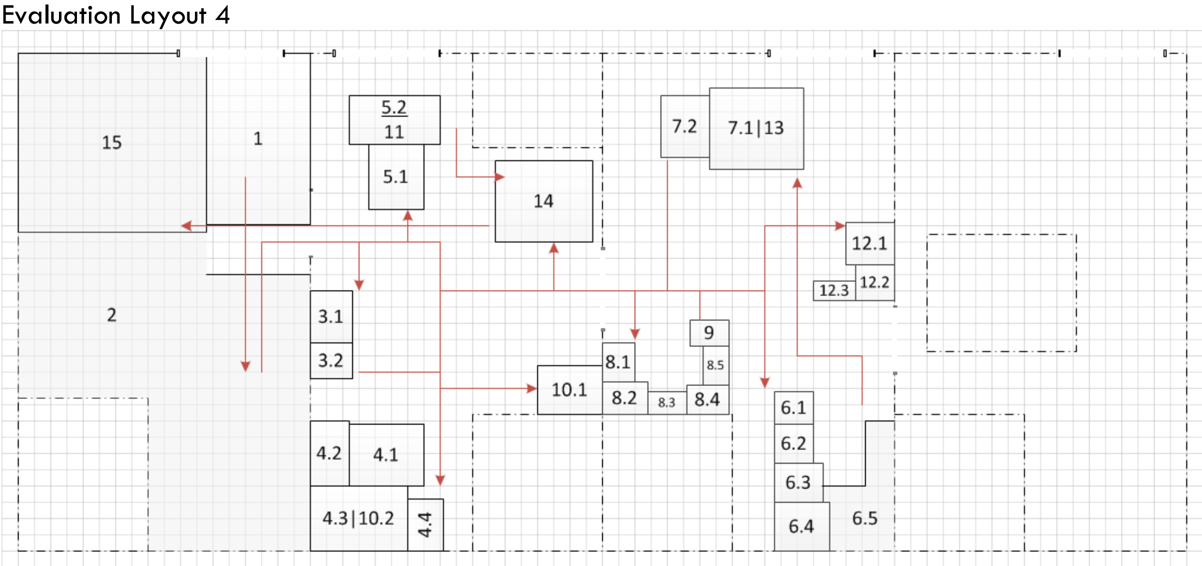
Evaluation Layout 2



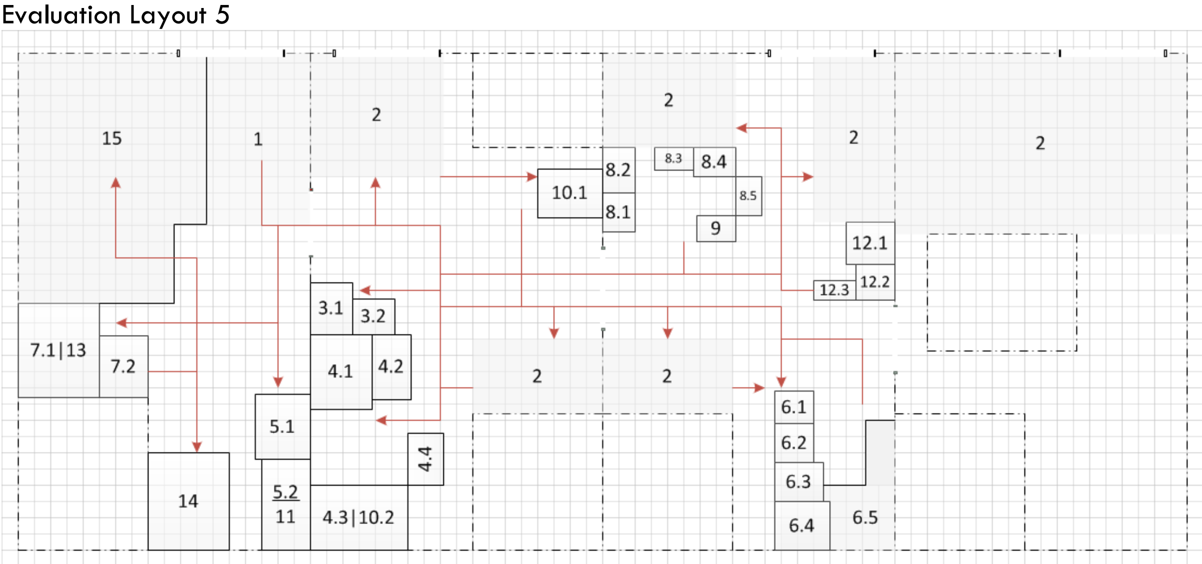
Evaluation Layout 3



Evaluation Layout 4



Evaluation Layout 5



5.5.2 Flow Process Charts

Items undergo several events throughout each process; these events are described in the first column. Each event is either an operation, a transportation, a delay, an inspection or a storage instance and each of these classifications are represented by a symbol (○ ⇨ D □ ▽ , respectively). Every time transportation occurs the distance travelled is measured in the current layout and in each alternative layout and then added to the chart. The distances are summed in the Summary block, where distance travelled in proposed layouts and the current layout is compared and possible savings are indicated. Some blocks are drawn through with a diagonal line; this is used where a specific layout doesn't require any travel for that instance.

TV (Tempering Valve) Flow Process Chart:

		Summary - Transport (m)		
Location: Apex Valves		Proposed	Present	Savings
Avtivity: TV Production				
Date: 17-09-2012	Alternative 1	41.5	82	40.5
Operator: / Analyst:	Alternative 2	44	82	38
Type: Material	Alternative 3	43	82	39
Remarks:	Alternative 4	53.5	82	28.5
