Layout Planning Of Assembly Areas for Optical Systems

by

MARLI VAN BILJON
26053668

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EXECUTIVE SUMMARY

The Eagle Eye Locating System is an innovative product, with significant international sales potential. For the manufacturer, Carl Zeiss Optronics Ltd (Pty), it is essential that the product should be of high quality and reliability. Marketing of the product concepts has already indicated an initial demand. Meeting the demand timeously is important since the technology is already in the public domain and could be copied by competitors.

This product is complex, and is currently assembled in batches, with the assembly line showing no signs of stable flow and consequently unable to achieve the desired production rate. Zeiss has decided to rearrange the production facility, and dedicate specific workstations and personnel to the assembly of the Eagle Eye, removing the risk of production floor congestion. In this document it is shown how various techniques have been used to draw a proposed facility layout that could sustain a stable assembly flow.

The proposed locations of the workstations inside the assembly area have been mapped. Not only the material movement, but also the important communication flows between the workstations have been incorporated. The best alternative layout has been selected with supporting simulations. A simulation showing the total cycle time at each workstation has been used to determine the effect of uncertain operation times and the balance of workload at each workstation. The actions to balance the cycle times and proposed close proximity of applicable workstations could ensure an optimal stable flow of assembly.

With a stable production flow established the sub-assemblies will not need to be moved to the store room for safety, decreasing inventory levels, material movement and labour required. Overall the throughput will be increased and the forecasted demand can be satisfied.

If the proposed actions are taken the total time required to produce a batch of ten Eagle Eyes will be reduced by ten man hours.

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1. INTRODUCTION AND BACKGROUND

1.1. The Company

Carl Zeiss Optronics (Pty) Ltd, a business unit of the Carl Zeiss Optronics group situated in Germany, is one of the leading providers of optical and opto-electronic products for security and defence. Heeding their slogan, “We make it visible” (shown in figure 1), the company provides its customers, such as the Army, Air Force and Navy, with more than a hundred years of experience in military optics. Products manufactured are complex, specialized and apply innovative technology. This complexity makes the production process consist mostly of assembly work, and is thus labour intensive. All the production workers are specially trained in the assembly of electro-optical components. Zeiss’s future is built on human intelligence and skills, and all functionaries are viewed as resources to be nurtured.

Figure 1: Zeiss Logo and Slogan

For all optical components ISO 14644 describes a scale for determining the quantity of dust particles present in a cubic metre of air, and states that certain sub-assemblies may only come into contact with a certain standard of cleanliness. Currently the production floor is divided into two sections: a 100 000 (100K) section and 1000 (1K) section, were the 1K section is the cleanest. Keeping the rooms clean is a group effort and a dress code and code of conduct has been established.

1.2. The Product

The Eagle Eye Locating System, or Eagle Eye, is a handheld binocular and Target Location System. The Eagle Eye determines the coordinates of a target by means of an integrated Eyesafe Laser Rangefinder, GPS and Digital Magnetic Compass. As shown in figure 3, the Eagle Eye also includes a digital camera for digital pictures and video, as well

Figure 2: Eagle Eye’s functionality breakdown.

as audio recording. The attendant data can either be stored or transmitted real-time.

In essence the product can locate a target (in GPS co-ordinates) using the co-ordinates of its current position, the direction it is pointing according to the compass, and the distance measured to the object.

The advanced technology applied and the uniqueness of the product affords Zeiss a competitive advantage in the international market. Producing and selling as many units as possible before competing companies create a similar product will ensure that Zeiss will have a large market share with the passage of time.

The application of this product realistically requires it to be tough, sturdy and of good quality to resist severe environments. Testing must be done to simulate the reality of the applied environment. After being subjected to enduring vibrations, extreme cold and heat, the product is retested to ensure that components are still correctly aligned and that optical measurements are still accurate.

Important facts about the manufacture of the Eagle Eye are as follows:

- All parts and sub-assemblies are outsourced. No manufacturing is done, only assembly.
- Parts and sub-assemblies are valuable and fragile, and must be packed away at the end of each shift.
- Various sub-assemblies must remain in the 1K section of the production line. The space in the 1K section is limited.
- After each assembly a quality check is required, performed by a quality functionary.
- After quality checks the products are packaged for storage and moved back to the warehouse, to be sourced when required.

A production line is at present being implemented for the Eagle Eye, with a current production rate of less than 20 units per month. The demand forecast for the product is 80 units per month for the coming year.

1.3. Current Situation

- A prototype has recently been approved and the product is in the Industrialization phase.
- Some assembly processes still requires engineering input.
- Projected process times have been determined.
- Workstations have arbitrarily been assigned responsibilities, and
- The integrated Management Information System and Enterprise Resource Planning software, SAP, is utilized for materials and inventory management, all process transactions are recorded by the system. SAP is already updated with the Bill of Materials and provides the projected process times, and instructions for each assembly process.

1.4. Current Problems Experienced

1. The current bottle-neck processes are Quality control, and packaging and retrieving of sub-assemblies from the stores.
2. Sub-assemblies are damaged during handling between workstations and the warehouse.
3. The production line is not properly configured in terms of material movement.
4. Several technicians are performing work that operators are capable of performing, thereby increasing the direct labour cost.
5. Work-in-process and warehouse inventory levels are erratically fluctuating.

2. PROJECT DESCRIPTION

2.1. Project Aim

Zeiss requires a planned flow and facility layout of the Eagle Eye's assembly area. The planned layout will aid Zeiss in rearranging the current facility layout to establish a more stable assembly flow. The project will examine the current tasks, desks and personnel allocated to each workstation, ensuring that the line is balanced in capacity. Once a stable and balanced flow is established functionary utilization, and throughput will improve while inventory levels will decrease.

Parts and sub-assemblies are fragile and expensive; hence work-in-process inventory and product movement should be minimized. This can be achieved by eliminating unnecessary transfers of sub-assemblies to and from the warehouse.

Sub-assembly quality checks should not increase cycle time and respectively contribute to an increase in product cost. While an functionary waits a valuable resource is lost, the effect on the total cycle time and direct labour cost differs depending on the functionary's level of skills. The relationship between the unpredictable waiting time for a functionary of the quality department, and the cycle time and direct labour expense of the whole assembly process, should be investigated.

2.2. Project Scope

Through implementation of the following tools and methods the outcomes of the project include:

1. Using Systematic Facilities Planning
   - A planned facility layout design, indicating locations of workstation tables, and testing equipment.
2. Using a Monte Carlo Simulation in Excel, the averages of the following:
   - The total cycle time for assembly
   - The total process time for each workstation and work desk
   - A Cost Function for determining the direct labour cost.

3. Combining the results
    - The location of each workstation desk and its job description, ensuring balanced flow, with minimum material movement.

The project includes the assembly, testing, and quality checking of the Eagle Eye; procurement and shipment are excluded.

2.3. Project Approach

Figure 3 shows the sequential elements, or groupings of steps, and accompanying tasks to be performed. The sequence of the elements depicted in Figure 3 below is used to navigate through this document. The tasks within each element are a combination of:

- The collection of data.
- The application of the appropriate tools and techniques for analysis.
- The evaluation of the results.

Tasks that require the collection of data are indicated with a letter ‘D’, while tasks that lead to a visible outcome are indicated with a letter ‘V’.

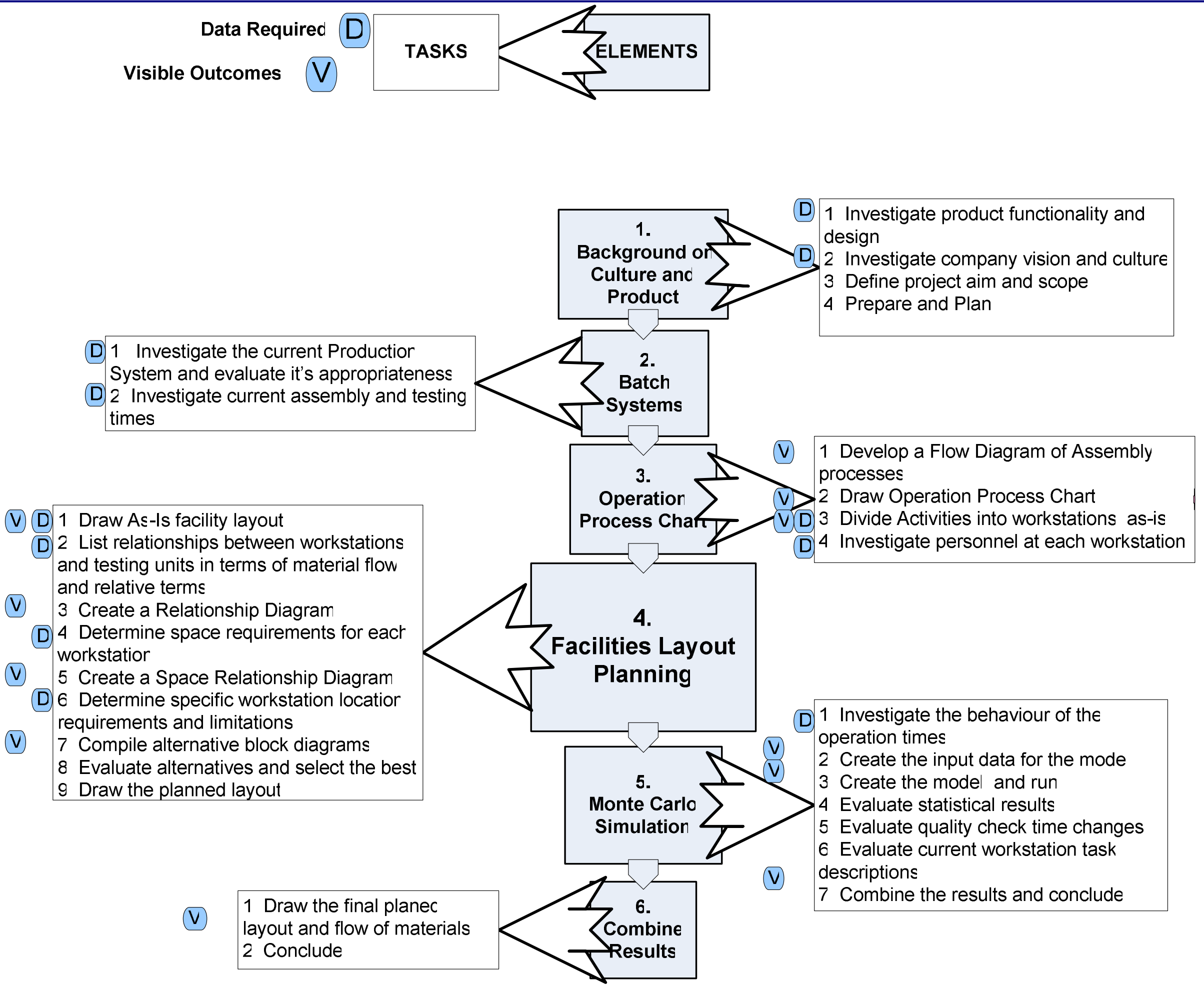


Figure 3: Project Approach

The relative importance of each element is portrayed by its relative size. Facilities Layout Planning dominates the project elements, followed by Monte Carlo Simulation, supplemented by Batch Production System and Operation Process Chart concepts. The goal of supplementary methods is to aid the decision making process during the application of the tools and techniques, to vouch for the value of the results achieved.

3. LITERATURE REVIEW

3.1. Introduction

According to Garzia-Diaz and Smith (2007:78) the first step in any decision making process is an examination of the current situation by performing a "Situational Analysis". Subsequently a set of goals should be established. Situational Analysis requires the collection of appropriate data while the goals set are used during the decision-making process to determine the best course of action.

The structure of the following literature review is done accordingly. For each method or tool used an overview, a list of required data and possible evaluation criteria is given, as shown in Figure 4. Additional categories are created when necessary.

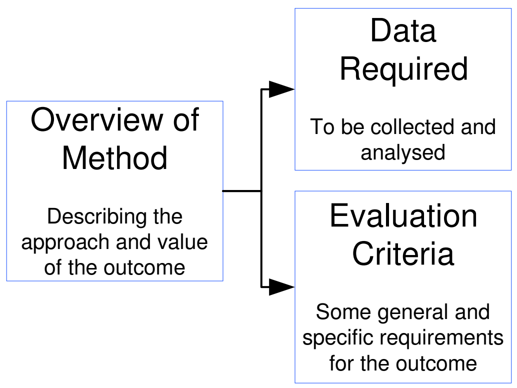


Figure 4: Basic structure literature reviews.

3.2. Batch Flow

A focused factory should use the production system most capable of producing the mix and volume of products and providing manufacturing outputs required by the factory's customers (Miltenburg, 2005:51). There are seven different production systems, including Batch Flow in a Batch Shop layout. A Batch Shop can be described as a fairly standardized job shop, and is appropriate for the production line of complex products, such as electronic devices (Chase et al, 2006:210).

Characteristics of a Batch Flow production system (Miltenburg, 2005:52):

- Functionaries: Few and Multi-skilled
- Material flow: Varied with noticeable patterns
- Material layout: Cells and functional
- Equipment: General purpose, some specialization
- Organization style: Entrepreneurial
- Production line: Relatively stable
- Manufacturing output required: Moderate quality; good performance, flexibility and innovativeness
- Products: large variety with low volume.

3.3. Operation Process Chart

The charting of work flows, working processes, systems and procedures is a useful way of recording the essential features of a work situation for subsequent analysis (Institute of Management, 2009).

The development of a facility layout involves the study of the production line flow charts, material flow diagrams, product routings, and process times (Aleisa and Lin, 2005:1381); all of which are combined on the Operation Process chart (Heragu, 2006:27). Assembly flow charts and route sheets combine to create the Operation Process Chart that not only shows the sequence of combining sub-assemblies, but also the production methods used (Tompkins et al, 2003).

The workstation job descriptions can be indicated on the Operations Process Chart by circling the grouping of processes (Hales, 1984:19). From this the interfaces and direct flow of materials between workstations becomes unambiguous.

3.4. Facilities Layout Planning

3.4.1. Overview

"Facility or plant layout is a part of facilities design, which includes more global issues such as plant location, building design, material handling et al." (Aleisa and Lin, 2005: 1381). Facilities can be generally defined as buildings where man, machine and materials come together for a stated purpose or goal (Heragu, 2006:3). In order to use the floor space available in the most effective manner Facilities Layout Planning examines the existing building's space available, and while still considering possible restrictions, divides the space between business units according to requirements. As described by Garzia-Diaz and Smith (2007:6): "…, facility layout is the field of selecting the most effective arrangement of physical facilities that allows the greatest efficiency in the allocation of resources needed to manufacture a product or perform a service. "

3.4.2. Objectives of Facilities Layout Planning

Some Facilities Layout Planning objectives are (Tomkins, 2003; Hales, 1984; Te-King, 2004) as follows:

- Increase total productivity and turnover.
- Effectively utilize space, equipment and people.
- Reduce production costs consisting of fixed and variable expenses.
- Improve materials handling, material flow and overall housekeeping.
- Provide functionary safety and comfort.
- Create an adaptable system for continuous improvement.
- Minimizing total inventory and work-in-process levels.

3.4.3. The Systematic Approach

Richard Muther developed Systematic Layout Planning (SLP) which is a procedure that can easily be employed to plan the layout of any business element. SLP is appropriate for problems where the quantity of product flow between departments is impractical or does not entirely reveal the qualitative factors important for layout decisions (Te-King, 2004; Chase et al, 2006). The nine-step procedure framework described in Muther's book (Systematic

Layout Planning) is an efficient and in-depth planning formula (Hales, 1984:40), shown in Figure 5. Each step requires the implementation of at least one planning technique. The pattern of procedures, or steps, are grouped into three Fundamentals: "Relationship, Space and Adjustment". If followed meticulously SLP provides clear rules and principles for guiding the development of planned layouts (Hales, 1984:40).

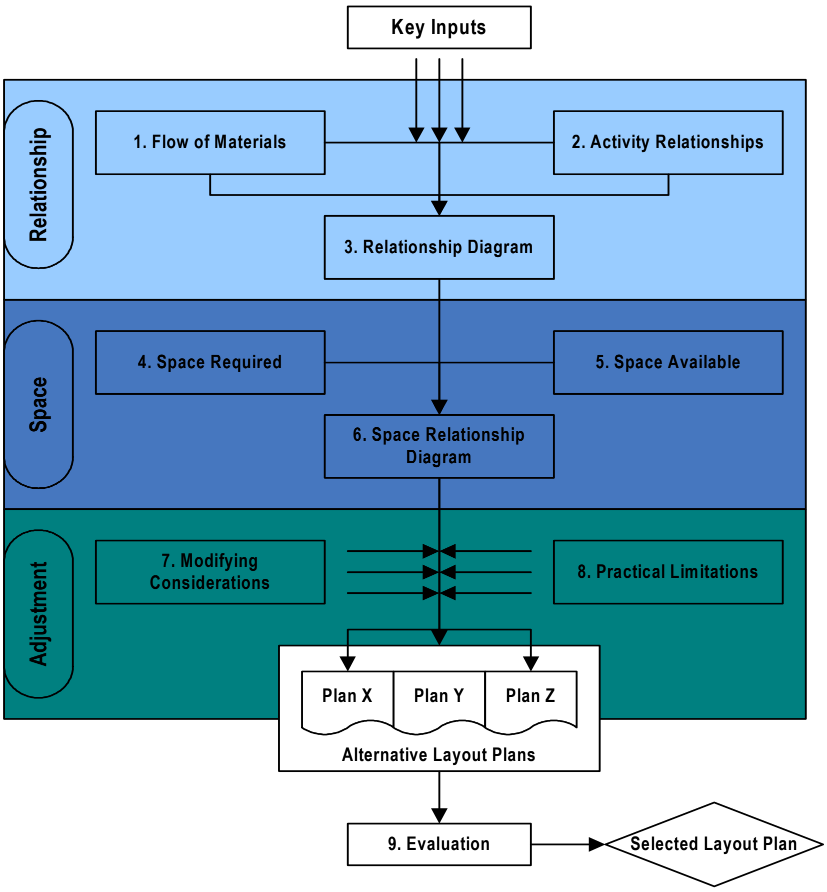


Figure 5: Systematic Layout Planning, SLP, Pattern of Procedures. Adopted from Hales (1984)

3.4.4. Breakdown of SLP Diagrams

Flow of materials and product routings, along with an Activity Relationship and/ or From-To Chart, forms the foundation of data input, collectively describing the flow and relationships between business units (Aleisa and Lin, 2005:1381; Tompkins et al, 2003). From this information a Relationship Diagram is drawn, with each business unit represented by a node, and lines connecting the nodes describing the relationship between the two nodes in question (Tompkins et al, 2003). Thereafter each department lists its space requirements and the available space is divided accordingly. Scaled blocks are drawn to replace the nodes to illustrate the space granted to each, creating the Space Relationship Diagram. The distance between blocks with a strong relationship is decreased until a variety of alternative block diagrams can be drawn. At this juncture the best solution may be selected. This process is shown in Figure 6. During all the above mentioned steps the constraints, obstacles and practical implications need to be considered.

