Computer Aided Manufacturing System Modelling and Development Using Virtual Reality

by

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This thesis is submitted to Dublin City University as the fulfilment of the requirement for the award of the degree of

Doctor of Philosophy

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School of Mechanical and Manufacturing Engineering
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DECLARATION

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of *Doctor of Philosophy*, is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

Singed: M. Iqbal

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Date : February 2000

Dedication

This thesis is dedicated to my parents who took all the troubles in the world with smile for the advancement of their children's knowledge and to my wife and daughter.

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I would like to express my sincere thanks and gratitude to Prof. M.S.J. Hashmi my supervisor and Head of School of Mechanical and Manufacturing Engineering of Dublin City University for his kind guidance, encouragement and supervision throughout the course of this work. His teaching to the subject matter of the work sometimes formally and sometimes not so formally will always be thankfully remembered.

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Times during the period of this work were never been even. There were times of happiness and there were times of distress. My wife, Salma and myself shared the both. She made life much better at the times of distress with her support and comfort. I must thank her for her supportive role during the work. I must also thank my daughter, Shahrin, who has always provided the balance between work and play.

I would also like to thank our families back home who always supported and comforted us through their letters during these long years.

Finally, all praise to God Almighty the Creater and Sustainer of the World for enabling me to complete this work.

Mohammad Iqbal

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Mohammad Iqbal, B.Tech., M.Sc.Eng.

ABSTRACT

This work focused on virtual factory environment created to assess the value of Virtual Reality (VR) and animation based software for design, visualisation and planning of production facilities (i.e. their user friendliness for the user to perform specific operation).

The project largely focused on what desk-top VR techniques can do to assist the design and planning of production facilities and application of techniques to solve plant layout problems using 3D and 2D views. The first part describes an approach to a virtual bi-cycle factory by means of a three dimensional modelling system and animation based simulation package (PC version of Animation Package 3D Studio Max) by taking into account the real data of a factory. This part also discussed how 3D solid modelling and animation based simulation can aid engineers in analysing the virtual factory's layout with a view (i) to identify bottlenecks in the existing factory (ii) proper utilisation of space and other facilities by applying plant layout problem solving techniques. Also the usability of the Superscape VRT 5.5 and 3D Studio Max System were assessed for how easy or difficult it was for the user to perform specific operations. The last part of the work deals with the application of CIM (Computer Intregated Manufacturing) concept in one of the virtual factories created earlier and to analyse the simulation result.

Firstly, the applicability of the 3D Studio Max system was assessed for its user friendliness (for the user to perform specific operations). The designer can build a virtual factory just like constructing a miniature model of the real factory. A 3D model of a real bi-cycle parts manufacturing factory has been modelled using 3D Studio Max Software. Participant can navigate through virtual factory and examine the virtual factory from different viewing points. After visualising different sections of the factory using viewing points, it is considered that both the factory walkthrough

and the visualisation facilities were useful for designing and planning activities in virtual environment. Various bottlenecks of the bi-cycle parts manufacturing factory layout were identified using 2D and 3D views and scientific factory layout problem solving concepts and techniques. The old layout and the new layout were compared using the concept of CRAFT (Computerised relocation of facilities technique) and further changes were made until the new layout was found to be the better one.

Secondly, a simple toy factory, which makes a toy sports car (for four to six year old children), has been modelled using Desktop Virtual Reality System (Superscape VRT 5.5).The factory model has been designed to visualise shop floor virtually and to test both the factory walk through and visualisation facilities. It was found that the factory walkthrough and viewing point facilities of Superscape VRT 5.5 is better than that of 3D Studio MAX. Participant can navigate freely through the virtual factory using Superscape VRT 5.5 mouse where as for the case of 3D Studio MAX, participant cannot navigate freely through the virtual factory using the mouse.

Lastly the process modelling and simulation software SimCad has been used to simulate the processes of the bi-cycle parts manufacturing factory in 2D. Simulation results were analysed. The results were found to be satisfactory.