	Alternative 5	62	82	20

Event Description	Symbol					Distance (m) Current	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
1→2 received to storage	○	**⇨**	D	□	▽	7	6.5	8.5	22	6	20.5
2 parts stored	○	⇨	D	□	**▽**						
2→12 parts to workstat.	○	**⇨**	D	□	▽	27	26	26.5	3	25.5	
12 place parts	○	⇨	**D**	□	▽						
12 assemble valves	**○**	⇨	D	□	▽						
12 place valves	○	⇨	**D**	□	▽						
12 test valves	○	⇨	D	**□**	▽						
12 place valves	○	⇨	**D**	□	▽						
12 post-assembly	**○**	⇨	D	□	▽						
12 place valves	○	⇨	**D**	□	▽						
12→13 to packaging	○	**⇨**	D	□	▽	9	7	4	3.5	3.5	26.5
13 place valves	○	⇨	**D**	□	▽						
13 label and package	**○**	⇨	D	□	▽						
13 place valves	○	⇨	**D**	□	▽						
13 box	**○**	⇨	D	□	▽						
13 stack boxes	○	⇨	**D**	□	▽						
13→14boxes to unitising	○	**⇨**	D	□	▽	18.5		2.5	11.5	9	4
14→15 to shipping/stock	○	**⇨**	D	□	▽	20.5	2	2.5	3	9.5	11

LVEV (Pressure Control Valve) Flow Process Chart:

Location: Apex Valves		Summary - Transport (m)			
Avtivity: LVEV Production			Proposed	Present	Savings
Date: 14-09-2012		Alternative 1	67.5	104.5	37
Operator:	Analyst:	Alternative 2	65	104.5	39.5
Type: Material		Alternative 3	65.5	104.5	39
Remarks:		Alternative 4	65.5	104.5	39
		Alternative 5	64	104.5	40.5