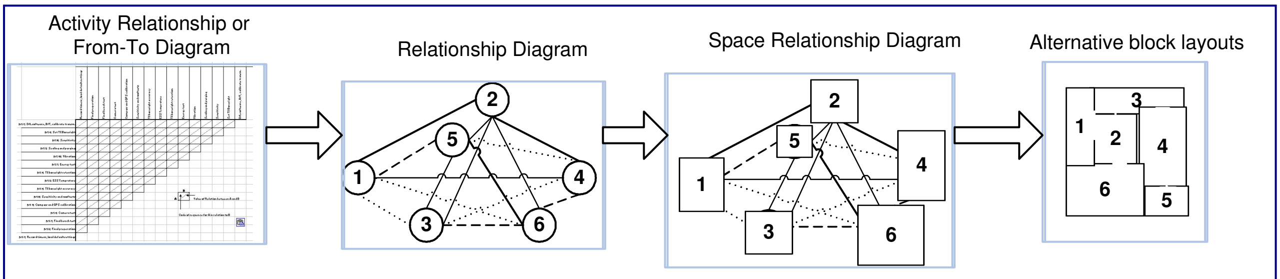


Figure 6: Extract from Muther's Systematic Layout Planning Procedure. Adopted from Tompkins et al (2003)

3.4.5. Data Requirements

Figure 7 shows the data required for making informed layout decisions as stated by Heragu (2006:55).

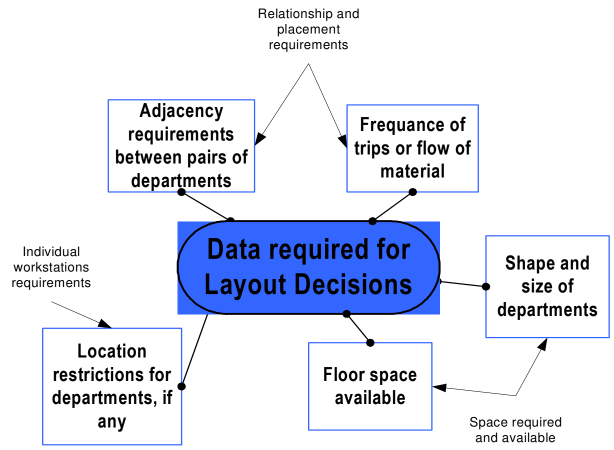


Figure 7: Data needed for layout decision-making, adapted from Heragu (2006)

3.4.6. Evaluation Criteria of solution

Evaluation criteria to be set and used as a measuring tool, can be categorized under three headings (Garzia-Diaz and Smith, 2007:78):

- Adaptability required.
- Allowable economic impact.
- Process effectiveness, flow of materials, and utilisation of resources.

Ranking and weighted average methods could be used to select the best alternative. Ranking the alternative solutions against the above evaluation criteria involves comparing each alternative against a common set of factors, and assignment of appropriate numerical values (Tompkins et al, 2003: 680).

3.5. Monte Carlo Simulation

3.5.1. Overview

In a Monte Carlo simulation an attempt is made to follow the time dependence of a model for which change does not proceed in some predefined fashion, but rather in a stochastic behaviour, which depends on random numbers generated during the simulation (Landau and Binder, 2005:1). The application of a Monte Carlo simulation is thus based on the statistical concept that, when random variables are aggregated, the total becomes increasingly unpredictable. A Monte Carlo (MC) simulation model requires a number of input parameters which to process using given mathematical expressions, to reveal the required outputs (Raychaudhuri, 2008: 91).

According to Wikimedia (2009) there is no single Monte Carlo method. The term describes a vast and widely-used class of approaches. All the approaches tend to follow a distinctive pattern (Wikimedia, 2009):

- Define a domain of possible inputs
- Use the input domain to generate inputs randomly
- Perform a deterministic computation using the inputs
- Aggregate the results of the individual computations into the final result.

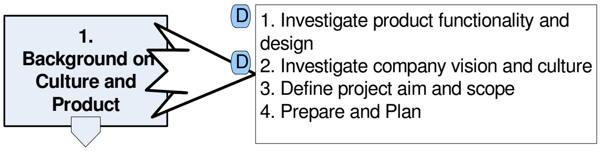
Using only the averages, or expected values, is sometimes infeasible or impractical. When significant uncertainty exists a MC simulation is used (Wikimedia, 2009). A Monte Carlo simulation model can be developed in Microsoft Excel, and add-ins such as @Risk aid the calculation and results analysis (Richardson et al, 2000:300, Winston et al, 2009:582). "First, it provides a number of probability functions that enable you to build uncertainty explicitly into Excel models. Then when you run a simulation @Risk automatically keeps track of any outputs you select, displays the results in a number of tabular and graphical forms, and enables you to perform sensitivity analyses, so that you can see which inputs have the most effect on the outputs." (Winston et al, 2009:19).

3.5.2. Data required

The input parameters describe the probability function of all possible random variable inputs. The input variable does not need to be simplified through assumption, which leads to the probability function reflecting the true uncertainty (Winston et al, 2009:722). A random variable is generated when the model is run, and the corresponding output is given. The second time the model is run the random variable inputs will differ, and the model will not yield identical results (Landau and Binder, 2005:1; Winston et al, 2009:616). The correlation between the input variable distribution and the output distribution can be determined using @Risk (Winston et al, 2009:632).

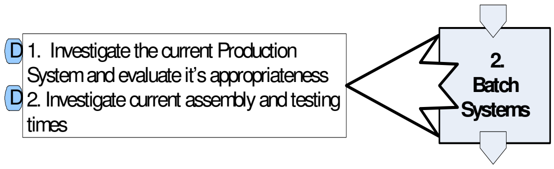
4. DEVELOPMENT OF CONCEPTUAL DESIGN

4.1. Background on Culture and Product



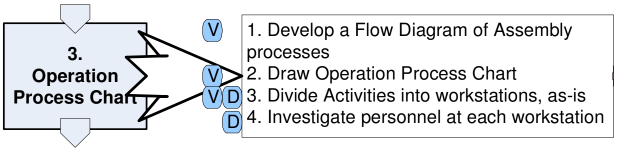
Through investigation of documentation and personal conversations an in depth understanding of the company culture and the collective goal has been created. The innovative and quality conscious atmosphere should be supported by the new Facility Layout. The documented project proposal has been approved.

4.2. Batch Flow Production System



The assembly at Zeiss is currently done in batches of 10. Measured against all the characteristics of a typical Batch Flow production system, it is appropriate for the assembly of the Eagle Eye. Thus, this production system should be used in the future facility layout.

4.3. Operations Process Chart



4.3.1 Assembly Flow Diagram

Figure A1, depicted in Appendix A, shows the flow diagram of the sub-assemblies, drawn form the family tree and Assembly Instructions. The diagram contains all the sub-assemblies necessary to produce the Eagle Eye. Each block represents a sub-assembly, already assembled from parts on the Bill of Material, except the green blocks which represents an outsourced PC Board. A dashed line around a block indicates that the sub-assembly is what is known as a 'Phantom': The sub-assembly is indicated, but is immediately and directly integrated, and therefore not seen as a separate sub-assembly. The number at the top of each block indicates the sequence of use during the assembly, and the letter indicates the sub-assembly it is integrated into.

4.3.2. Operations Process Chart

The flow diagram, assembly instructions, and process times collectively form the Operations Process Chart. For simplicity the chart is divided into two separate figures in Appendix A: All the operations needed to be completed up to sub-assembly F, or the Right channel Assembly, is shown in Figure A2, and completion of the product G, or the Main assembly, and the final mandatory tests are shown in Figure A3.

4.3.3. As-is Workstation Allocation

Twelve workstations have been created and assigned operations. Workstations group functional areas or cells, corresponding to the Batch Shop characteristic. The workstations each consist of a few workstation desks, each manned by an functionary according to need. All the workstations are listed below in Table 1.

Workstation Number	*Name*	*Main function*
1	Class 1000	Sub-assembly in main 1K section
2	Class 100 000	Sub-assembly in main 100K section
3	Glue rubbers	Gluing
4	OPO/Transmitters	Align and insert Transmitters
5	Right Channel Assembly	Complete Right Channel assembly
6	Final integration	Complete final assembly
7	TX Alignment/Optical Test	Conducting optical tests
8	Debugging/Testing	Overall testing
9	ESS, Leak test/Purge	Test seal and cleaning
10	ATP/Roof test	Test by aiming at set target outside
11	Compass/GPS test	Test GPS and compass readings outside
12	Vibration Test	Vibrate for a prolonged period of time

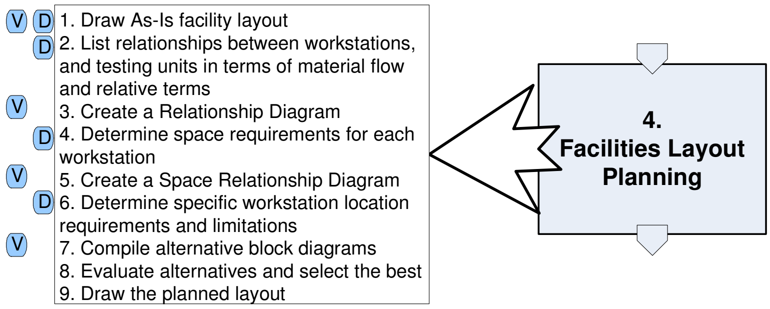
Table 1: Workstations currently defined

In Figure A4, in Appendix A, the responsibilities of each of the workstations have been indicated on the Operation Process Chart by the number of the workstation inside the diamond shape corresponding to the numbers given in Table 1.

4.3.4. Task Allocation

Each assembly operation requires an operator, artisan, technician or quality controller, and functionaries are assigned to operations automatically by SAP. Functionaries neither man a single workstation desk, nor assemble sub-assemblies only for the Eagle Eye. The first available component functionary to fulfil the skill is assigned to the following pending operation.

4.4. Facilities Layout Planning



4.4.1. As-is Facility Layout

The current location of each of the workstations inside the entire production area is shown in Figure A6, in Appendix A. The 100K and 1K section is also indicated in the sketch. The dressing room is accessed through an airlock room with a double door entry. Sub-assemblies crossing the border between the two workstations need to be moved through an airlock. Workstations number 10, 11 and 12 are all situated at a distance from the production floor.

4.4.2. Relationships

The relative relationship between any two workstations is the combination of two factors: firstly the amount of material or sub-assemblies that would flow directly, once the movement to the storage is removed; secondly the information and communication channels required and the relative amount of communication. To quantify the material flow the movement to storage is momentarily avoided and direct links have been created. In most cases the information and communication flow resembles that of the material flow, for example the documentation needs to be forwarded along with each sub-assembly. Communication flow also exists in the opposite direction to the material movement when an error or defect is found. This constructive feedback allows for total quality improvement.

- **From-To Chart**

For the quantifiable material movement relationship a From-To Chart has been created after transforming the data received. The Operation Process Chart with the previously indicated workstation numbers (Figure A4 and A5), shows the location where each activity is performed. It has been found that the activities performed after final integration is more complex than indicated previously. The flow diagram in the Figure A7, in the Appendix, shows the final tests performed clearly. The figure has been created using symbols similar to those of the Operation Process Chart. The test groupings of the Operation Process Chart are shown in dashed blocks.

The flow of the sub-assemblies are depicted in the simplified flow diagram in Appendix A Figure A8. The number in each diamond corresponds to a workstation number, and the in-and-out flow of sub-assemblies is graphically illustrated with connecting lines. The number indicated on the line is the number of sub-assemblies that indirectly move between the two workstations, in the direction of the arrowhead. The kits received from storage are not shown. The From-To chart is Figure A9 in the Appendix. The numerical value in a block indicates the number of batches of sub-assemblies that would directly move from the workstation number on the left, to the workstation number indicated above.

- **Relationship Chart**

Feedback loops are required for continuous quality improvement initiatives. Communication is likely between the testing and assembly workstations, a relationship that has been noted as "Ordinary" on the Relationship Chart in Figure A10, in Appendix A. If the possibility of direct material flow exists the relationship is stronger, and has been noted either as "Important", "Especially Important" or "Absolutely Necessary", depending on the amount of sub-assemblies.

Workstation number seven has a unique relationship with all the other workstations. During the operations performed on the final assembly at workstation number seven, mostly tests, problems and errors come to light. All the other workstations have contributed to this final system, including the vibration test, and any one could be the cause. If an assembly fails the tests or quality checks, the sub-assembly causing the problem is located and the workstation responsible for that sub-assembly is informed and questioned.

Zeiss encourages open line of communication for feedback and comments between workstations, no relationship is undesirable. Even if communication only flows during a crisis, communication channels are always available.

4.4.3. Relationship Diagram

The values in the Relationship Chart include the significance of the indirect material flow, the From-To Chart values. The relationships in the Relationship Chart have been directly used to create a Relationship Diagram, shown in Figure 8.

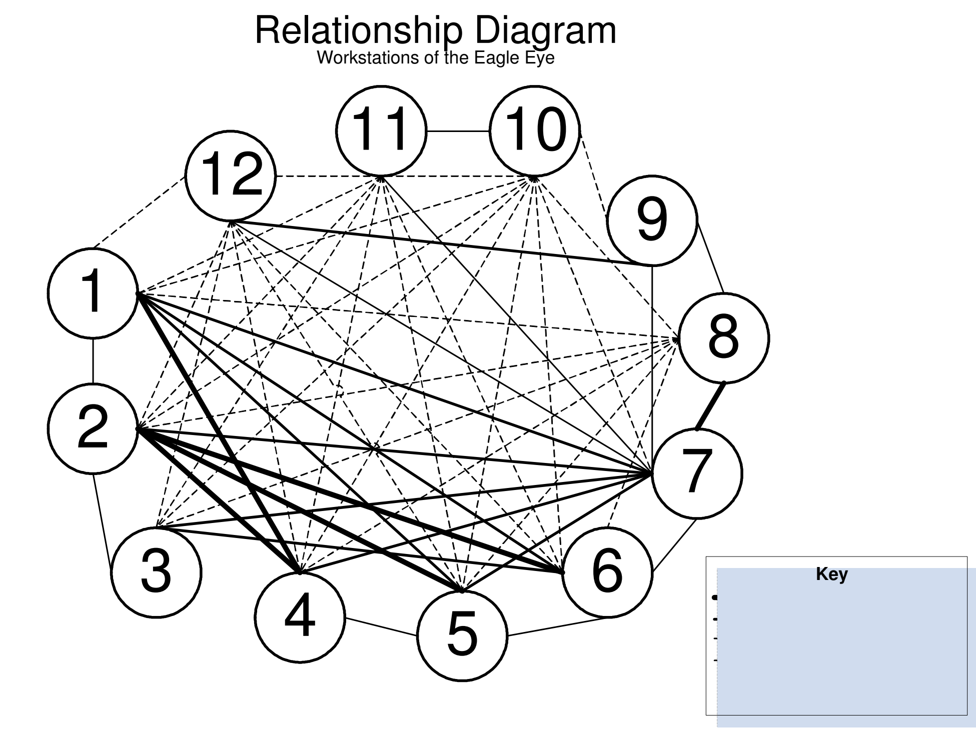


Figure 8: Relationship Diagram of the Eagle Eye's workstations

4.4.4. Space Requirements

The floor space currently occupied by each workstation does not reflect the actual floor space required. At certain workstations space is wasted, while at others functionaries cannot move and operate comfortably. The current space occupied and the projected space required by each workstation has been determined, shown in Table A1, in the Appendix. The space currently used by each workstation has been determined. The measurements that have been taken are shown in Figure A11, in the Appendix. The total floor space required is a sum of the space occupied by the work desks, storage and other equipment, as well as adequate space for comfortable movement.

The most common work desk used has a rectangular surface with dimensions of 1800 mm x 800 mm, at a comfortable height for working while standing or sitting on a high chair. As a standard Zeiss allows at least 1.35 m in front of each desk for comfortable working space, but desks may be arranged next to each other or back to back without allowance. The work desk surface and the allowed space behind the desk summed together equals 3.87 m^2, the total space required by each desk. The number of desks required by each workstation is as a result of the work desk configuration. The tools required for operations of groups of operations are determined and the tools and equipment required is that assigned to a desk. The number of work desks required does not reflect the number of functionaries assigned to it.

A second kind of workstation desk is larger and softened by air pockets, with dimensions of 1040 mm x 2050 mm. The surface of the table is supported by compressed air to minimize the natural disturbance and vibrations during assembly and testing. To ensure comfort during work the functionary should be able to move around at least three sides of the table freely. A total space of 9.3 m^2 should be reserved for this desk.

The dimensions of the large cabinets used to store excess tools and equipment are 500 mm x 1200 mm each. Normally a minimum of two is required, adding up to a total space of 1.2 m^2.

4.4.5. Space and Relationship Combined

The space requirements have been scaled and fitted to the Relationship Diagram, forming the Space Relationship Diagram, shown in Figure 9. The space required is shown below the workstation number.

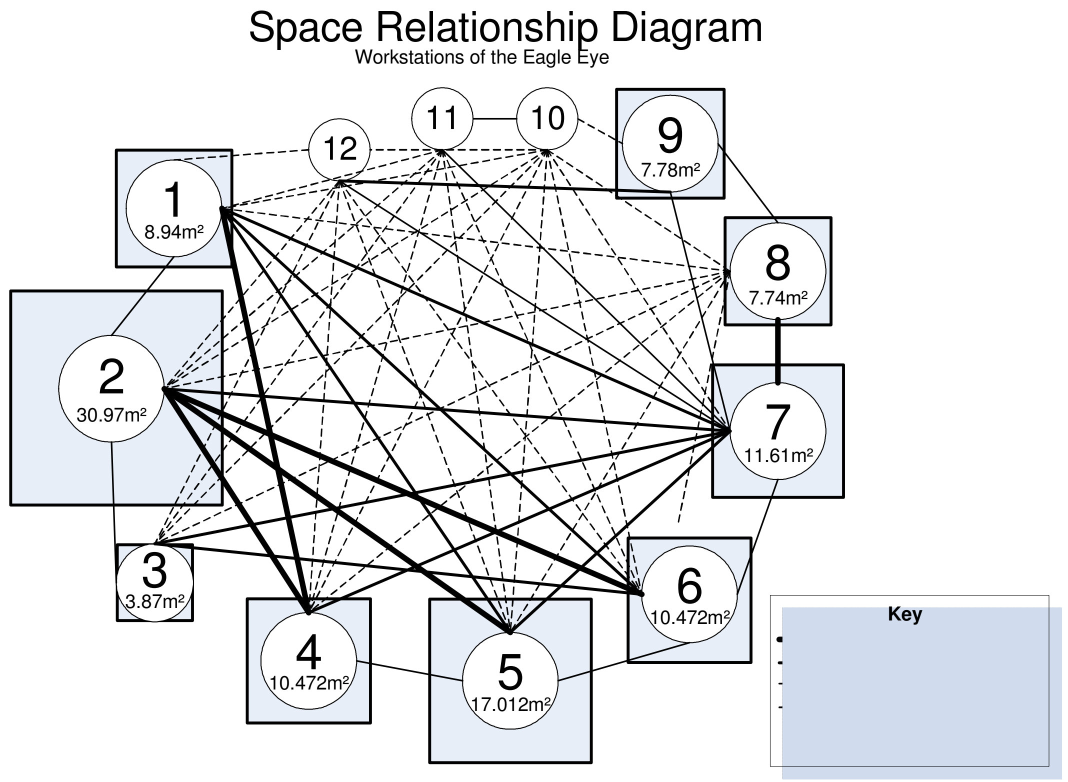


Figure 9: Space Relationship Diagram of the Eagle Eye's workstations

4.4.6. Special Requirements

Information regarding the specific requirements and limitations of each workstation has been obtained through the use of a questionnaire shown in Figure A12, Appendix A. The information is summarized in Table 2 given below. If a workstation has a special location the location and the reason for being in that location is given. A requirement that must be met if the workstation is moved is also listed.