Nomenclature

2-D	Two Dimensional
3D	Three Dimensional
3D S MAX	3-D Studio Max
ASCII	American Standard Character for Information Interchange
ARC	Advance Robotic Center
AVR	Advance Virtual Reality
CAD	Computer Aided Design
CAI	Computer Aided Instruction
CAM	Computer Aided Machining
CIM	Computer Integrated Manufacturing
DoF	Degree of Freedom
DOS	Disk Operating System
DXF	Database Exchange Files
FMC	Flexible Manufacturing Cells
FMS	Flexible Manufacturing System
GUI	Graphics User Interface
HMD	Head Mounted Display
IVR	Immersion Virtual Reality
LCD	Liquid Crystal Display
MB	Mega Byte
NASA	National Aeronautics & Space Administration
NCSA	National Centre for Supercomputering Applications
PC	Personal Computer
RAM	Read Access Memory

SCL	Superscape Control Language
S.E	Shape Editor
SGI	Silicon Graphic
SID	Spatially Immersive Display
SVGA	Super Video Graphic Adapter
W.E	World Environment
WoW	World on Window
VE	Virtual Environment
VGA	Video Graphic Adapter
VM	Virtual Manufacturin
VRS	Virtual Reality and Simulation
VIRART	Virtual Reality Application Research
VR	Virtual Reality

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Chapter 1

INTRODUCTION

1.1 Virtual Reality

1.1.1. Introduction

Growing interest in Virtual Reality (VR) techniques over the past few years have lead to numerous applications of them, such as in science fiction movies, landscaping, designing building and most obviously the video game industry. Its advantages over the existing technologies are primarily that users can visualise, feel involvement and interact with virtual representations of real world activities in real time. Virtual Reality (VR) can be used to enhance engineering design in the early stages of conceptual design, in the early stages of design and during design analysis. Some of the areas where VR can contribute to increase engineering productivity are in the areas of design, prototyping, design for maintenance and assembly, factory planning, network design, workshop training and concurrent engineering.

Virtual Reality (VR) started from an unknown science and progressed into a highly exclusive, yet known science. The technology was born from the merging of many disciplines including psychology, cybernetics, computer graphics, database design, real time and distributed systems, electronics, robotics, multimedia and telepresence. There are many emerging and evolving concepts and definitions of virtual reality. Any representation that emulates reality (i.e. a drawing, a photograph, a movie or an audio recording) is, in a sense a virtual reality. Many different people with many meanings use the term Virtual Reality (VR) but all imply the same meaning. For a definition of VR to be accurate, it should include the terms, three dimensional, computer generated and interactive. Therefore, Virtual Reality may be defined as a computer simulation of a three dimensional environment, in which the user is able to both view and manipulate the contents of three-dimensional environment [1]. Also Virtual Reality (VR) can be defined as a computer integrated system that supports user interaction allowing them to participate in an environment that mimics a scenario in the real world [1]. If a virtual environment is to be interactive, then the objects that make up the environment need to have some form of intelligence. This intelligence is normally pre-programmed into each of the objects in the environment e.g. A door could be programmed in such a way that if the user interacted with its handle, the door would either open or close.

1.1.2. Virtual Reality: Past, Present and Future

Virtual reality can be seen as logical evolution of existing human-computer interface. In the beginnings of computerisation, humans interacted with computers by moving physical switches on the computer itself. Virtual Reality (VR) originated in the 1960's, the person accredited with pioneering the concept of VR is Dr. Ivan Sutherland,[1] who made groundbreaking contribution to the computer graphics and immersive interaction at Harvard University, and the University of Utah. Sutherland showed that a person with the aid of a light pen could interact with a computer via a display surface. Later he developed the first algorithms to remove " hidden line" in

3D drawings, which are now essential to ascertain a true realistic picture of a 3-D object. In 1967, Sutherland and his research group developed into what was probably their most memorable project by experimenting with the presentation of three-dimensional data through the use of a binocular display system which was attached to the users head called a Head Mounted Display (HMD)[1].

Later, in the 1960's, human interacted with computer through the use of punch cards. In the 1970's came minicomputers and networks, which provided time-shared computing. In the 80's, UNIX-based, multi-tasking, multi-windowing interaction with computers was through the keyboard and mouse, while viewing the display on monitor. Virtual Reality (VR) offers a new, unique way to interact with computer data and images and opens up new opportunities to expand the use of computer technology for the engineers [2].

1.2 Virtual Reality and Simulation Technology

Computer simulation is the development of a model of an actual or theoretical system, executing the model on a computer and analysing the output. Simulation is used to develop a level of understanding of the interaction of parts in a system. Computer graphics is the driving force towards a true representation of the system to be simulated. Simulation is often used because the level of understanding achieved is seldom achievable with other methods. A simulation is made up of a model and system. A system is an entity, which maintains its existence through the mutual interaction of its parts. A model is a simplified representation of the parts that make up the system.