Event Description	Symbol					Distance (m) Current	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
1→2 received to storage	○	➡	D	□	▽	7	6.5	8.5	13.5	6	14.5
2 parts stored	○	⇨	D	□	▼						
2→3 bodies to stamping	○	➡	D	□	▽	25	12.5	10	3	8.5	7.5
3 stamp	●	⇨	D	□	▽						
3→4 bodies to workstat.	○	➡	D	□	▽	15.5	15.5	5	5.5	6	
4 place bodies	○	⇨	**D**	□	▽						
2→4 parts to workstation	○	➡	D	□	▽	12.5	15	18.5	8.5	17	4
4 place parts	○	⇨	**D**	□	▽						
4 assemble jumps	●	⇨	D	□	▽						
4 place jumps	○	⇨	**D**	□	▽						
4 assemble springs	●	⇨	D	□	▽						
4 place springs	○	⇨	**D**	□	▽						
4 assemble valves	●	⇨	D	□	▽						
4 place valves	○	⇨	**D**	□	▽						
4 tighten valves	●	⇨	D	□	▽						
4 place tightened valves	○	⇨	**D**	□	▽						
10→4 cartridges to work	○	➡	D	□	▽	6	7	8	4.5	6	11
4 place cartridges	○	⇨	**D**	□	▽						
4 attach cartridges	●	⇨	D	□	▽						
4 place valve+cartridge	○	⇨	**D**	□	▽						
4 valve+cart. to testing	○	➡	D	□	▽	4.5					
4 place valve+cartridge	○	⇨	**D**	□	▽						
4 test valves	○	⇨	D	■	▽						
4 place tested valves	○	⇨	**D**	□	▽						
4 secure valves	●	⇨	D	□	▽						
4 attach red caps	●	⇨	D	□	▽						
4 place final valve	○	⇨	**D**	□	▽						
4→5 final valve to pack	○	➡	D	□	▽	8.5	5	6	11.5	9.5	16
5 place final valves	○	⇨	**D**	□	▽						
5 attach nuts	●	⇨	D	□	▽						
5 label valves	●	⇨	D	□	▽						
5 place labelled valves	○	⇨	**D**	□	▽						
5 labelled valves to box	○	➡	D	□	▽			3			
5 place labelled valves	○	⇨	**D**	□	▽						
5 box valves	●	⇨	D	□	▽						
5 stack boxed valves	○	⇨	**D**	□	▽						
5→14 to unitize	○	➡	D	□	▽	5	4	3.5	16	3	
14→15 to shipping/stock	○	➡	D	□	▽	20.5	2	2.5	3	9.5	11

TP (Safety Valve) Flow Process Chart

Location: Apex Valves		Summary - Transport (m)			
Avtivity: TP Production			Proposed	Present	Savings
Date: 14-09-2012		Alternative 1	124	144.5	20.5
Operator:	Analyst:	Alternative 2	92	144.5	52.5
Type: Material		Alternative 3	75.5	144.5	69
Remarks:		Alternative 4	108	144.5	36.5
		Alternative 5	93.5	144.5	51

Event Description	Symbol					Distance (m) Current	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
1→2received to storage	○	**⇨**	D	□	▽	7	6.5	8.5	22	6	18
2 parts stored	○	⇨	D	□	**▽**						
2→3 bodies to stamping	○	**⇨**	D	□	▽	25	12.5	10	3	8.5	11
3 stamp/drill	**○**	⇨	D	□	▽						
3 place bodies	○	⇨	**D**	□	▽						
3→6 bodies to workstat.	○	**⇨**	D	□	▽	8	26	17.5	13.5	18	16
2→6 probes to cutting	○	**⇨**	D	□	▽	22	26.5	27	3	24	1
6 place probes	○	⇨	**D**	□	▽						
6 cut	**○**	⇨	D	□	▽						
6 place probes	○	⇨	**D**	□	▽						
6 short probes to workst.	○	**⇨**	D	□	▽	6	2	1			
6 place probes	○	⇨	**D**	□	▽						
6 ass. probes & bodies	**○**	⇨	D	□	▽						
2→6 parts to workstation	○	**⇨**	D	□	▽	22	26.5	17.5	3	24	1
6 place parts	○	⇨	**D**	□	▽						
6 assemble parts	**○**	⇨	D	□	▽						
6 place parts	○	⇨	**D**	□	▽						
6 total assembly	**○**	⇨	D	□	▽						
6 place valves	○	⇨	**D**	□	▽						
6 valves to testing	○	**⇨**	D	□	▽	5	9		7		
6 valves placed	○	⇨	**D**	□	▽						
6 valves tested	○	⇨	D	**□**	▽						
6 valves placed	○	⇨	**D**	□	▽						
6→7valves to packaging	○	**⇨**	D	□	▽	10.5	13	5.5	9.5	9	31.5
7 valves placed	○	⇨	**D**	□	▽						
7 nuts attached valves	**○**	⇨	D	□	▽						
7 place complete valves	○	⇨	**D**	□	▽						
7 labelling & core	**○**	⇨	D	□	▽						
7 plastic bag sealed	**○**	⇨	D	□	▽						
7 bagged valves placed	○	⇨	**D**	□	▽						
7 boxing	**○**	⇨	D	□	▽						
7 boxes stacked	○	⇨	**D**	□	▽						
7→14 boxes to unitising	○	**⇨**	D	□	▽	18.5		2.5	11.5	9	4
14→15 to shipping/stock	○	**⇨**	D	□	▽	20.5	2	2.5	3	9.5	11