Workstation number	*Section*	*Current Special Location*		*Requirements if moved*
		Location	*Reason*	
1	1K	N/A		
2	100K	N/A		
3		Oven Room	Extractor fan required for fumes	Extractor fan required
4	1K	Separate Room	Minimum movement for minimum dust exposure	Minimum movement, Eye safe environment
5	1K	Separate Room	Minimum movement for minimum dust exposure	Minimum movement
6	100K	Separate Room	Minimum movement for minimum dust exposure	Minimum movement
7	100K	Separate Room	Test equipment location	Equipment must be moved
8	100K	N/A		
9		Oven Room	Oven location and extractor fan for heat	Extractor fan for heat
10		Upstairs	Target needs to be measured at a distance	Clear window and target
11		50 meters outside building	No magnetic influence of environment	No magnetic interference
12		Testing room	Location of equipment, noisy and large	Sound proof room

Table 2: Special Location requirements of workstations

The separate rooms inside the clean rooms comply with ISO 4644 standards. The separation from the rest of the production area decreases the amount of movement in the vicinity of the assembly or testing operations, and decreases the risk of contamination. Certain sensitive and important assembly operations should be performed in such a separate room. Another reason for the creation of separate rooms is when operations, such as alignment during assembly, emit a laser that could be harmful to other functionaries' eyes. Other general limitations to consider are fire, health and safety, as well as utilities such as power and light required.

To visualize the limitations of each workstation's location and the relationships between the workstations, the Space Relationship Diagram and the As-Is facility layout have been integrated in Figure A13, in the Appendix. The "Ordinary" relationship links have been removed for simplicity.

From this diagram certain conclusions can be drawn:

1. The space currently allotted to workstations number six and seven is too small for simultaneous use.
2. Two "Absolutely Necessary" relationships cross the borders between the different sections, and the sub-assemblies following this path need to be moved through the airlock.
3. Workstation number seven has the most "Especially Important" and "Absolutely Necessary" relationships with workstations in the production area.

To resolve the space problem of workstations number six and seven additional in depth analysis is required. Performing the assembly process of workstation number six in a separate room in the 100K section is compulsory, whereas workstation number seven activities could be done in the larger production area, if the equipment used is moved.

The number of assembly processes performed in the 1K section has already been minimized before production of the Eagle Eye started. The workstations, and their assigned activities, currently situated in this section may not be moved.

4.4.7. Alternative Layout Plans

The Space Relationship Diagram drawn on the Facility blueprints has been used to create a bouquet of possible layouts, shown in the Appendix. With the workstation blocks drawn on the facility's blueprint the physical constraints and limitations are combined with the Systematic Layout Planning's Alternative Block Diagrams. During the creation of the Alternatives the focus has been set on three objectives of Facility Layout Planning:

1. To increase the total productivity and turnover by means of removing the time wasted on material movement.
2. To improve the materials handling, material flow and overall housekeeping by moving the appropriate workstations closer together.
3. To minimize the total inventory in the stores and work in process levels, through the elimination of waiting times.

Two workstations with a strong, or "Absolutely Necessary", relationship have been moved closer together, within the allowed space, to decrease the physical distance, and facilitate material movement and communication. The amount of preparation necessary, capital expenditure required and possible benefits to be gained of each of the alternatives increases sequentially. If required the alternatives can be combined.

- **Alternative A (Figure A14)**

By only moving the workstations around in the allowable areas the physical distance between the workstations could be reduced. No permanent or semi-permanent changes have been made. Workstation number two is the central workstations, moved closer to the air lock for easier movement of the materials crossing the barrier of the sections.

- **Alternative B (Figure A15)**

Workstation number three has been moved to a separate room in the 100K section, for this a built in extractor fan will be required. Workstations number four and five have been placed in separate rooms with more appropriate sizes, for better space utilization.

- **Alternative C (Figure A16)**

Almost all of the workstations have been moved to the one side of the production area. This will decrease the amount of movement necessary and communication will be facilitated.

Workstation number two is the link between workstations in the two separate sections. An alternative airlock and extractor fan will be required.

- **Alternative D (Figure A17)**

Most of the workstations are grouped around the border between the two sections. This grouping of the workstations could simplify operations. This layout will required three extra separate rooms to be built using the semi-permanent walls, as well as an extractor fan and airlock. To move or create new separate rooms within the production area the original manufacturer and installer needs to be contracted.

4.4.8. Evaluation Criteria

The following evaluation criteria have been set:

- Adaptability required

For the nature of production at Carl Zeiss the workstations should not be set permanently. The system needs to be adaptable to change in the design or even the product. Thus, a section can be devoted to the production of the Eagle Eye, but minimal permanent implementations should be made. The outer building walls are permanent.

- Allowable economic impact

No large financial expenditures should be necessary. The duration of implementation should be kept to a minimum, since the current assembly operations will be interrupted.

- Process effectiveness

The material movement distance should be decreased, and a list of sub-assemblies that can be moved directly to the next workstation, without being packed away and shipped to storage, should be created.

Each of the Alternative Block Diagrams has been evaluated against the chosen criteria. A ranking, which is stated as a value out of ten, has been given to each alternative; this is shown in Table 3. Since the three main evaluation criteria are equally important for Zeiss the Weighted Average method and the Ranking method yields similar results. In the column at the right the totals are given.

Block Diagram	Evaluation Criteria					
	Adaptability		*Economic Impact*		*Process Effectiveness*	
Alternative A	Easily adaptable to changes in assembly processes, no permanent changes made	10	Only time required	8	Will be improvement, but some sub-assemblies will still need to be packed away for movement	4 22
Alternative B	Extractor fan is permanently installed, still usable in the near future	7	Funds required for purchase and installation of extractor fan	7	Movement between clean rooms and other is reduced	5 18
Alternative C	Extractor fan and air lock is permanently installed, still usable in the near future	7	Funds required for purchase and installation of extractor fan and air lock	6	Movement is significantly reduced, and communication facilitated	9 22
Alternative D	Changes are semi-permanent and permanent	3	A great amount of funding will be required	3	A flow could be generated and productivity increased	9 15

Table 3: Evaluation of Alternative Block Diagrams

Ranking method has revealed that Alternatives number A and C are equally sufficient planned layouts. To resolve the tie break the main objective of this project has been revisited: to create a balanced flow and to eliminate unnecessary material transfers.

Even though in Alternative A the workstations with strong relationships have been moved closer together, a distance still exists. Moving the sub-assemblies manually could lead to an increase in the number of sub-assemblies damaged. In contrast, in Alternative C almost all of the workstations are grouped closely together, with an opportunity of overlapping. This close proximity ensures that certain sub-assemblies could be directly moved between workstations without concern.

4.4.9. Planned Facility Layout

Alternative Block Diagram C has been selected as the best alternative with a shorter travel distance for sub-assemblies. This layout is only feasible with a direct flow of material between work stations and work in progress inventory is reduced. With balanced workstations, the travel distance of sub-assemblies will be reduced significantly. The improved distance matrix is indicated in Table A2 in Appendix A. In this table the amount of batches that flow to and from each workstation has been multiplied with the distance travelled each time. As a result the total travelling distance, measured in meters, for the current layout and the layout of Alternative number C were determined. Currently, with the unbalanced workload sub-assemblies are packaged and moved to the store room after each assembly and quality check operation. In the proposed layout this element is eliminated in the calculations of Alternative number C, assuming that the workstations are balanced.

For both groups of calculations all the operations, until the final testing operations, are considered. Workstations number ten, eleven and twelve must move to testing and to eliminate this unnecessary movement is inevitable. The distance between the door and all workstations were taken into consideration, although the distance between the door and testing locations remains constant for the duration of the simulation.

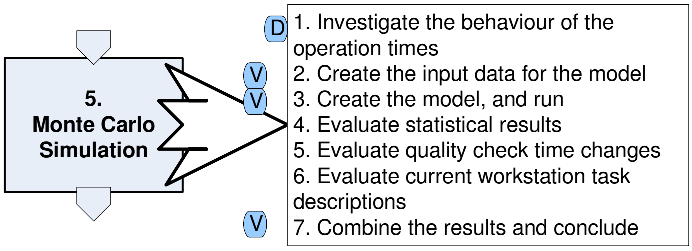
To calculate the distances to the door and the airlock the centre of the workstation has been used. When a workstation is located inside a room a distance to the door of that room and the distance from that door to the main door have been added.

The number of times sub-assemblies move to and from workstations is ninety times per production cycle from the storeroom with a total distance of 2250 meters. The previously mentioned distance is for the unnecessary movement between the store room and workstations and should be eliminated.

In the layout of Alternative number C the distance to the airlock is shorter than the distance to the door. Although workstations number seven and eight each have one direct link of material flow from or to workstation number nine, which is outside of the assembly area. Thus, the distance from these workstations to the door of the assembly area needs to be added to conclude the link between these workstations.

Table A1 shows that by implementing Alternative layout C the total distance of the batch decreases significantly. This proposed layout change with the reduced travelling distance is beneficial and results in saving time of valuable resources, reduce packaging costs and unnecessary exposure to damage sensitive material and products.

4.5. Monte Carlo Simulation



Constant and random inputs, in terms of operation durations, are transformed using a range of equations. The equations yields cycle times that indicate the total time a batch of ten Eagle Eyes spend at each workstation, and all the workstations combined. This outline is shown in Figure 10.

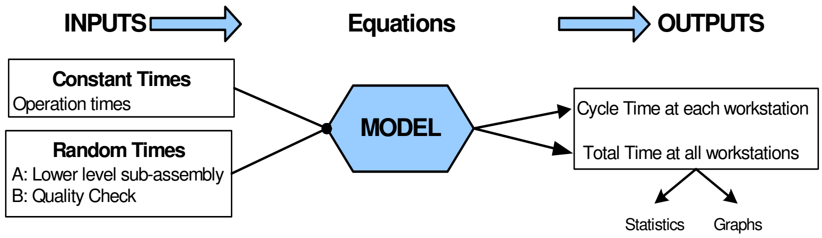


Figure 10: Outline of the Simulation Model

4.5.1. Operation Times

The Operations Process Chart, shown in Figure A2 and Figure A3 in the Appendix, indicate the durations of the operations, as uploaded in SAP. The process, assembly, testing and packaging operations' durations are well known, as indicated in the inputs of Figure 10. If two values are indicated the first shows the setup time and the second the operation duration when performed on a batch of ten. The seven quality check times have been recorded through random sampling, and have no affiliation to the processes it follows, or the workstation at which it occurred.

All the lower level sub-assemblies that enter the different assembly processes have already been assembled from components, inspected and packed. The total duration of these three operations is believed to be at least 30 minutes, at most 60 minutes and typically 50 minutes.

The assumptions made for the creation of the model:

- Assembly, packing, testing and other operations' durations are assumed to be constant.
- For the grouped tests performed after the final assembly the durations have been divided equally.
- Time, in units of hours, is a continuous variable, not a discrete value.
- Each batch contains ten units, and the setup for each operation will be performed since larger batches are not allowed.

4.5.2. Model Input Data

- **Lower level sub-assembly times**

The time to prepare the lower level sub-assemblies has been entered using the RiskTriang function of @Risk, which creates a triangular probability distribution, shown in Figure 11. The corners of the triangle are defined by the shortest, most likely and longest durations, which are 30, 50 and 60 minutes respectively. The horizontal axis indicates the durations. To accommodate the calculations the time unit has been transformed to hours.

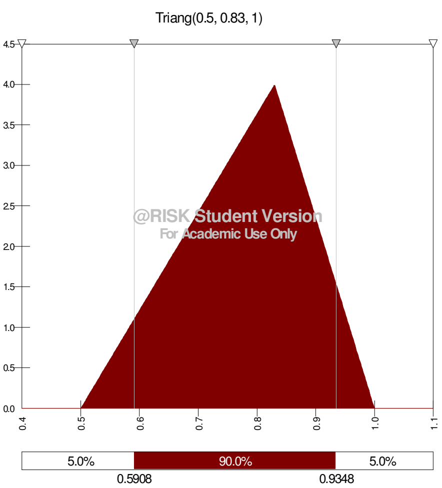


Figure 11: Triangular Distribution of lower level sub-assemblies

- **Quality Check Times**

To fit a familiar probability distribution to a histogram drawn from a sample of seven observations wouldn't be feasible. Therefore the RiskGeneral function of @Risk has been used. All the data points and the number of occurrences have been entered as inputs, as shown in Figure 12. @Risk automatically fits a continuous probability density function, as shown in Figure 13. The highest peak value

Ref :	X	P
1	0.25	1
2	0.5	4
3	0.75	1
4	3	1

Figure 12: Inputs to the General Distribution of quality check times

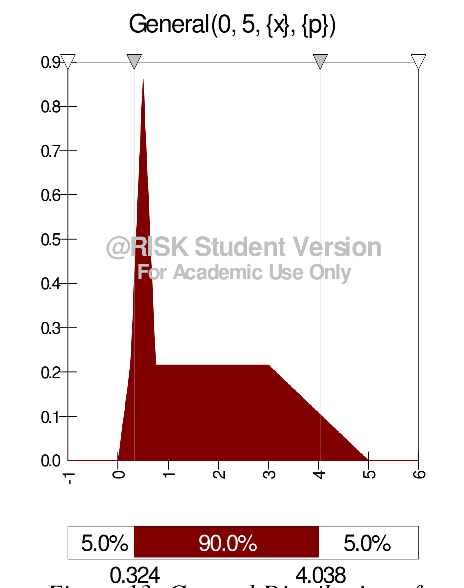


Figure 13: General Distribution of quality check times

indicates that the duration of 30 minutes (0.5 hours) has been the most common. There is a constant probability for values to be between 0.75 and 3 hours. From this the real random variables have been generated. @Risk shows the average of the distribution in the input blocks on the Excel spreadsheet.

4.5.3. The Simulation Model

The Excel model shown in Figure B1 in Appendix B is the snapshot of the model after 10,000 iterations.

The variable inputs have been indicated with the letters A and B:

A. The triangular distributed times for the preparation of the lower level sub-assemblies.
B. The general distribution of the recorded quality check durations.

Through a summary of the operation times the equations to calculate each workstation's total cycle time have been determined. Each equation is a summation of the total constant operation times and the number of occurrence of both the variable inputs. The total cycle time of workstations number one to five, and seven depend at least on one of the two random variables. These cycle time blocks are the output of the model, as previously indicated in Figure 10. The remaining workstations all have a constant cycle time.

To determine whether the workstations would be able to produce the maximum allowable quantity, the demand forecast has been stated in terms of the required cycle time. If any one of the workstation cycle times exceed 21.5 hours, the workstation will constrain the entire assembly process. The workstations of which the cycle time is above this value will not be able to deliver the necessary quantity with only one functionary performing all the operations. A 'Yes' indicates all the workstations of which the average cycle time have been above the allowable cycle time, and the calculated difference.

Figure B2 shows that the random variables that have been generated do follow the defined distribution. Also the output that calculate the actual average of the generated variables, are similar to the expected averages.

The averages indicated have been obtained after running the model 10,000 times. This value is the average of ten thousand calculated cycle times. The standard deviation has also been determined.

The most important output is the average total hours. The total time is a separate output, determined 10 000 times, and then the average has been calculated.

4.5.4. The Results

The main conclusion to be drawn from the foregoing is that completing a batch of ten Eagle Eyes requires on average 150 man hours. On average almost 27 hours of the total time has been spent at workstation number two.

If a workstation's cycle time is longer than the allowed maximum cycle time it is indicated with a Yes. Four of the twelve workstations would not have been able to deliver the required number of Eagle Eyes. Also, the workstations are unbalanced, which would result in bottleneck processes, constraining the number of products assembled.

@Risk automatically generates charts for analysis. The two most common are the Histogram and the Tornado graph. The Histogram shows how frequent output values inside a certain interval where obtained. The Tornado graph shows the correlation between the output and the input variables. If the correlation fraction is large, the input distribution greatly determines the output distribution.

- **Histogram of Total Time**

Figure 14 shows the distribution of the total time output values in a Histogram. The average value is 149.97 hours, with the distribution of occurrences ranging from the minimum value of 130.95 to the maximum value of 176.28 hours.

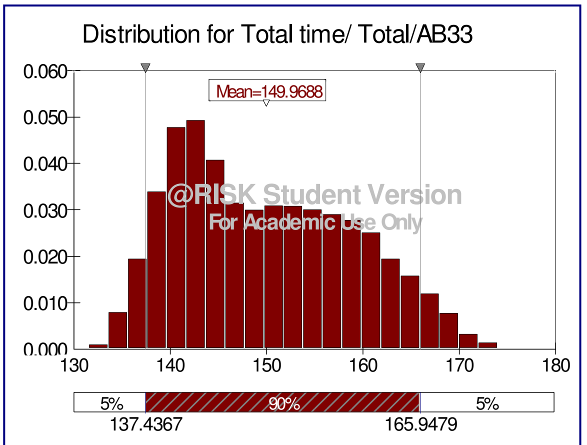


Figure 14: Histogram of output of total time

- **Tornado Graph**

Figure 15 shows the Regression Sensitivity (Tornado) graph of the Total time. The large bar at the top indicates that the uncertainty of the input variable B (quality check times) has a significant impact on the total cycle time. The impact of variable A is small in comparison. The histograms of the generated quality check times and the Total time values are as a result similar in shape. The total time will be affected significantly with a change in the distribution the quality check durations.

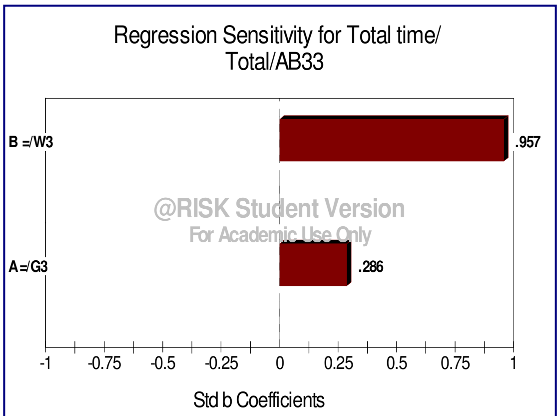


Figure 15: Regression sensitivity graph

Currently the entire assembly process will not be able to produce enough Eagle Eyes to serve the forecasted demand.

Two alternative changes have been investigated follows:

- Alternative 1: Decreasing the uncertainty and size of the quality check times.
- Alternative 2: Shortening workstation cycle times through better task allocation.

4.5.5. Quality Check Times – Alternative 1

Investigation has shown that in the instance where the quality check took three hours to complete the functionary was occupied with another sub-assembly. This value has been the result of an external influence. Even though the assembly process and quality check durations have variations, this is the result of common causes of variation internal to the process.