Simulators, such as the flight simulator, were first built for the aircraft industry and the U.S. Air Force. The Flight Simulator dates back to 1929 when Edwin A. Link patented the first ground-based flight trainer. The first time in 1934 the U.S. Army used Simulators to train their pilots. During World War II the United States and its allies purchased 10,000 "blue box" link trainers to teach instrument flying and radio navigation skills. Student Pilots learned how to manoeuver aeroplane by manipulating controls in specially built cockpits. These cockpits were initially removed from the aeroplane and mounted on moveable platforms that tilted and rolled, based on the pilot's actions on the controls. Since that time, flight simulators have advanced well beyond basic instrument and radio navigation trainers. Today, Simulators enable pilots to 'feel' the simulated emergency in motion-based systems and conduct air-to-air combat in visualy based systems [3]. A major limitation of these early simulators was that they lacked visual feedback. This changed when video displays were coupled with the model cockpits and now the video displays have been replaced with highly detailed Virtual World's. Table 1.1 illustrates the path that related VR technologies have followed since the 1920's [3].

Table 1.1: The path, which Virtual Reality has followed.

1920's	Edwin Link worked on vehicle simulation, arguably the forerunner of Virtual Reality technology.
1940's	Teleoperation technology began. Teleoperation allows a human operator to use a visual display and a "master" manipulator (e.g. a joystick) to manually control a remote "slave" device such as a vehicle or robotic arm.
1950's	"Cinerama" was developed using 3-sided screens. Cinerama uses 3 projectors showing three films to fill an immense deeply curved screen. The deeply curved screen created an intense participatory effect for the audience.
1966	Flight Simulation, NASA. Present flight simulation techniques attempt to provide a pilot with enough sensory cues to sufficiently fool the pilot into believing that an actual aircraft is being flown.
Late 1960's	Development of synthetic computer-generated displays used for virtual environments, pioneered by Dr. Ivan Sutherland.
1970s	Krueger introduced the term "Artificial Reality", which is one of the earlier terms of Virtual Reality.
1984	William Gibson published the term "cyberspace" in his book, "Neuromancer". The term 'Cyberspace' was latter refined to Virtual Reality.
1989	Jaron Lianier, founder of VPL research, introduced the term "Virtual Reality".
1990	Continued research for specific uses of Virtual Reality, such as the entertainment industry (e.g. Sega & Nintendo companies).

1.3 Layout of the Thesis

Chapter 2 presents the author's review of research that has been carried out to enable the application of Virtual Reality in product design, prototyping, virtual training and analysis of manufacturing process in virtual environment.

Chapter 3 presents components of Virtual Reality system and different types of Virtual Reality systems.

Chapter 4 describes the software and hardware selected to create a realistic presentation of production facilities in virtual environment. This chapter also explains how data can be transferred from one software to another.

Chapter 5 focuses on some important topics in industrial and production engineering field, which would help in creating virtual environment.

Chapter 6 is related to application of two different types of software to design two different types of virtual factory and to analyse the existing layout of one of the factory using factory layout solving techniques. Superscape VRT 5.5 software has been used (i) to construct a virtual factory (ii) to test factory walk through system, and (iii) to visualise different sections of the factory. Also assessment of applicability of both the software systems for their user friendliness for the user to perform specific operations.

Chapter 7 describes the process modelling and simulation software SimCad and its application to the bi-cycle parts manufacturing factory in 2D to analyse manufacturing processes.

Chapter 8 presents the conclusions of the research described within this thesis, and puts forward some suggestions for future work that could be carried out.

Chapter 2
LITERATURE REVIEW AND SCOPE OF WORK

2.1 Virtual Environment

2.1.1. Introduction

Virtual Environments are made up of 3-D graphical images that are generated with the intention of interaction between the user and the objects in that environment. The term virtual environment (VE) describes a computer-based generation of an intuitive perceivable and experienceable scene of a natural or abstract environment [4]. VE applications will contribute to enhancing the qualities of human-computer interaction, the importance of which, in view of increasing complex information and communication applications, is constantly rising. VE technologies are more able than conventional computer applications to influence the thinking and behaviour of people and to come to grips with social processes. Consequently, VE applications are not only challenging technical and social concepts, but also philosophical ideas. The concept of Virtual Environment came from Virtual Reality originated in the 1960's. At that time, however, because of limited computer capacity, one was only able to create primitive geometric objects and environments.

The recent surge in VR technologies gives a new impetus to the development of new and better training solution. First VE applications were employed under the U.S. military and at NASA, who tested telepresence for the purpose of remote control tasks in space. The U.S. military was using flight simulators with computer-generated graphics to train its pilots. The availability of powerful graphic computers led towards a technological push and the research in diverse application fields within science, industry, and entertainment. As a result, the commercial development of VE applications started during the 1980s. Today, both, science and industry commit themselves world-wide to the further development and expansion of VE systems. In the 1970's. Hollywood started to realise the power of VR in the film industry due to it's potential to create extraordinary Visual Scenarios. Films such as 'Star Wars', followed by 'Terminator' and 'Jurassic Park' are just some of the films that benefited immensely from VR and computer graphics in general. Recently Pentagon has conducted a Virtual Nuclear War Game to predict its consequence.