VRV (Vacuum Breaker) Flow Process Chart

Location: Apex Valves		Summary - Transport (m)			
Avtivity: VRV Production			Proposed	Present	Savings
Date: 17-09-2012		Alternative 1	52.5	70	17.5
Operator:	Analyst:	Alternative 2	94	70	-24
Type: Material		Alternative 3	54	70	16
Remarks:		Alternative 4	56.5	70	13.5
		Alternative 5	61	70	9

Event Description	Symbol					Distance (m) Current	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
1→2 received to storage	○	➡	D	□	▽	7	6.5	8.5	8	6	25.5
2 parts stored	○	⇨	D	□	▼						
2→8 bodies to stamping	○	➡	D	□	▽	17.5	19	34.5	5.5	17	
8 place bodies	○	⇨	◗	□	▽						
8 stamp	●	⇨	D	□	▽						
8 place bodies	○	⇨	◗	□	▽						
8 bodies to workstation	○	➡	D	□	▽	4.5					
8 place bodies	○	⇨	◗	□	▽						
2→8 parts to workstation	○	➡	D	□	▽	17.5	19	34.5	5.5	17	
8 place parts	○	⇨	◗	□	▽						
8 assemble parts	●	⇨	D	□	▽						
8 place assembled parts	○	⇨	◗	□	▽						
8 assemble breakers	●	⇨	D	□	▽						
8 place breakers	○	⇨	◗	□	▽						
8 tighten breakers	●	⇨	D	□	▽						
8 place tightened break	○	⇨	◗	□	▽						
8 test breakers	●	⇨	D	□	▽						
8 place breakers	○	⇨	◗	□	▽						
8 attach red caps	●	⇨	D	□	▽						
8 place breakers	○	⇨	◗	□	▽						
8 seal into bags	●	⇨	D	□	▽						
8 place bagged breaker	○	⇨	◗	□	▽						
8→9 breakers to packag	○	➡	D	□	▽						
9 place breakers	○	⇨	◗	□	▽						
9 box breakers	●	⇨	D	□	▽						
9 stack boxed breakers	●	⇨	D	□	▽						
9→14 boxes to unitising	○	➡	D	□	▽	3	8	14	32	7	24.5
14→15 to shipping/stock	○	➡	D	□	▽	20.5	2	2.5	3	9.5	11

LVC (Replaceable Cartridge) Flow Process Chart

Location: Apex Valves		Summary - Transport (m)			
Avtivity: LVC Production			Proposed	Present	Savings
Date: 17-09-2012		Alternative 1	38.5	61.5	23
Operator:	Analyst:	Alternative 2	46.5	61.5	15
Type: Material		Alternative 3	60.5	61.5	1
Remarks:		Alternative 4	51	61.5	10.5
		Alternative 5	48	61.5	13.5