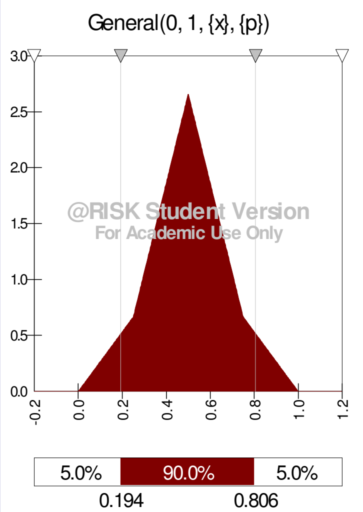


Figure 16: Adapted General Distribution of quality check times

If two quality functionaries are assigned to serve the Eagle Eye assembly process, the occurrence of such an event could be prevented. If two quality functionaries are assigned the quality check times distribution would be affected. This affect cannot be predicted beforehand. Still, the large values, such as three hours, would be removed.

- **Model – Alternative 1**

The input variable B has been adapted. The extreme value of three hours has been removed, and the resulting probability distribution is shown in Figure 16. The probability distribution function's standard deviation has decreased from 1.24 to 0.18. No other changes have been made. The model has been run using the new input variable distribution, and the resulting model is shown in Figure B3.

- **Results – Alternative 1**

The average Total time has decreased from the original 149.97 hours, to 140.56 hours, and the shape of the output distribution has changed to resemble a triangle, as shown if Figure 17. The minimum value has not changed significantly, but the maximum has decreased to 148.76 hours.

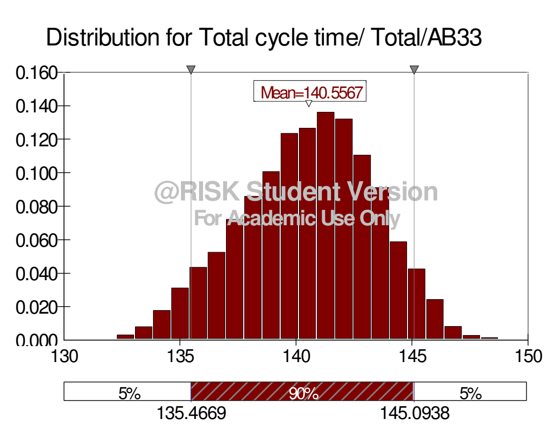


Figure 17: Histogram of output of total time, quality check times adapted

The standard deviation of the total time has been reduced from 9.11 to 2.89. The result of this reduction is a more predictable total time, with a smaller deviation from the average value. The more predictable average value can be used during planning and forecasting with greater confidence.

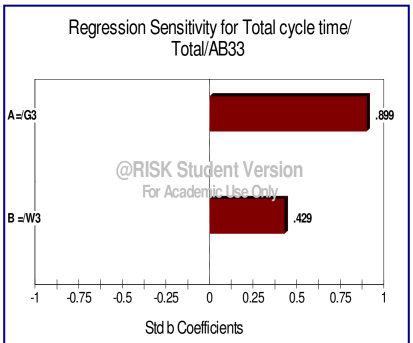


Figure 18: Regression sensitivity graph, quality check times adapted

The Regression Sensitivity graph of Figure 18, shows that the distribution of the input variable A (lower level sub-assembly times) now has a dominating effect on the output distribution. The Histogram in Figure 16 and the input probability distribution of variable A in Figure 11 is very similar. This indicates that further changes to the quality check times would not have such a significant effect on the output distribution.

The four workstations, with the out of specification cycle times, are still above the allowable maximum, but lower than before. Workstation number two's cycle time is dependant on three quality check time values. Its cycle time is no longer the longest anymore.

4.5.6. Workstation Allocation – Alternative 2

In the original simulation the cycle times of workstations number two, five, six and seven exceeded the allowable. This is true when only one functionary is assigned to each workstation. Currently functionaries have not been allocated to workstations, and the allocation could determine whether the forecasted demand is reached and if the workstations are in balance. Dividing the cycle time of each workstation with the number of functionaries appointed would not be practical since each operation is a single complete task. The operations should be grouped and assigned to a functionary.

Assumptions

- Functionaries with the correct skills are available.
- The workstation desks can be altered to accommodate the changes.

Assigning tasks to different functionaries at one workstation should not result in more material movement. Thus, sequential operations should be grouped together and assigned to a single functionary. Extracts form the Operations Process Chart have been used to indicate the task allocation. In Figures B4, B5, and B6 white blocks show the groupings of operations assigned to the first and second functionary, at workstations number two, five and seven, respectively.

- **Model – Alternative 2**
  - Workstation number two

The first and second group of operations can be performed simultaneously, and thereafter be used in Assembly F. The second group of operations is assigned to a functionary. Since the total operation time of the first grouping is smaller the third grouping, and most of the lower level sub-assemblies, have also been grouped with it. The cycle times of both groupings are still dependant on the random input variables.

- Workstation number five

The assembly time for the A&A Camera is 7.66 hours. If this relatively large value is added to the first group of operations the difference between the two groupings' cycle times will be large. Even if the quality check time variable equals its maximum value of five hours the second grouping's cycle time would still be smaller than the allowed maximum. The uncertainty of the random input variables does not affect the first grouping.

- Workstation number six

The final integration of all the sub-assemblies is performed at workstation number six. This is done slowly and carefully by a single skilled functionary. The quality of the final product depends greatly on this assembly operation. All these factors indicate that the assembly operation should not be corrupted by assigning another functionary to the workstation. For this simulation the assembly process has been left assigned to one functionary.

- Workstation number seven

The first test performed at workstation seven has an operation time of 12.5 hours. This value alone has been assigned to the second functionary, and all the other operations have been grouped together and allocated to the first functionary. As a result the second grouping's cycle time is constant.

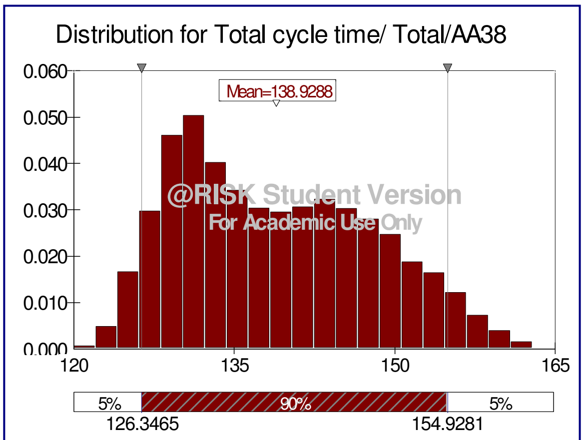


Figure 19: Histogram of output of total time, workstation tasks allocation adapted

- **Results – Alternative 2**

The model is shown in Figure B7, and the resulting graphs of the Total time are shown in Figure 19 and 20. The average Total time has reduced to 136.93 hours. This average is lower than the average obtained after the quality check times have been adapted, but this average still has a large correlation with the quality check time variable.

After the tasks have been grouped and separately calculated, only workstation six has remained above the allowed maximum cycle time.

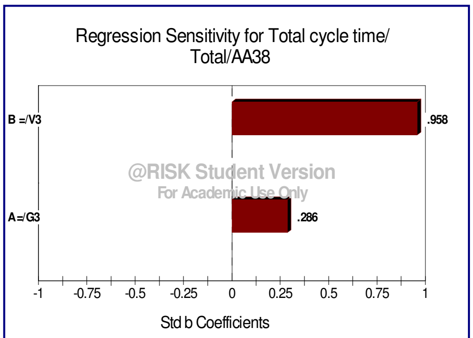


Figure 20: Regression sensitivity graph, workstation tasks allocation adapted

4.5.7. Combined

Both of the above alternatives contribute to achieving a stable flow. The quality check time changes increase the certainty of the calculated cycle times, and the workstation allocation changes ensure a more even distribution of tasks. Both can be done simultaneously. The two changes have been combined in one simulation model. If the combined results show a balanced assembly process, the direct material movement can be achieved. When the sub-assemblies are moved directly between the workstations packaging the sub-assemblies is unnecessary. Assuming the direct movement is created, the packaging operation times has been removed from the simulation. The adapted simulation is shown in Figure B8.

- **Results**

The average Total time is 139.67 hours, shown in Figure 21. This value is higher than that of the workstation allocation adapted model, but the dispersion of the values are smaller. This shows that the output is more predictable and stable. As shown in Figure 22 Variable A is now the biggest contributing factor.

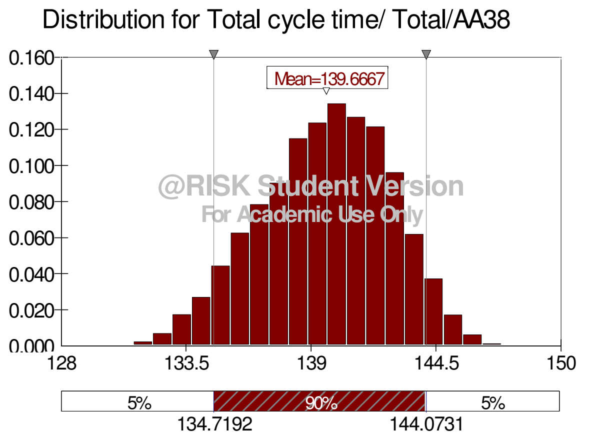


Figure 21: Histogram of output of total time, adapted

Both the averages and standard deviations of the outputs have been decreased, and all the workstations, apart from workstation number six, will be able to deliver the sub-assemblies at the correct pace.

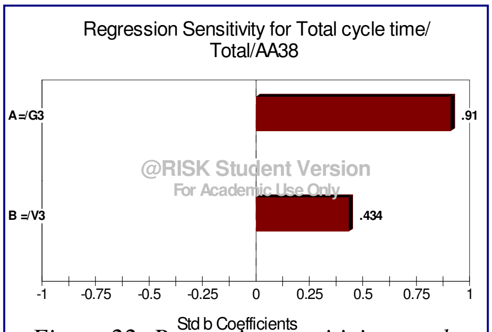


Figure 22: Regression sensitivity graph, adapted

With this result workstation number six's cycle time is above the required maximum cycle time. Still, the knowledge that this workstation will not be able maintain the production rate is an advantage. Deep analysis of this assembly operation is required to determine whether the tasks can be divided between functionaries, or some other alternative to decrease the operation time.

▪ **Conclusion**

By dividing operations between functionaries at workstation numbers two, five and seven has changed the average cycle times as shown in Figure 23. Certain workstations, that have not been assigned another functionary, have smaller cycle times since the packaging operation durations have been removed. The variation between workstation cycle times has been reduced.

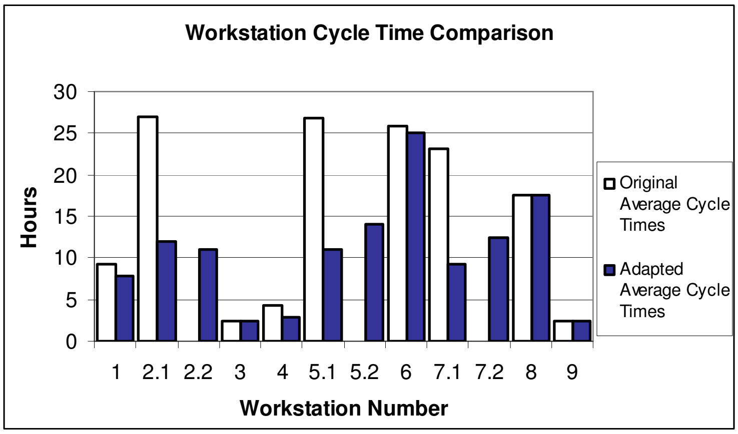
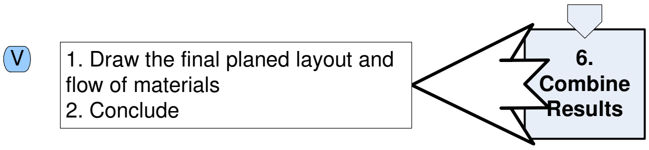


Figure 23: Bar graph of the average cycle times

The total time has been reduced by 10 man hours. The average total time of Alternative 2 has been a larger improvement, but now the improvement of the standard deviation of Alternative 1 has been included. The average total time is larger, but the certainty of the value has increased.

Assign two quality check personnel to the assembly of the Eagle Eye, and two functionaries at workstations number two, five and seven.

4.6. Combined Results



4.6.1. Planned Facility Layout

The proposed layout is depicted in Figure B9 in Appendix B. This layout incorporates both the flow of assemblies between work stations as in Figure A8 and the Alternative Block Diagram C. The numbers inside the diamond shape shows the workstation's number. Also in this diagram the number of sub-assemblies that will be moved directly between workstations are shown on the links, although the links do not show the physical path the materials will follow.

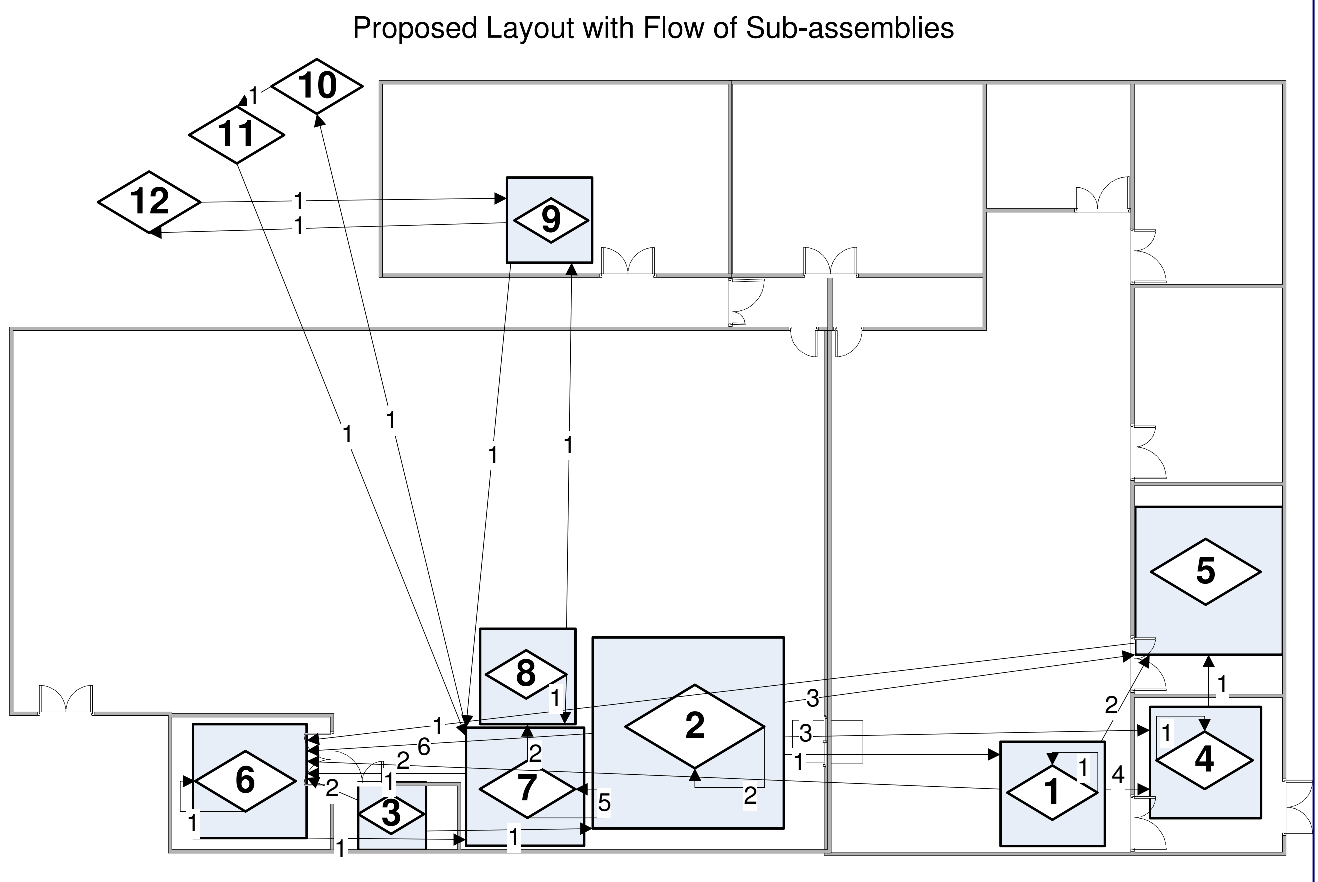


Figure 24: Proposed locations of the Workstations

The workstation desks and other equipment required by the workstation should be arranged inside the space allocated for each workstation. With the physical placement of desks within each workstation ergonomics such as ease of movement and ease of use should be considered.

The proposed layout of the workstations requires the following changes to the assembly area:

- The room where the proposed workstation number two is to be located should be removed.
- An additional airlock should be installed inside the divider of the two sections.
- An extractor fan should be installed in the new gluing room.

None of the above changes are permanent or expensive, as required by the evaluation criteria stated for the facility layout.

Alternative Block Diagram C has the potential to satisfy all Zeiss's requirements for the planned layout, although this layout is only more practical than other alternatives if the workstations are balanced enough for direct flow of the sub-assemblies. In attempting to balance the cycle time of each workstation the result from the Monte Carlo simulation indicate that the following be done:

- Assign two functionaries to workstations number two, five and seven.
- Assign two quality check personnel to the assembly process of the Eagle Eye.
- Investigate the assembly operations performed at workstation number six to decrease the cycle time to the allowed maximum.

4.6.2. Conclusion

Zeiss should arrange the assembly area as shown in Figure B9 in Appendix B, and implement the foregoing changes. These changes can be made without much effort and assembly processes can commence without being kept back. With the proposed changes 90% of all workstations, are capable of producing the Eagle Eye at the desired production rate, satisfying the forecasted demand. The cycle time at workstation number six does not satisfy the required production rate and will only once the assembly operation is analysed and improved.

The Systematic Layout Planning approach has been used to ensure that workstations with direct material and communication flows are located in close proximity. This facilitates the assembly process, decreases material movement and increases quality through feedback loops. Together the relationships between the workstations and the floor space required by respective workstations have determined some alternative layouts to evaluate.

The sub-assemblies were packed and stored in the store room to decrease the amount of work-in-process in the production area. With a balanced flow at all workstations there will be no more work-in-process inventory which accumulates at workstations. If the workload at each workstation is balanced and a flow of the sub-assemblies can be created the work-in-process inventory will not accumulate. A Monte Carlo simulation has been used to determine the cycle time at each workstation and the total man hours required for the assembly process. Simulation alternatives run with adjustments to quality check times and task allocations decreased average cycle times and most importantly reduced the common causes of variation in the cycle times. This results to a reduction in overall assembly time and ensures that the predicted average time is more accurate and production planning is able to plan accordingly.

The balanced workload and close approximation of workstations ensures that the sub-assemblies can be moved directly between the workstations, which eliminate the unnecessary packaging and storing operations. The reduction in movement of the expensive and fragile sub-assemblies will further decrease the amount of damages obtained from physical handling.

BIBLIOGRAPHY

Type	*Name*
Book	TOMPKINS, J.A., WHITE, J.A., BOZER, Y.A. & TANCHOCO, J.M.A. 2003. *Facilities Planning*. 3rd ed. NJ, USA: John Wiley & Sons, Inc.
Interview	VAN WYK, P. 2009. [Personal communication]. On several occasions.
Interview	STYGER, D.D. 2009. [Personal communication]. On several occasions.
Interview	GREYLING, C. 2009. [Personal communication]. May 14.
Internet website	WIKIMEDIA. 2009. *Monte Carlo Method*. [Online]. Available: http://en.wikipedia.org/wiki/Montecarlomethod.[3 May 2009].
Journal	TE-KING, C. 2004. An Empirical study of facility layout using a modified SLP procedure. *Journal of Manufacturing Technology Management,* 15(6), pp. 455-465.
Book	CHASE, R. B., JACOBS, F. R., AQUILANO, N. J. 2006. *Operations Management for Competitive Advantage.* 11th ed. NY, USA: McGraw-Hill/Irwin.
Internet website	INSTITUTE OF MANAGEMENT SCIENCES. 2009. *Process Charts*. [Online]. Available: http://www.ims-productivity.com/page.cfm/content/Process-Charts/. [10 May 2009]
Book	HERAGU, S.S. 2006. *Facilities Design*. 2ND ed. USA: iUniverse
Book	LANDAU, D.P., BINDER, K. 2005. *A guide to Monte Carlo simulations in statistical physics*. USA: Cambridge University Press
Book	MILTEN, J. 2005. *Manufacturing Strategy: how to formulate and implement a winning plan*. 2nd ed. USA: Productivity Press
Book	GARCIA-DIAZ, A., SMITH, J.M. 2007. *Facilities Planning and Design*. Illustrated ed. Prentice Hall
Book	HALES, H. L. 1984. *Computer-Aided Facilities Planning*. 2nd ed. CRC Press
Book	NEVILLE, C. 2007. *The complete guide to referencing and avoiding plagiarism.* MacGraw-Hill

Journal	RAYCHAUDHURI, S. 2008. Introduction to Monte Carlo Simulation. *Proceedings of the 2008 Winter Simulation Conference.* No. 1, pp.1-10
Journal	ALEISA, E.E., LIN, L. 2005. For effective Facilities Planning: Layout Optimization then Simulation, or visa versa? *Proceedings of the 2005 Winter Simulation conference.* Pp. 1381-1383
Journal	RICHARDSON, J.W., KLOSE, S.L., GRAY, A.W. 2000. An Applied Procedure for Estimating and Simulating Multivariate Empirical (MVE) Probability Distributions In Farm-Level Risk Assessment and Policy Analysis. *Journal of Agricultural and Applied Economics.* pp. 299-315.
Book	WINSTON, W. L., ALBRIGHT, S. C., BROADIE, M. N., LAPIN, L. L., WHISLER, W. D. 2009. *Practical Management Science*. 3rd ed. USA: South-Western Cengage Learning.