Event Description	Symbol					Distance (m)					
	○	⇨	D	□	▽	Current	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
1→2 received to storage	○	●	D	□	▽	4	6.5	8.5	13.5	6	7
2 parts stored	○	⇨	D	□	●						
2→10 parts to workstat.	○	●	D	□	▽	12.5	16.5	13	8.5	17	3
10 place parts	○	⇨	●	□	▽						
10 assemble parts	●	⇨	D	□	▽						
10 place parts	○	⇨	●	□	▽						
10 glue and tighten	●	⇨	D	□	▽						
10 place parts	○	⇨	●	□	▽						
10 measure test	○	⇨	D	●	▽						
10 post-assembly	●	⇨	D	□	▽						
10 place cartridges	○	⇨	●	□	▽						
10→4 to testing	○	●	D	□	▽	11	4.5	8	6	6	11
4 place cartridges	○	⇨	●	□	▽						
4 test	○	⇨	D	●	▽						
4 place cartridges	○	⇨	●	□	▽						
4→11 to packaging	○	●	D	□	▽	8.5	5	11	11.5	9.5	16
11 place cartridges	○	⇨	●	□	▽						
11 label and package	●	⇨	D	□	▽						
11 place cartridges	○	⇨	●	□	▽						
11 box	●	⇨	D	□	▽						
11 stack boxes	○	⇨	●	□	▽						
11→14 to unitising	○	●	D	□	▽	5	4	3.5	18	3	
14→15 to shipping/stock	○	●	D	□	▽	20.5	2	2.5	3	9.5	11

Outline of savings identified in all five Flow Process Charts:

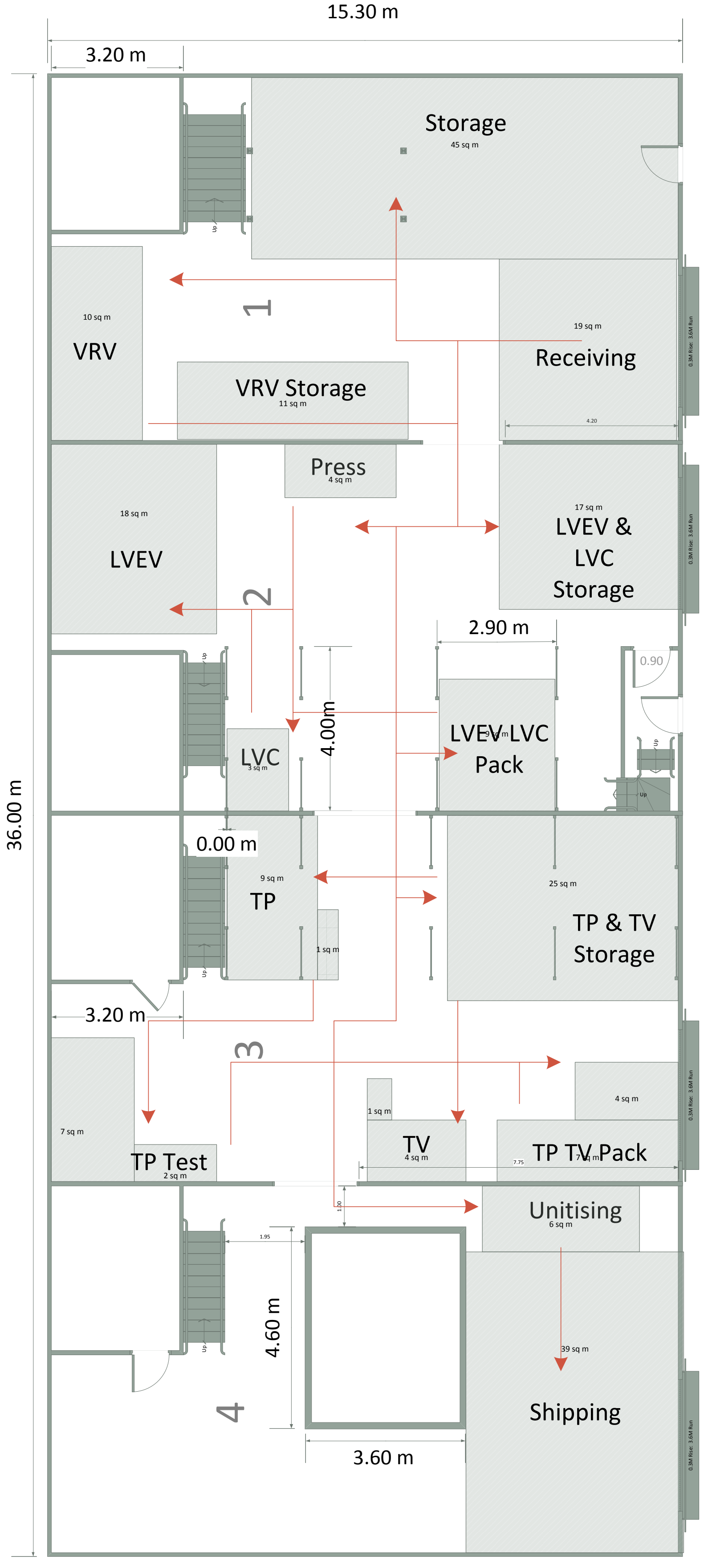
Flow Process Chart	Current Layout Flow (m)	Alternative Layout Flows (m)	Savings (m)	Alternative
LVEV Flow Process Chart	104.5	67.5	37	1
		65	39.5	2
		65.5	39	3
		65.5	39	4
		64	40.5	5
TP Flow Process Chart	144.5	124	20.5	1
		92	52.5	2
		75.5	69	3
		108	36.5	4
		93.5	51	5
VRV Flow Process Chart	70	52.5	17.5	1
		94	-24	2
		54	16	3
		56.5	13.5	4
		61	9	5
LVC Flow Process Chart	61.5	38.5	23	1
		46.5	15	2
		60.5	1	3
		51	10.5	4
		48	13.5	5
TV flow Process Chart	82	41.5	40.5	1
		44	38	2
		43	39	3
		53.5	28.5	4
		62	20	5