APPENDIX A

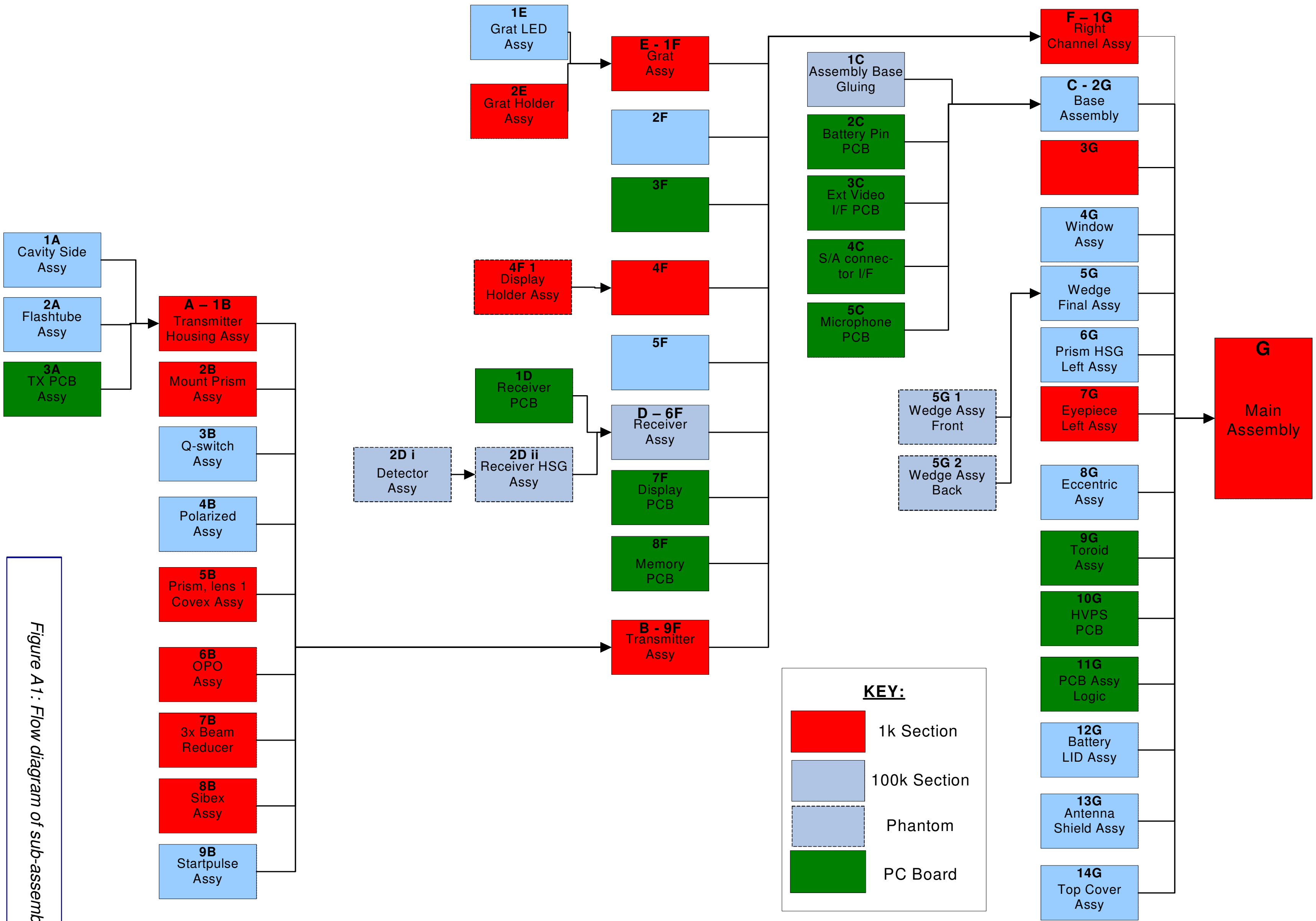


Figure A1: Flow diagram of sub-assemblies

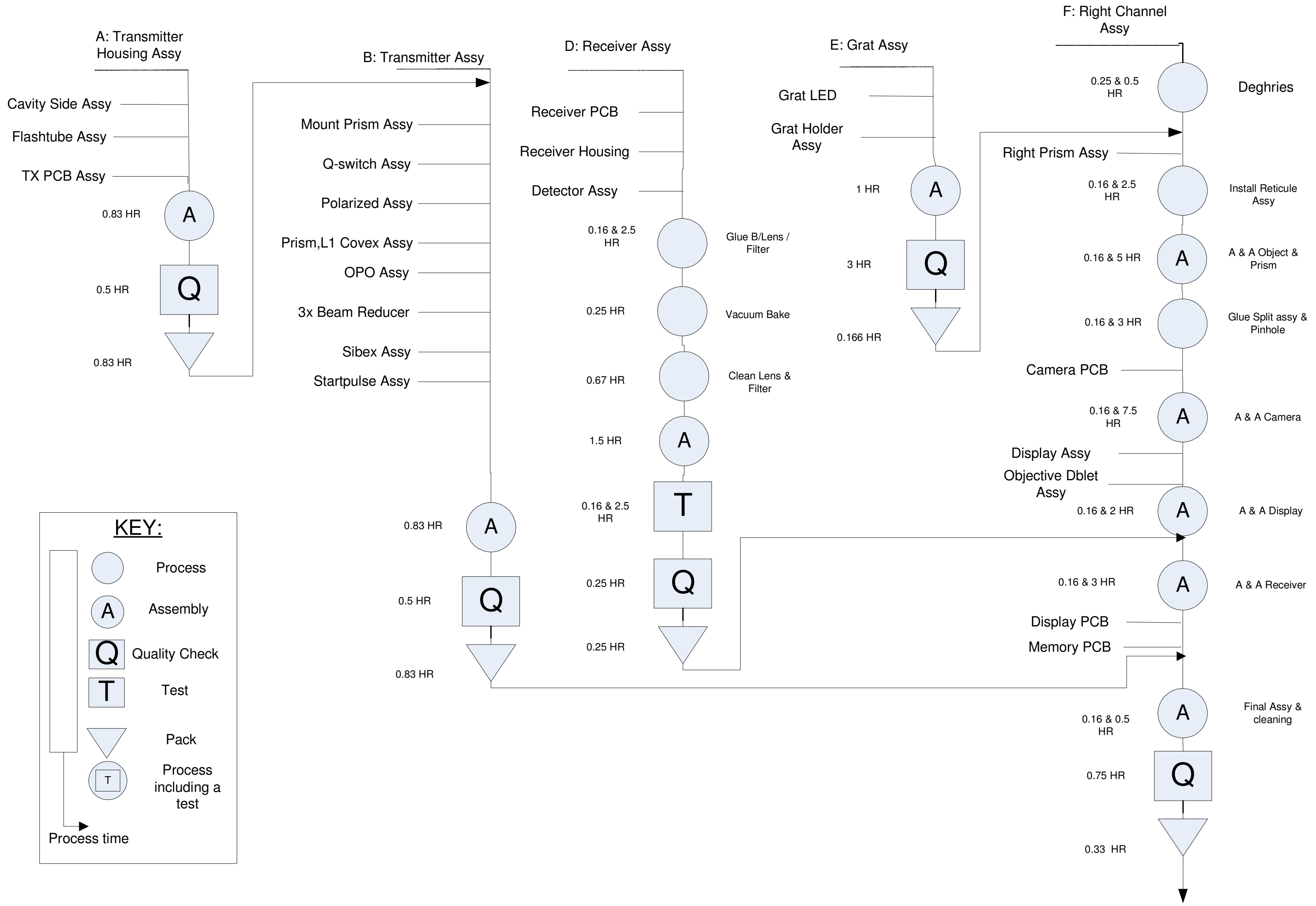


Figure A2: Operations Process Chart, part 1

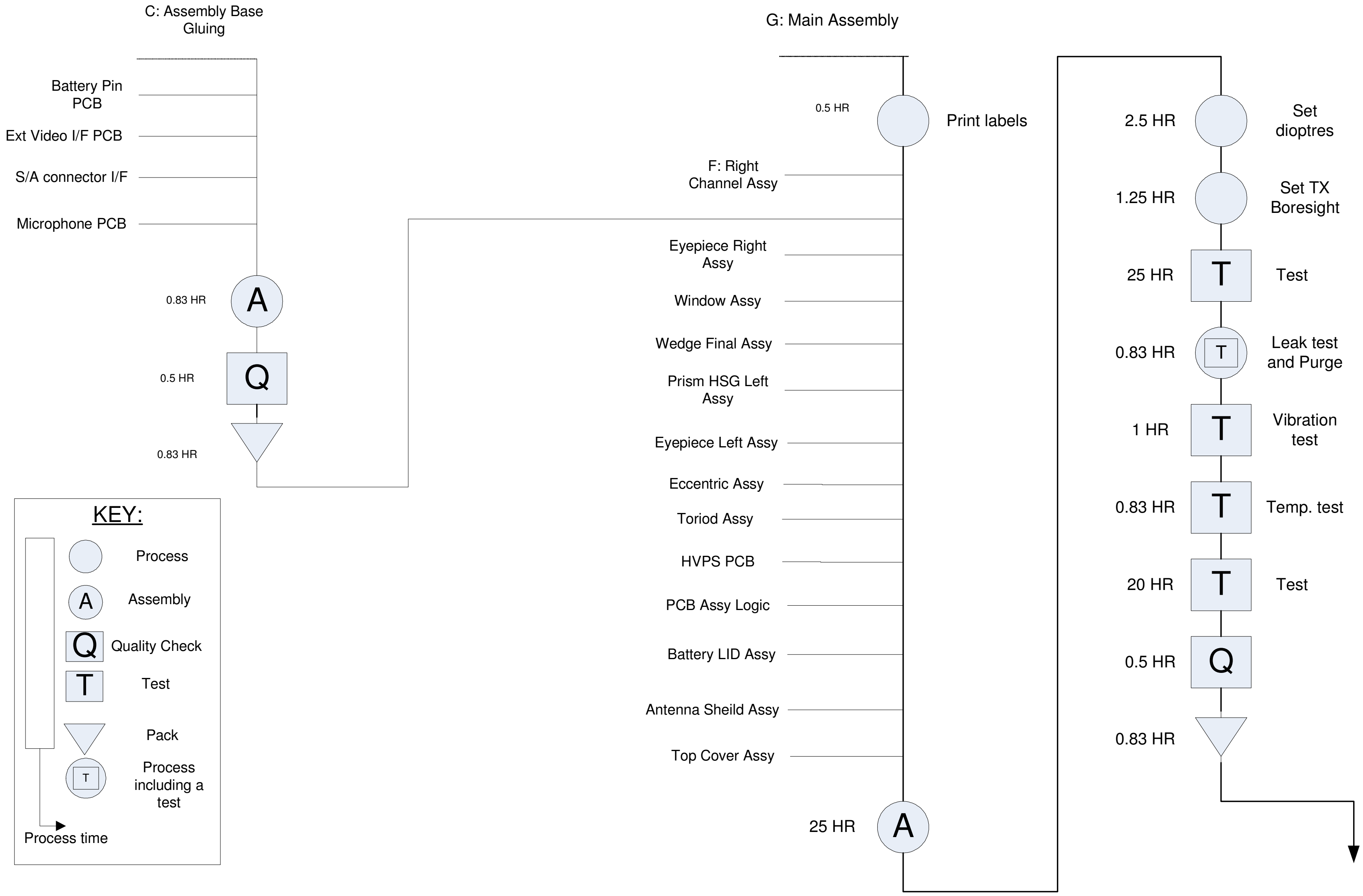


Figure A3: Operations Process Chart, part 2

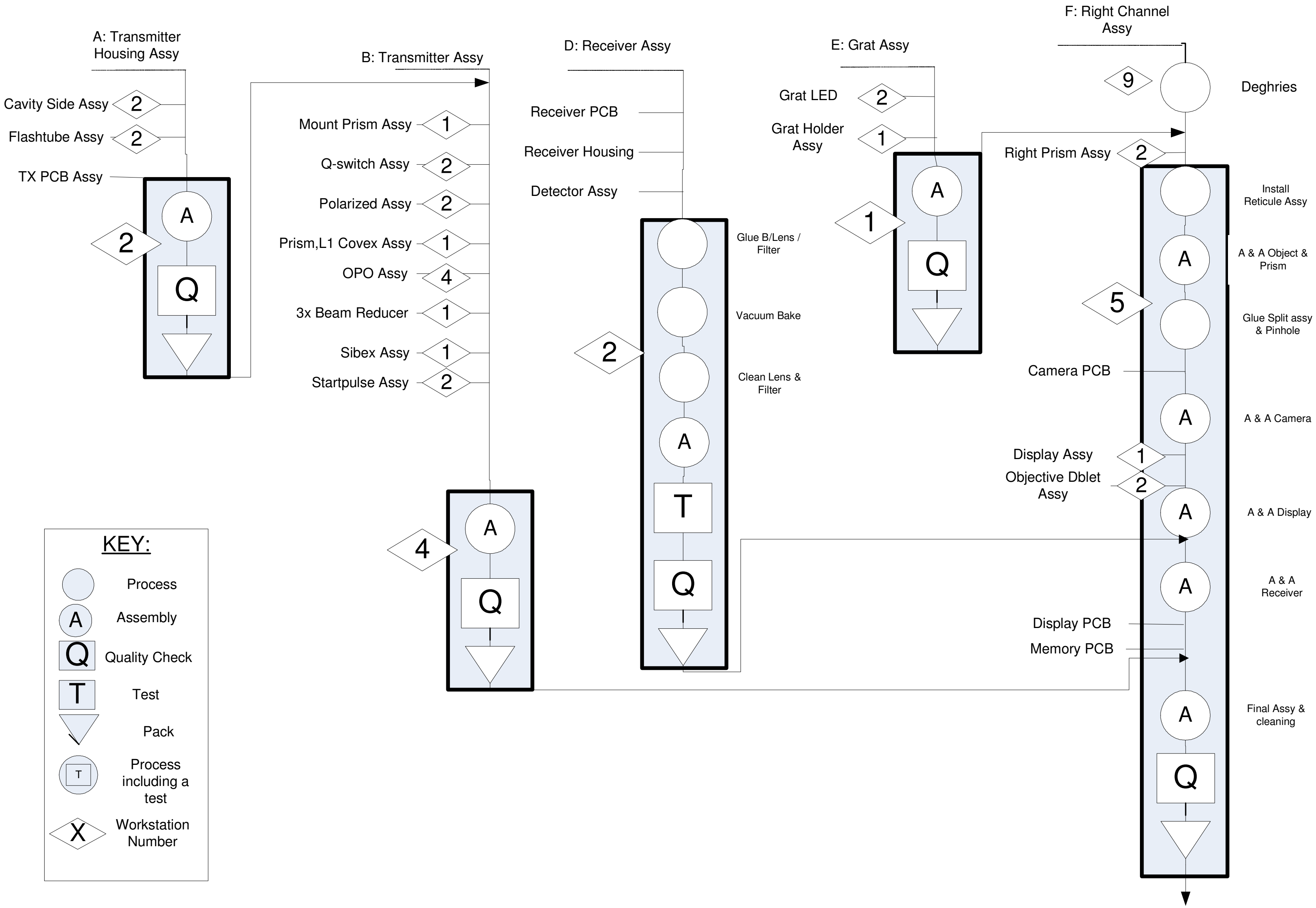


Figure A4: Operation Process Chart, Part 1 with workstation allocation

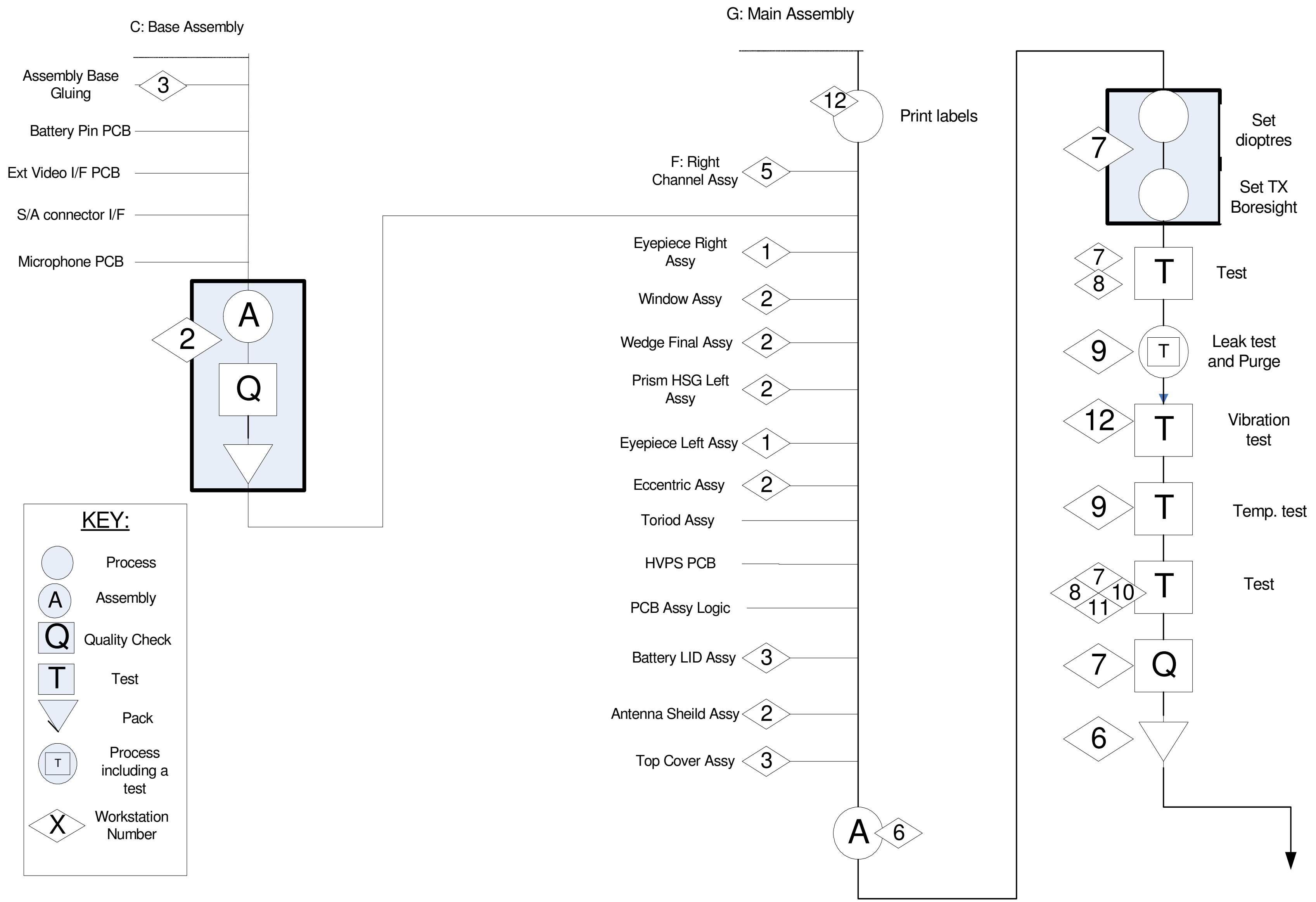


Figure A5: Operation Process Chart, Part 2 with workstation allocation

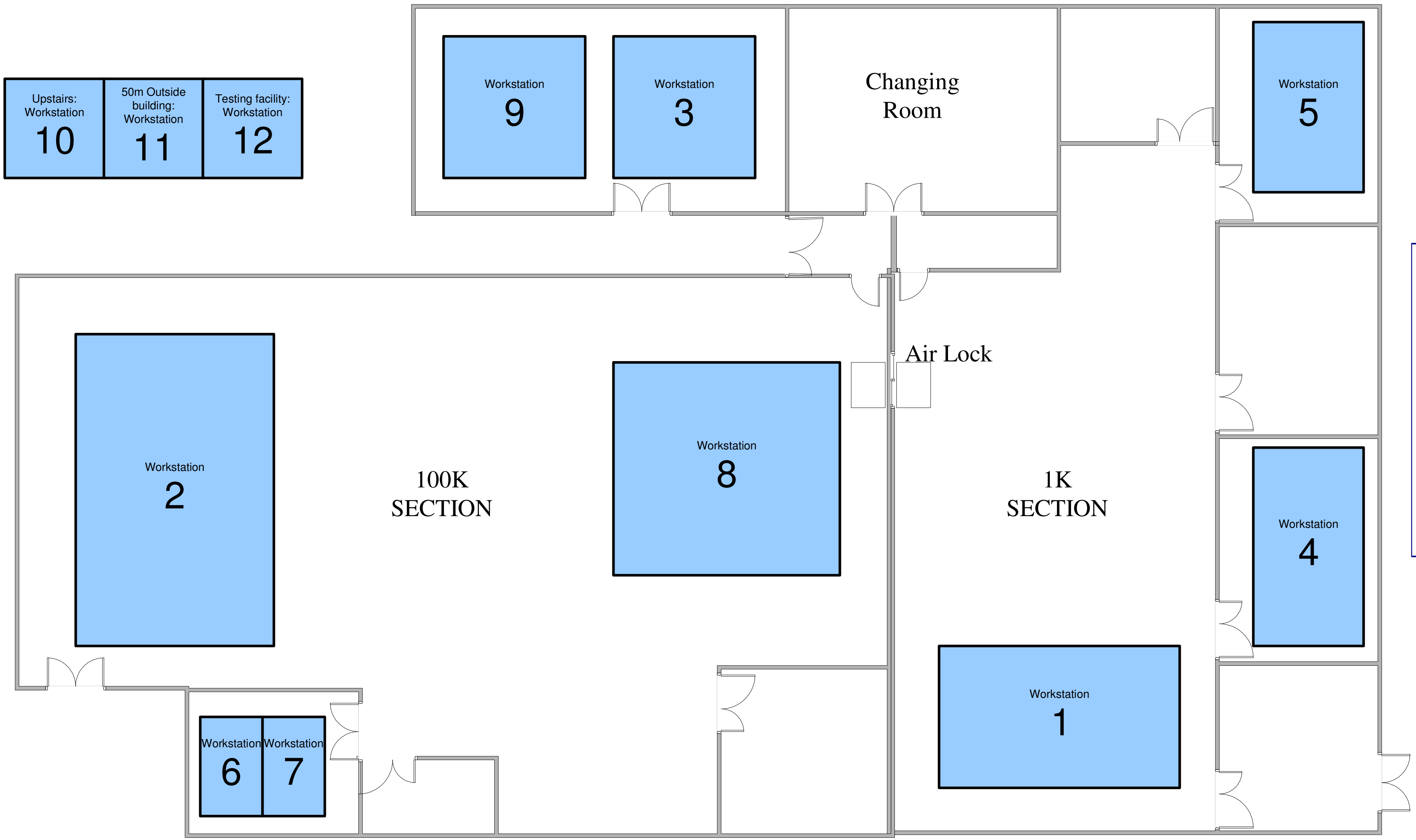


Figure A6: As-Is Facility

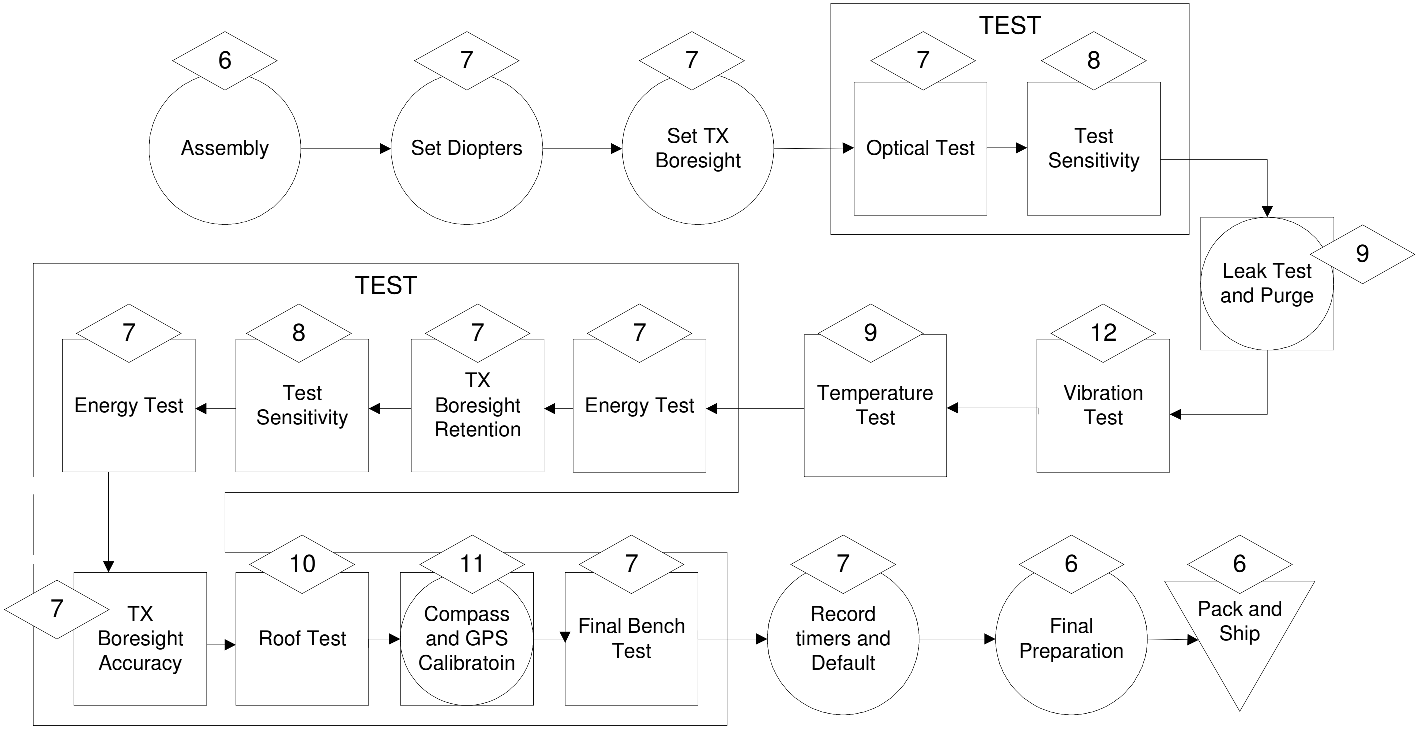


Figure A7: Flow Diagram of the tests performed after final integration and the workstation number

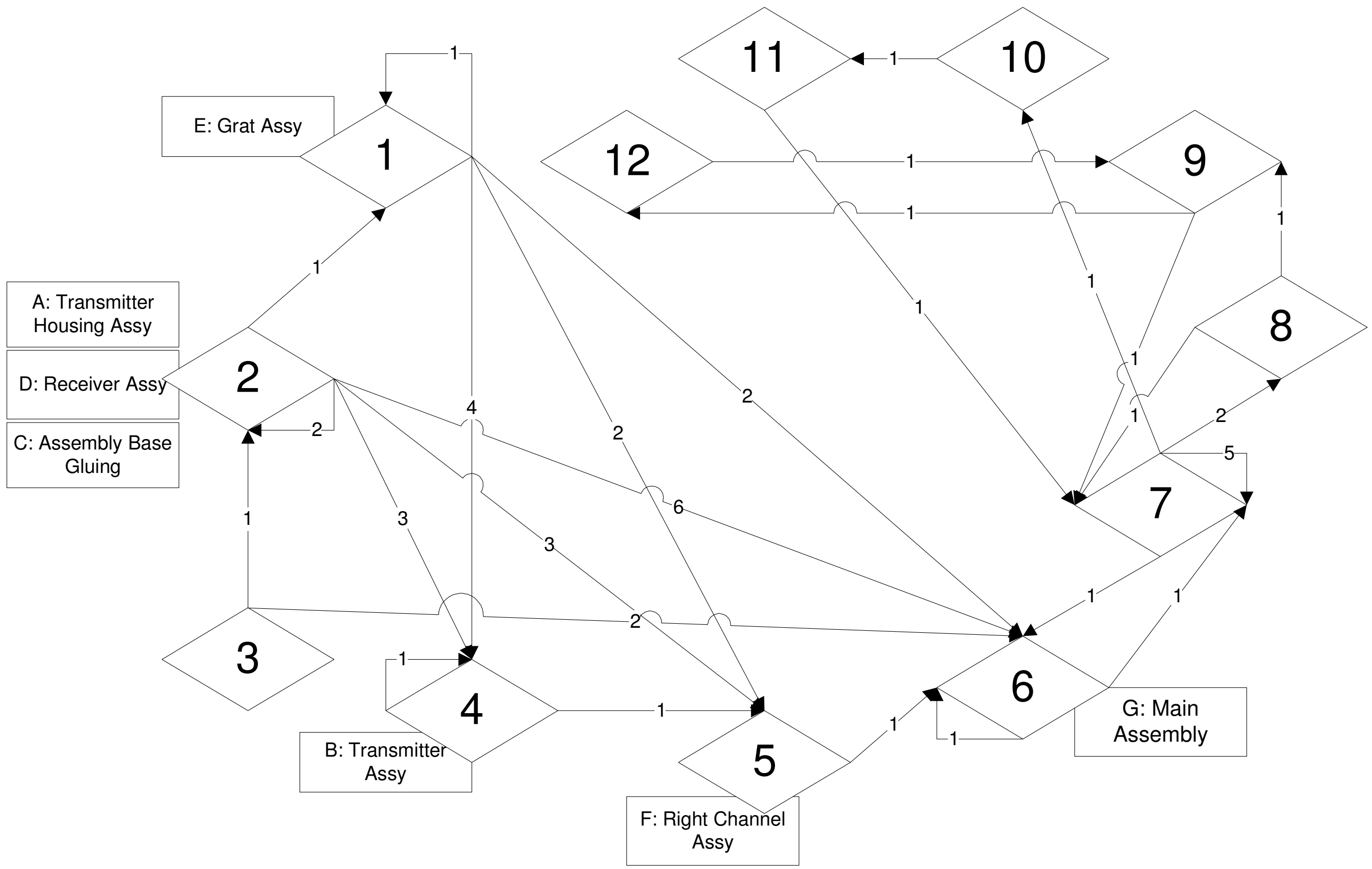


Figure A8: Flow of sub-assemblies between workstations

Relationship Chart

Workstations of the TLS40

	WS 12	WS 11	WS 10	WS 9	WS 8	WS 7	WS 6	WS 5	WS 4	WS 3	WS 2	WS 1
WS 1	O	O	O	U	O	E	E	E	A	U	I	
WS 2	O	O	O	U	O	E	A	A	A	I		
WS 3	O	O	O	U	O	E	E	U	U			
WS 4	O	O	O	U	O	E	U	I				
WS 5	O	O	O	U	O	E	I					
WS 6	O	O	O	U	O	I						
WS 7	I	I	O	I	A							
WS 8	O	O	O	I								
WS 9	E	O	O									
WS 10	O	I										
WS 11	O											
WS 12												

Key	
A	Absolutely Necessary
E	Especially Important
I	Important
O	Ordinary
U	Unimportant
X	Not Desirable

Figure A10: Relationship Chart of relative unquantifiable relationships between workstations

From - To Chart

Between Workstations of the TLS40

From \ To	WS 1	WS 2	WS 3	WS 4	WS 5	WS 6	WS 7	WS 8	WS 9	WS 10	WS 11	WS 12	Total out
WS 1	1			4	2	2							9
WS 2	1	2		3	3	6							15
WS 3		1				2							3
WS 4				1	1								2
WS 5						1							1
WS 6						1	1						2
WS 7						1	5	2		1			9
WS 8							1		1				2
WS 9							1					1	2
WS 10											1		1
WS 11							1						1
WS 12									1				1
Total In:	2	3	0	8	6	13	9	2	2	1	1	1	

Figure A9: From-To Chart of the flow of sub-assemblies between workstations

Table A1: Space currently occupied and required by each workstation

	Current	***Required for Future***				
Workstation Number	*Total Space Used (m^2)*	*Number of Desks*		*Additional Space Required*		*Total Minimum Space Required(m^2)*
		Normal	*Large*	*Space Required(m^2)*	*Reason*	
1	25.9	2	0	1.2	Cabinets	8.94
2	43.5	6	0	7.74	Machines	30.96
3	2.6	1	0	0		3.87
4	18.3	0	1	1.2	Cabinets	10.472
5	18.3	2	1	0		17.012
6	9.4	0	1	1.2	Cabinets	10.472
7	9.4	3	0	0		11.61
8	31.6	2	0	0		7.74
9	2.6	1	0	4	Machine	7.87

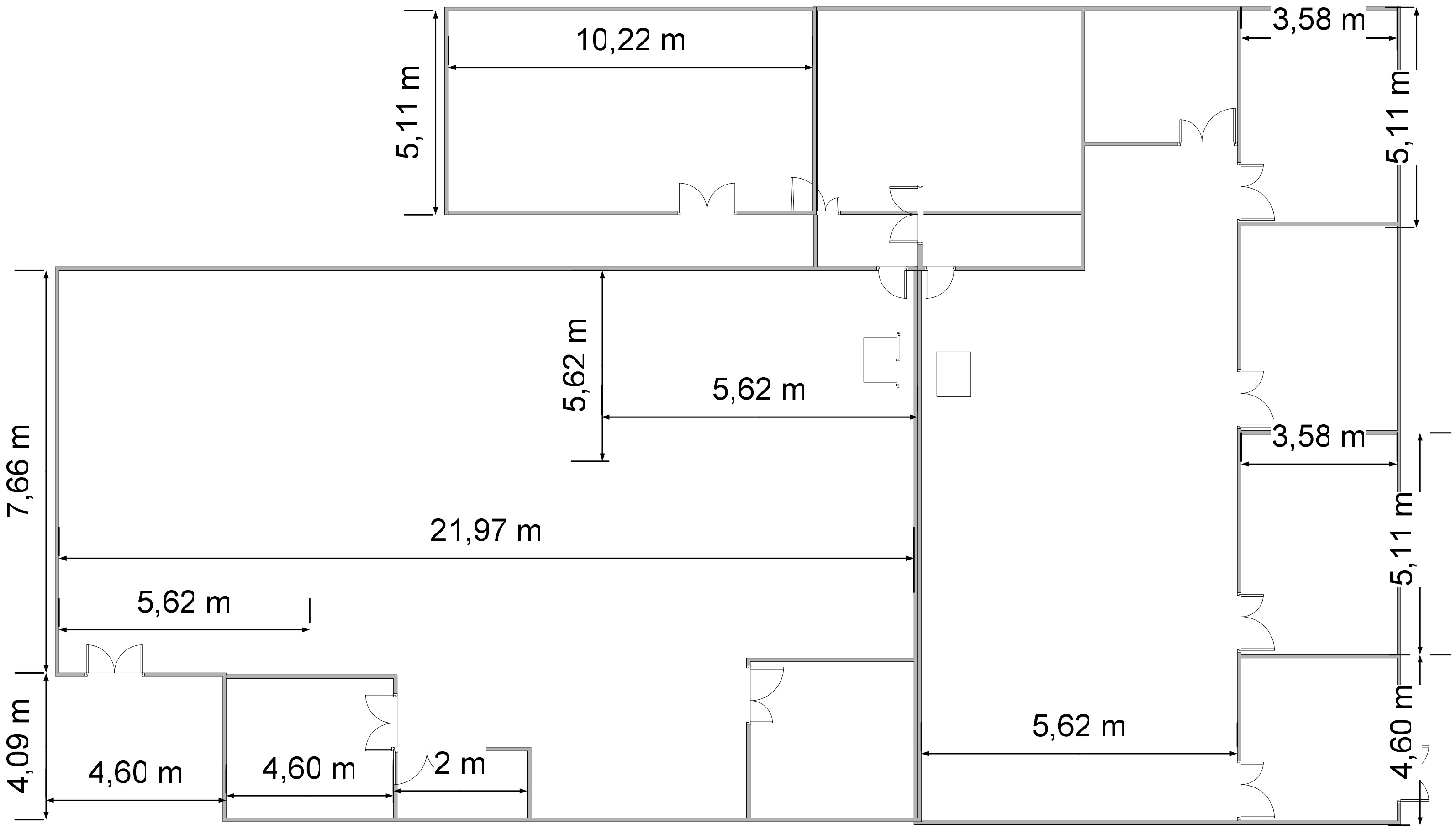


Figure A11: Measurements of current facility layout

SPACE AND LOCATION REQUIREMENTS FOR WORKSTATION

Workstation number: ________

Processes Performed:

____

____

____

Workstation Requirements Mark with 'X'

In which department must the workstation be? | 1K | 100K |

How many normal desks does the workstation require? | 1 | 2 | 3 |

Any additional space required? | YES | NO |

If yes, please state:

____

____

Does the workstation need to be located at a specific location? | YES | NO |

If yes, location and reason:

____

Any other requirements for the workstation:

____

____

____

Figure A12: Questionnaire for space and location requirements

Space Relationship Diagram in the Current Layout

Workstations of the Eagle Eye (As-is)

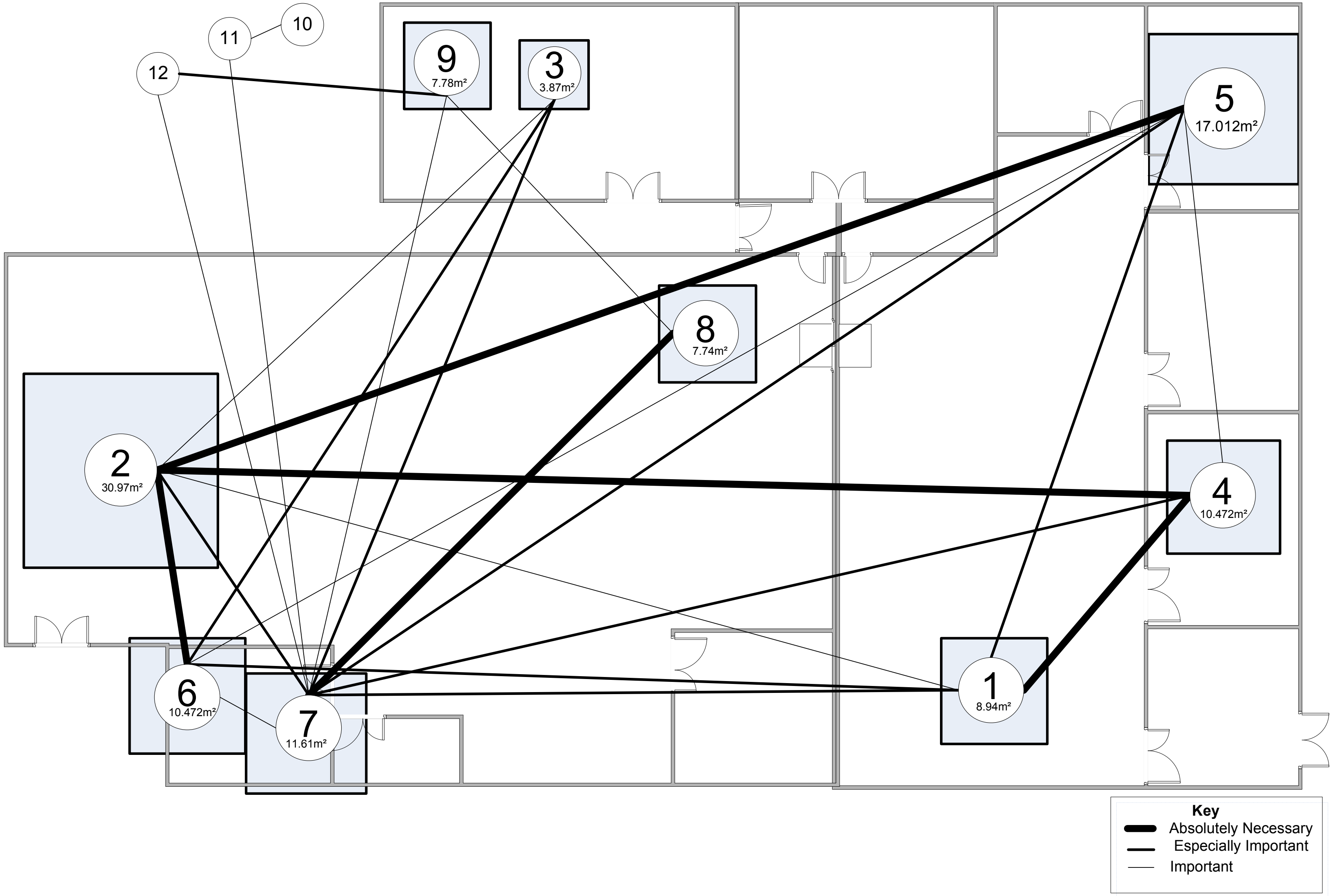


Figure A13: Space Relationship Diagram on Current Layout

Alternative Block Diagram Number A

Workstations of the Eagle Eye (Planned)

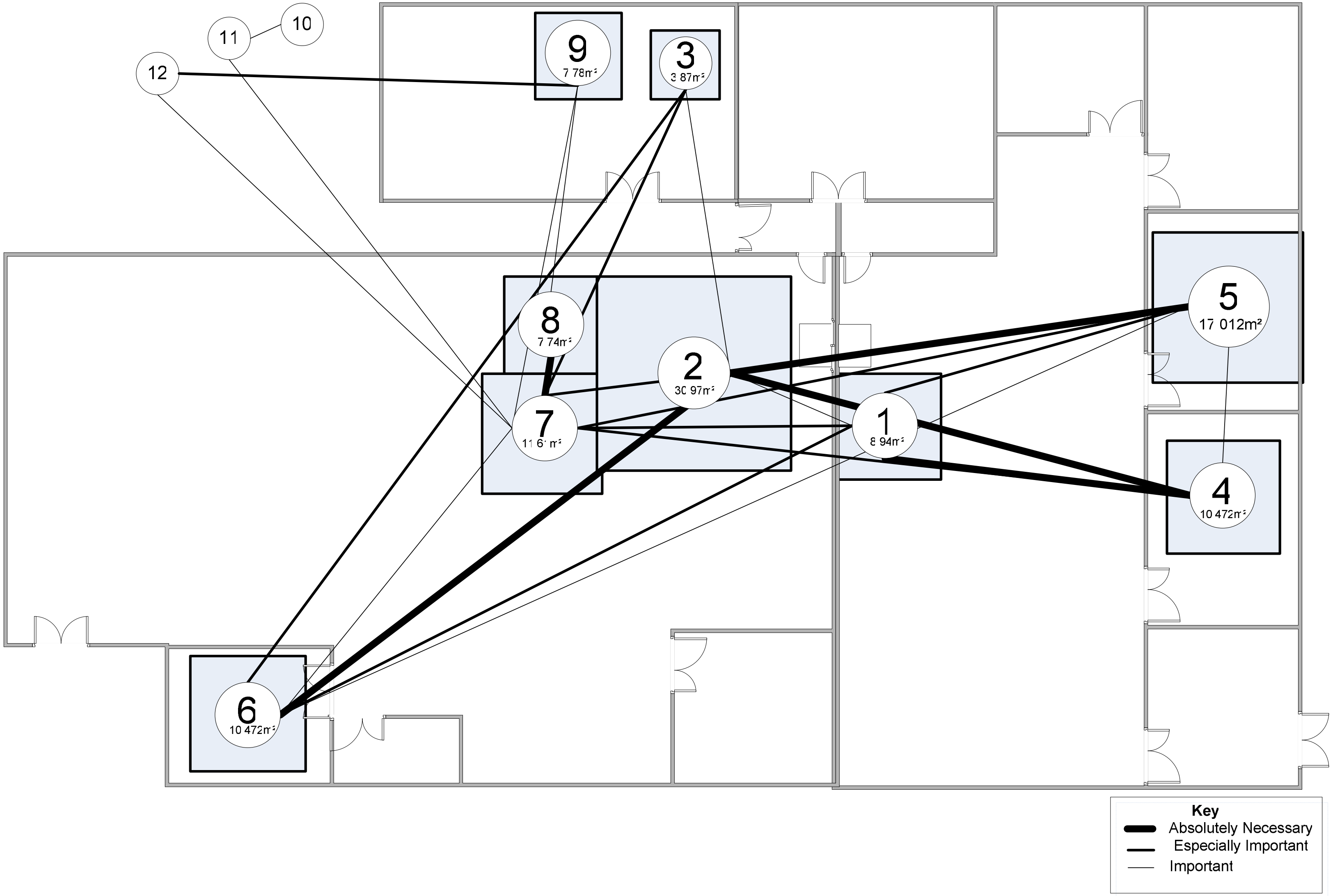


Figure A14: Alternative Block Diagram Number A

Alternative Block Diagram Number B

Workstations of the Eagle Eye (Planned)

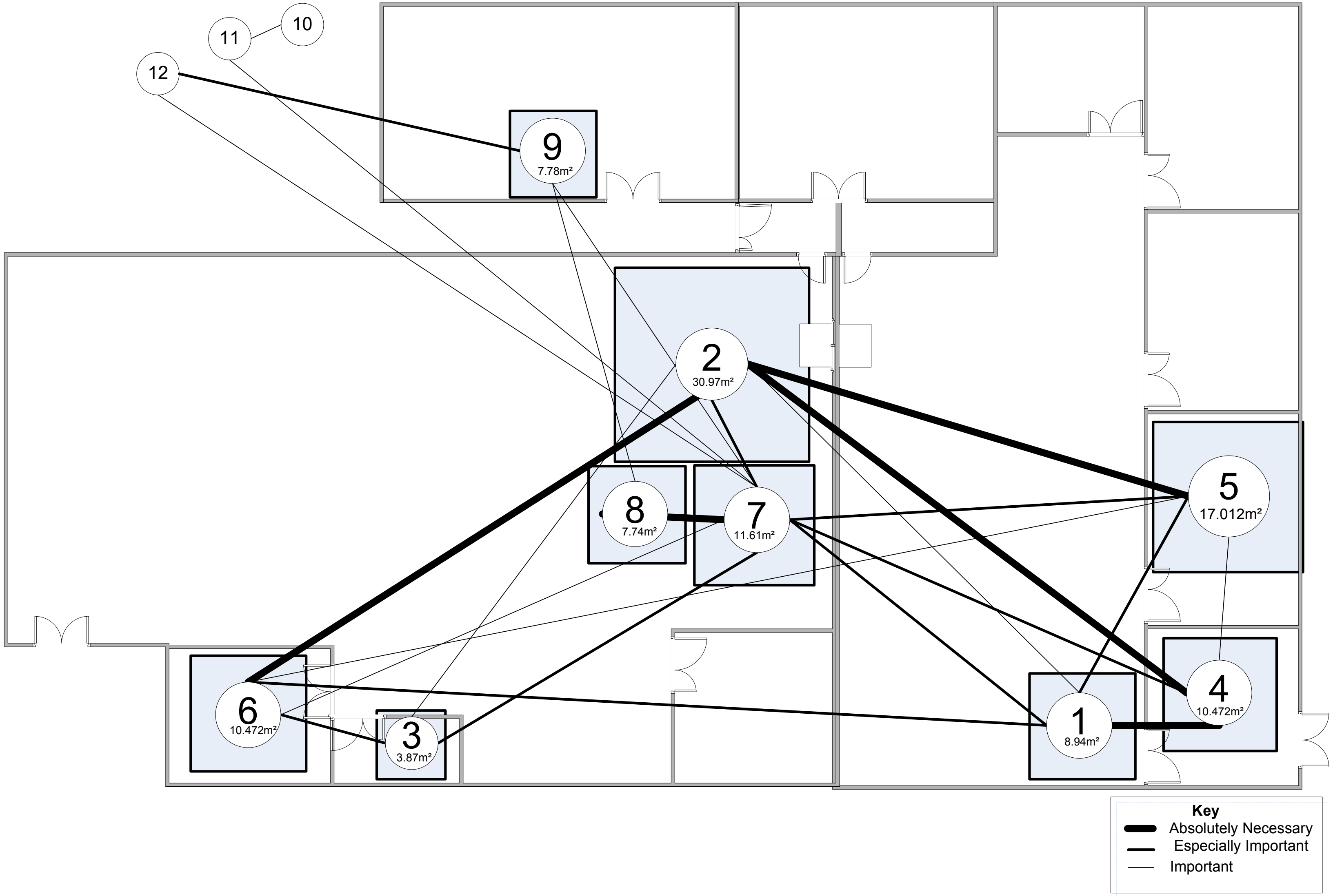


Figure A15: Alternative Block Diagram Number B

Alternative Block Diagram Number C

Workstations of the Eagle Eye (Planned)

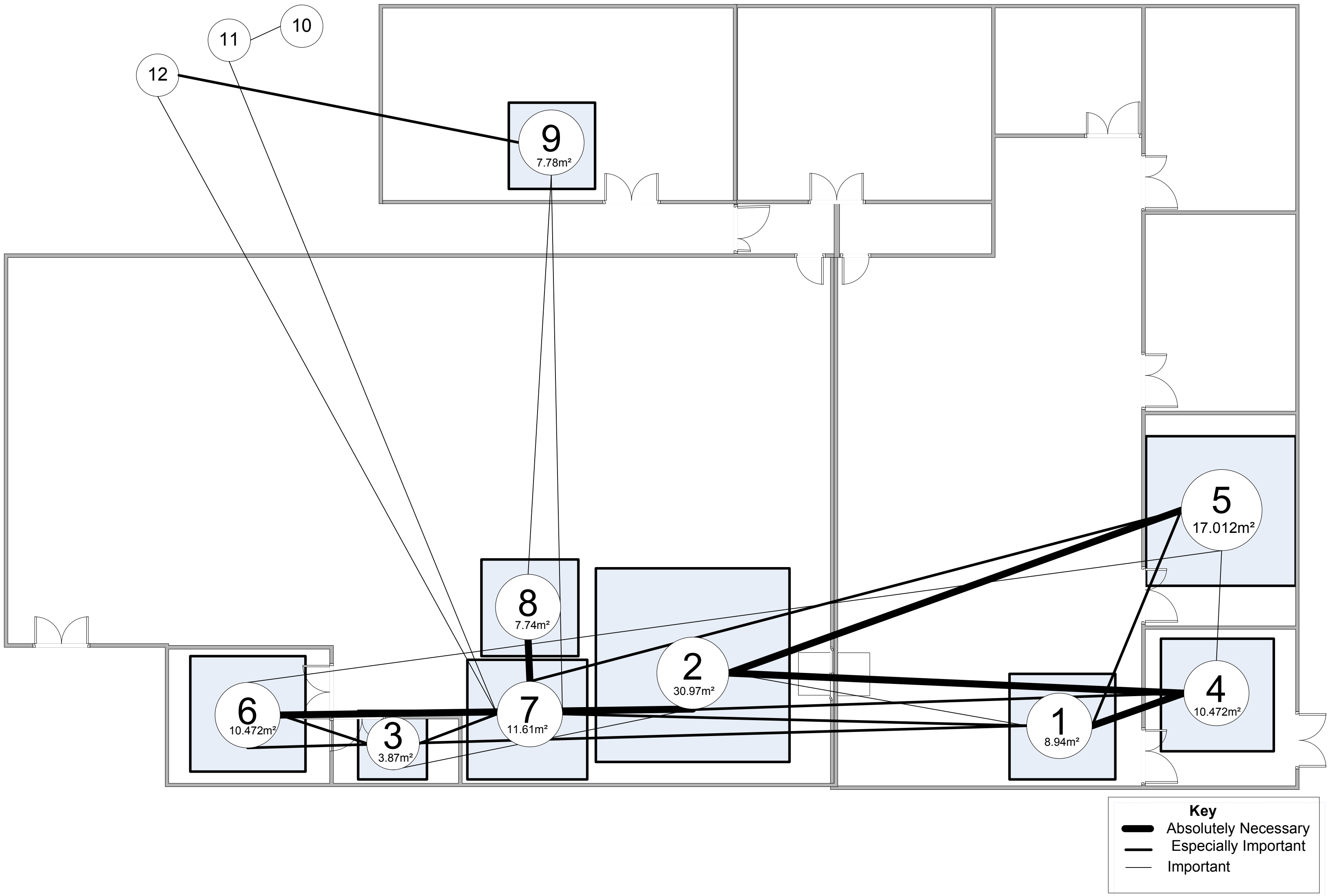


Figure A16: Alternative Block Diagram Number C

Alternative Block Diagram Number D

Workstations of the Eagle Eye (Planned)

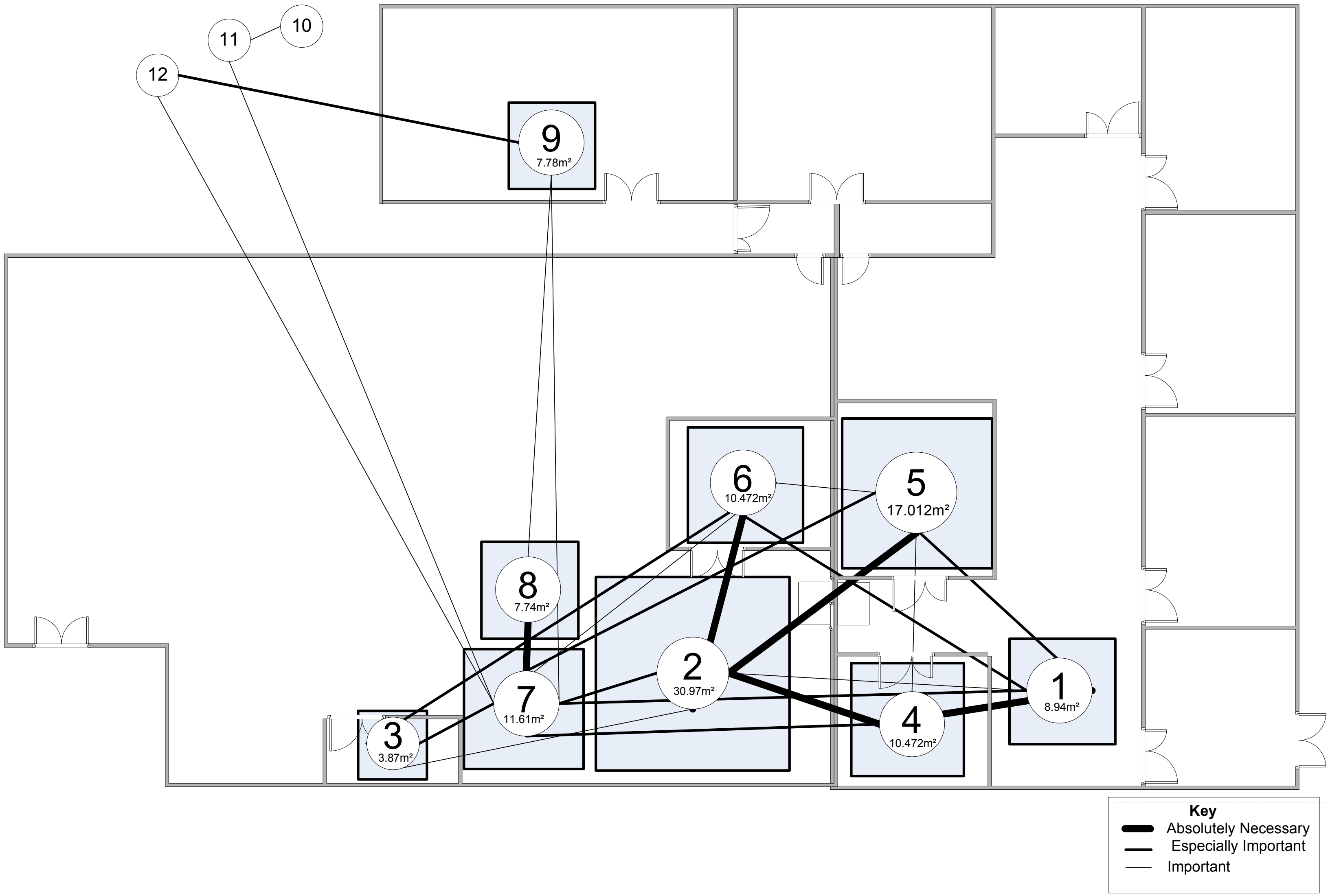


Figure A17: Alternative Block Diagram Number D

Table A2: Distance calculations of the current layout and Alternative number C

Distance door to store (m): 25

WS	Movement		Current		Alternative C		
	From	To	Distance to Door	Total Distance (m)	Distance to Airlock	Distance to Door	Total Distance (m)
1	9	2	11.54	401.94	4.33		47.63
2	15	3	19.29	797.22	2.78		50.04
3	3	0	6.75	95.25	13.45		40.35
4	2	8	11.37	363.7	9.71		97.1
5	1	6	7.74	229.18	7.8		54.6
6	2	13	17.92	643.8	15.76		236.4
7	9	9	17.92	772.56	9.13	13.53	168.74
8	2	2	3.97	115.88	11.04	11.42	44.54
9	2	2	8.86	135.44	2.99		11.96
	Current Total Distance			3554.97	Total Distance		751.36