This table shows that Layout Alternative 5 would benefit LVEV (Pressure Control Valve) production the most; with a saving of 40.5m. Layout Alternative 3 would benefit TP (Safety Valve) production the most, with a saving of 69m. It can also be seen that TP production currently requires the largest amount of parts travelled, which could have been reasonably predicted when looking at the complex travel around the built in vault to move completed valves to packaging. Layout 1 is preferred to reduce travel for VRV (Vacuum Breaker), LVC (Replaceable Cartridge) and TV (Tempering Valve) production. To get an overall indication of transport saving, however, we add transport distances required from all products in each layout:

Layout	Total Travel (meter)
Current	462.5
Alternative 1	324
Alternative 2	341.5
Alternative 3	298.5
Alternative 4	334.5
Alternative 5	328.5

The table of total distances travelled in each layout reveals that Layout Alternative 3 would lead to the least amount of material travel and the largest saving in transport.

Detailed drawing of selected layout (Layout Alternative 3):



5.6Conclusion

To create an environment shaped by the rule of time saving is the goal of this project. Focussing on material flow and the placement of activities, transport saving leads to time saving. In this project production processes of five products assembled at Apex Valves were analysed. Each prominent activity was identified and arranged in an optimal structure relative to one another according to Systematic Layout Planning.

With the attained structure five alternative layouts were proposed for the improvement of material flow and time saving. Using a distance travelled method with the aid of Flow Process Charts and scale drawings of each layout, the alternatives were evaluated and compared to result in a final selection.

The layout alternative selected was Layout Alternative 3. This layout utilises a different approach to storage; instead of a single storage source there are added intermediate storage areas. This element enables more small distances travelled with materials, rather than long distances across more than one factory unit. Every factory unit possesses a roller door which could be utilised more. At present only one roller door (unit 1) experiences high utilisation.

The selected layout also moves the packaging process currently in the 'vault obstructed factory unit 4' to factory unit 3. This saves a great deal of transport for the product (Safety Valve) that presently requires the most material travel. Unitising and Shipping/Inventory is moved to factory unit 4 in place of packaging; this enables the move to Unitising to be the absolute last move in the process (since very little movement is required from unitising to shipment right next to it). The placement also creates an approximate straight flow through the four factory units, from Receiving to Shipment.'

An analysis and improvement of batching is recommended for further optimising of Apex Valves. Detailed designs and restructuring of individual workstations will also benefit material flow and efficiency. The first step however; will be to implement the selected layout.

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