APPENDIX B

Monte Carlo Simulation: Current Cycle Times

INPUTS **A =** 0.8 => Triangular distribution of lower level assembly process times **B =** 1.8 => General distribution of Quality check times

SUMMARY Durations of operations performed at each workstation (All values in hours)

WS	RANDOM: Lower Level Assemblies	Sum	CONSTANT: Assembly Processes	Other Processes	Packaging	Sum	RANDOM: Quality Checks	Sum
1	A A A A A A A A	8	1		0.17	1.17	B	1
2	A A A A A A A A A A A A A	13	0.83 1.5 0.83	2.66 0.25 0.67 2.66	0.83 0.25 0.83	11.3	B B B	3
3	A A A	3				0		
4	A	1	0.83		0.83	1.66	B	1
5			5.16 7.66 2.16 3.16 0.66	2.66 3.16	0.33	25	B	1
6			25		0.83	25.8		
7				2.5 1.25 12.5 5		21.3	B	1
8				12.5 5		17.5		
9				0.75 0.83 0.83		2.41		
10				5		5		
11				5		5		
12				0.5 1		1.5		

EQUATIONS

WS	Random		Constant		Random		Constant
1	8*A	+	1.17	+	1*B		
2	13*A	+	11.3	+	3*B		
3	3*A						
4	1*A	+	1.66	+	1*B		
5			25	+	1*B		
6			25.8			=	25.8
7			21.3	+	1*B		
8			17.5			=	17.5
9			2.41			=	2.41
10			5			=	5
11			5			=	5
12			1.5			=	1.5

FORCASTED DEMAND

Forcasted Demand: 80 per month
Hours per month: 172
Size of Batches: 10
Maximum Cycle time: 21.5 hours

RESULTS

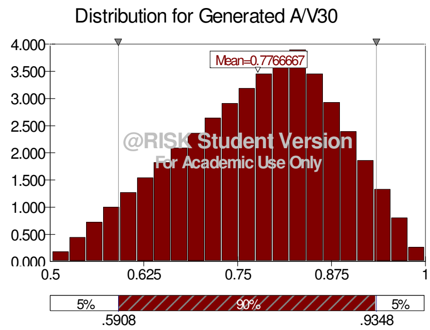
Average Total Hours: 149.9688 hours
Standard Deviation of Total: 9.108274
Longest average cycle time 26.93045 hours, at workstation 2
Shortest average cycle time 1.5 hours, at workstation 12

OUTPUTS 0.8 => Generated A 1.8 =>Generated B

WS	1	2	3	4	5	7	Total
	9.22792793	26.9304505	2.33	4.28126126	26.8445946	23.1445946	149.9688288

Workstation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Averages	**9.227929**	**26.93045**	**2.33**	**4.281262**	**26.84459**	**25.8**	**23.14459**	**17.5**	**2.41**
Stand. Dev.	1.504659	3.981307	0.311387	1.247195	1.241156	0	1.241156	0	0
Higher than Max?	No	Yes	No	No	Yes	Yes	Yes	No	No
Difference	0	5.430452	0	0	5.344595	4.3	1.644595	0	0

Figure B1: The Excel Simulation Model



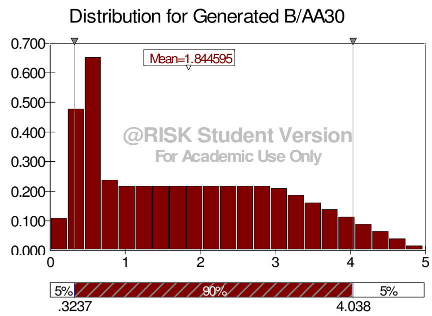


Figure B2: Histogram of generated input variables

Monte Carlo Simulation: Current Cycle Times - Quality Check times adapted

INPUTS **A =** 0.8 => Triangular distribution of lower level assembly process times **B =** 0.5 => Adapted General distribution of Quality check times

SUMMARY Durations of operations performed at each workstation (All values in hours)

WS	RANDOM: Lower Level Assemblies	Sum	CONSTANT: Assembly Processes	Other Processes	Packaging	Sum	RANDOM: Quality Checks	Sum
1	A A A A A A A A	8	1		0.17	1.17	B	1
2	A A A A A A A A A A A A A	13	0.83 1.5 0.83	2.66 0.25 0.67 2.66	0.83 0.25 0.83	11.3	B B B	3
3	A A A	3				0		
4	A	1	0.83		0.83	1.66	B	1
5			5.16 7.66 2.16 3.16 0.66	2.66 3.16	0.33	25	B	1
6			25		0.83	25.8		
7				2.5 1.25 12.5 5		21.3	B	1
8				12.5 5		17.5		
9				0.75 0.83 0.83		2.41		
10				5		5		
11				5		5		
12				0.5 1		1.5		

EQUATIONS

WS	Random		Constant		Random		Constant
1	8*A	+	1.17	+	1*B		
2	13*A	+	11.3	+	3*B		
3	3*A						
4	1*A	+	1.66	+	1*B		
5			25	+	1*B		
6			25.8			=	25.8
7			21.3	+	1*B		
8			17.5			=	17.5
9			2.41			=	2.41
10			5			=	5
11			5			=	5
12			1.5			=	1.5

FORCASTED DEMAND

Forcasted Demand: 80 per month
Hours per month: 172
Size of Batches 10
Maximum Cycle time: 21.5 hours

OUTPUTS

WS	1	2	3	4	5	7	Total
	7.88333333	22.8966667	2.33	2.93666667	25.5	21.8	140.5566667

Workstation	1	2	3	4	5	6	7	8	9
Averages	7.883332	22.89666	2.33	2.936666	25.5	25.8	21.8	17.5	2.41
Stand. Dev.	0.850995	1.455601	0.311383	0.206052	0.176785	0	0.176785	0	0
Higher than Max?	No	Yes	No	No	Yes	Yes	Yes	No	No
Difference	0	1.396663	0	0	4	4.3	0.3	0	0

RESULTS

Average Total Hours: 140.5567 hours
Standard Deviation of Total: 2.887929
Longest average cycle time 25.8 hours, at workstation 6
Shortest average cycle time 1.5 hours, at workstation 12

Figure B3: The Excel Simulation Model, with quality check times adapted

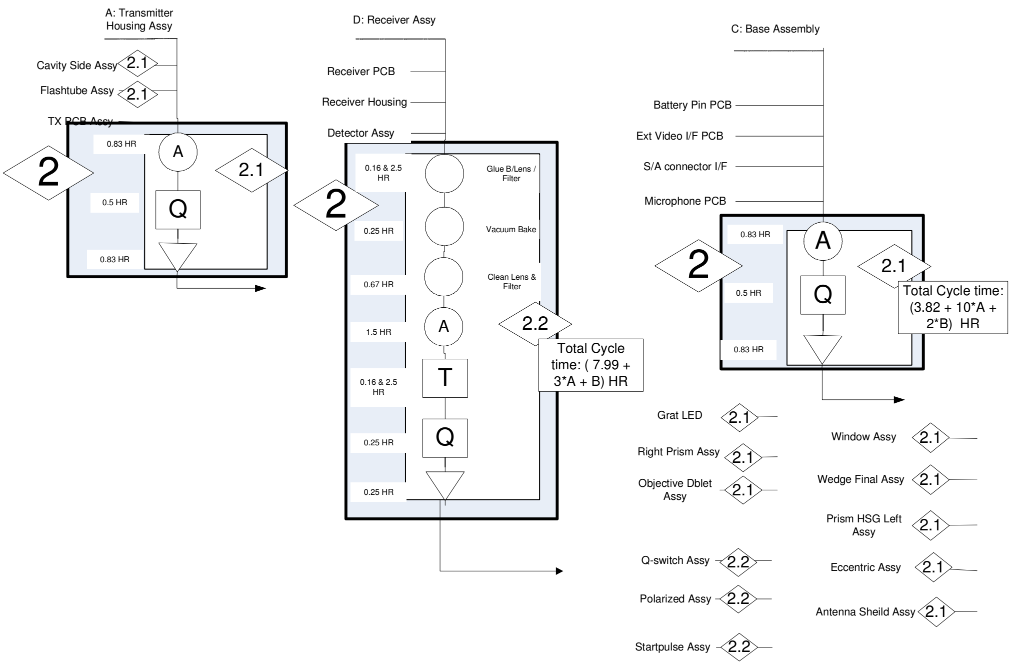


Figure B4: Task groupings of workstation number two

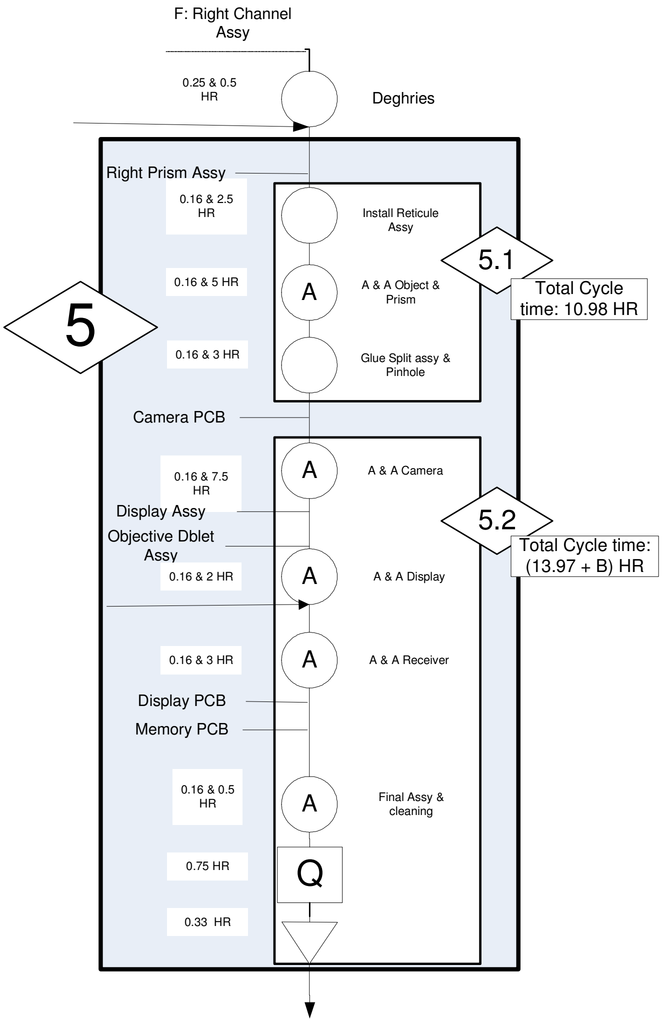


Figure B5: Task groupings of workstation number five

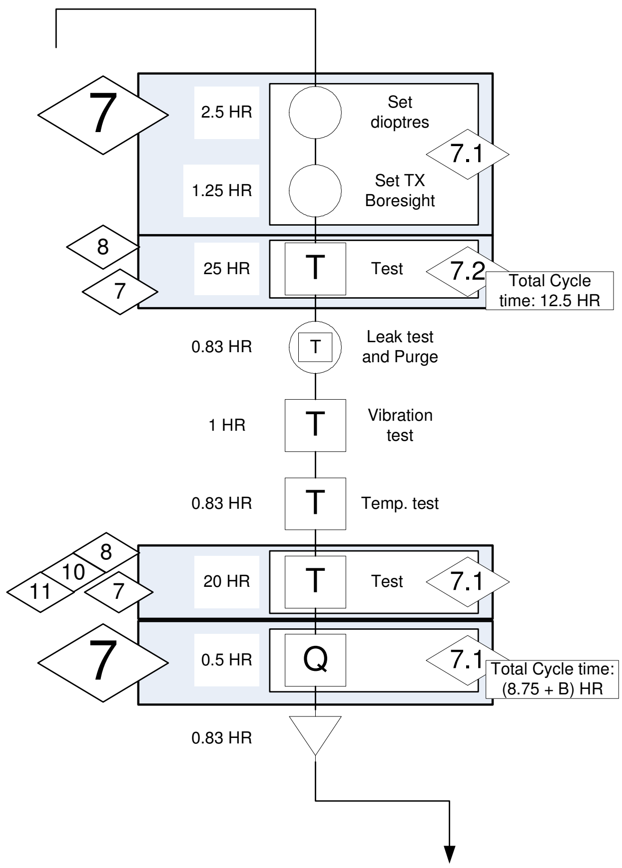


Figure B6: Task groupings of workstation number seven

Monte Carlo Simulation: Current Cycle Times - Workstation task allocation changed

INPUTS **A =** 0.8 => Triangular distribution of lower level assembly process times **B =** 1.8 => General distribution of Quality check times

SUMMARY Durations of operations performed at each workstation (All values in hours). Workstation 2, 5 and 7 broken into two groupings

WS	*RANDOM* Lower Level Assemblies	Sum	*CONSTANT* Assembly Processes	Other Processes	Packaging	Sum	*RANDOM* Quality Checks	Sum
1	A A A A A A A A	8	1		0.17	1.167	B	1
2.1	A A A A A A A A A A	10	0.83 0.83		0.83 0.83	3.32	B B B	3
2.2	A A A	3	1.5	2.66 0.25 0.67 2.66	0.25	7.99		
3	A A A	3				0		
4	A	1	0.83		0.83	1.66	B	1
5.1			5.16	2.66 3.16		10.98		1
5.2			7.66 2.16 3.16 0.66		0.33	13.97	B	
6			25		0.83	25.83		
7.1				2.5 1.25 5		8.75	B	1
7.2				12.5		12.5		
8				12.5 5		17.5		
9				0.75 0.83 0.83		2.41		
10				5		5		
11				5		5		
12				0.5 1		1.5		

EQUATIONS

WS	Random		Constant		Random		Constant
1	8*A	+	1.167	+	1*B		
2.1	10*A	+	3.32	+	2*B		
2.2	3*A	+	7.99	+	1*B		
3	3*A						
4	1*A	+	1.66	+	1*B		
5.1			10.98			=	10.98
5.2			13.97	+	1*B		
6			25.83			=	25.83
7.1			8.75	+	1*B		
7.2			12.5			=	12.5
8			17.5			=	17.5
9			2.41			=	2.41
10			5			=	5
11			5			=	5
12			1.5			=	1.5

FORCASTED DEMAND

Forcasted Demand: 80 per month
Hours per month: 172
Size of Batches 10

Maximum Cycle time: 21.5 hours

RESULTS

Average Total Hours: 138.9288 hours
Standard Deviation of Total: 9.07027
Longest average cycle time 25.83 hours, at workstation 6
Shortest average cycle time 1.5 hours, at workstation 12

OUTPUTS

WS	1	2.1	2.2	3	4	5.2	7.1	Total
	9.22792793	14.8	12.2	2.33	4.28126126	15.8145946	10.5945946	138.9288288

Workstation	1	2.1	2.2	3	4	5.1	5.2	6	7.1	7.2	8	9
Averages	9.227924	15	12	2.329999	4.28126	11	16	25.83	11	12.5	17.5	2.41
Stand. Dev.	1.494123	2.7	1.3	0.311386	1.245613	0	1.2	0	1.2	0	0	0
Higher than Max?	No	No	No	No	No	No	No	Yes	No	No	No	No
Difference	0	0	0	0	0	0	0	4.33	0	0	0	0

Figure B7: The Excel Simulation Model, with workstation tasks adapted

Monte Carlo Simulation: Current Cycle Times - Adapted

INPUTS **A =** 0.8 => Triangular distribution of lower level assembly process times **B =** 0.5 => General distribution of Quality check times, *adapted*

SUMMARY Durations of operations performed at each workstation (All values in hours). *Workstation 2, 5 and 7 broken into two groupings*

WS	*RANDOM* Lower Level Assemblies	Sum	*CONSTANT* Assembly Processes	Other Processes	Packaging	Sum	*RANDOM* Quality Checks	Sum
1	A A A A A A A A	8	1			1	B	1
2.1	A A A A A A A A A A	10	0.83 0.83			1.66	B B B	3
2.2	A A A	3	1.5	2.66 0.25 0.67 2.66		7.74		
3	A A A	3				0		
4	A	1	0.83			0.83	B	1
5.1			5.16	2.66 3.16		10.98		1
5.2			7.66 2.16 3.16 0.66			13.64	B	
6			25			25		
7.1				2.5 1.25 5		8.75	B	1
7.2				12.5		12.5		
8				12.5 5		17.5		
9				0.75 0.83 0.83		2.41		
10				5		5		
11				5		5		
12				0.5 1		1.5		

EQUATIONS

WS	Random		Constant		Random		Constant
1	8*A	+	1	+	1*B		
2.1	10*A	+	1.66	+	2*B		
2.2	3*A	+	7.74	+	1*B		
3	3*A						
4	1*A	+	0.83	+	1*B		
5.1			10.98			=	10.98
5.2			13.64	+	1*B		
6			25			=	25
7.1			8.75	+	1*B		
7.2			12.5			=	12.5
8			17.5			=	17.5
9			2.41			=	2.41
10			5			=	5
11			5			=	5
12			1.5			=	1.5

FORCASTED DEMAND

Forcasted Demand: 80 per month
Hours per month: 172
Size of Batches 10

Maximum Cycle time: 21.5 hours

RESULTS

Average Total Hours: 139.6667 hours
Standard Deviation of Total: 2.852612
Longest average cycle time 25 hours, at workstation 6
Shortest average cycle time 1.5 hours, at workstation 12

OUTPUTS

WS	1	2.1	2.2	3	4	5.2	7.1	Total
	7.88333333	12.1	10.8	2.33	2.93666667	14.47	9.25	139.6666667

Workstation	1	2.1	2.2	3	4	5.1	5.2	6	7.1	7.2	8	9
Averages	7.883331	12	11	2.329999	2.936667	11	14	25	9.3	12.5	17.5	2.41
Stand. Dev.	0.845532	1.1	0.4	0.311384	0.203221	0	0.2	0	0.2	0	0	0
Higher than Max?	No	No	No	No	No	No	No	Yes	No	No	No	No
Difference	0	0	0	0	0	0	0	3.5	0	0	0	0

Figure B8: The Excel Simulation Model, adapted