The capabilities to put the ergonomic knowledge into practice, efficient computer-supported methods of integrated work system design are being investigated, developed, and used, which make new dimensions of application possible. Essential characteristics of these methods, which are based on virtual environment technologies, are the three-dimensional modelling and simulation of virtual objects and situations, where the users are intensively and multisensorily integrated by means of intuitive, real time-oriented intersection modes [5]. Virtual Environment works as a communication tool. In a way, virtual environments are like telephones; people were particularly poor at predicting what the telephone would be used for before it became widespread, and it has turned out to be used for all sorts of communication (via speech) between people. Like online comprehension, virtual environments can be used to bring insight to users while they are in the environment. When using virtual environments for communication, however, the aim of the interface is to facilitate transfer of knowledge (and other types of communication) between users, rather than insight about the environment itself. Virtual Environment is simply the medium for communication between users. Virtual Environment can be used to communicate the design of a building to prospective clients via architectural walk-through or to reconstruct the scene of a crime from available evidence and communicate this reconstruction to jurors.

The first paper on Virtual Reality was published by Sutherland [6] in 1965 describing what the ultimate display would be like. He described that it would be a room within which the computer can control the existence of matter. A chair display in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland which Alice walked. Table 2.1 illustrates the technologies applied to Virtual Environment [6].

In the course of this project, a literature survey has been carried out into the greater involvement of virtual reality in design, prototyping, assembly, virtual training and factory modelling in virtual environment. The results of this survey are presented in this chapter.

2.2 Review of Relevant Literature on Virtual Reality Application in Different Areas

Many theoretical studies and research work have produced methodologies and basic software techniques which are at a level of refinement that is required for subsequent development of virtual reality in design, prototyping, assembly, virtual training, engineering analysis and factory modelling in virtual environment as briefly outlined as follows:

Table 2.1 Technologies applied to VEs today [6].

echnology	Description	Feature
Simulators	Projected display, sound (and vibration) and replica of Physical surroundings (e.g. cab or flight deck).	Often expensive, usually Dedicated to specific Applications, high quality experience.
Head Mounted Display (HMD)	Screens and lenses fitted in goggles or helmet, giving Stereoscopic, binocular display; frequently have ear-phones or auditory environment; head and trackers allow continual pdating of display for user movement and orientation.	Range from cheap to relatively expensive; use with range of sophistication in VE software and graphics engine.
Head Coupled Display	CRT monitor and controls supported on Universally jointed Stand. The monitor is held and moves as if it was a large, Heavy pair of binoculars.	Improved graphics, fast tracking, increased comfort; Expensive.
Mixed Environment	Use of HMD with some replication of 'hard' features of Environment (e.g. seat, steering wheel).	Approaching a flexible simulator.
Augmented Reality Display	Information from computer system overlaid onto view of real world, for instance 'see through' displays on Windscreen or helmet visor.	Probably not a virtual Environment.
Artificial Reality	Video cameras capture participant body movements that are included within large display of the generated virtual environment.	Inflexible.
Desktop(or Monitor)	Virtual environment displayed on desktop screen; control via variety of '3D' input devices.	Improved graphics quality, flexible and user comfort over HMDs, possibly at the expense of 'presence'. Range of software and hardware options from very cheap to very expensive. Can have HMDs fitted for necessary applications.
Wall Mounted	As for desktop but display enlarged and projected on wall.	Greater sense of immersion than for desktop; less display quality unless very expensive. Inflexible.
Spatially Immersive display (SID).	As for wall mounted, but across several walls, ceiling.	As for wall mounted.

Stone [7] describes the advantages of computer aided design in which both the designer and the end user can observe, manipulate computer generated object. Similarly Haney and Romero [8] envisage VR-which enables designers and developers to actually 'see' the piece or system being designed and the manner in which it functions in operational environments. On similar lines Kalawsky [9] proposed virtual environments to prototype product designs in order to remove design and development risks early in the manufacturing life cycle. B. Bahr and G. Li [10] reported examining motion behaviour of an existing dump truck in a virtual environment, the motion behaviour of the dump truck can be easily and effectively evaluated and verified. Thus, design change can be performed before actual production. The period of the system design cycle can be shortened and thus reducing production cost. Gibson [11] used the virtual reality tool (VIRART linked to CAD system) to provide a complimentary technology to rapid prototyping to control software in a form that models the real life in design and manufacturing. Holland's [12] searched possible solutions to an information management system to connect to Virtual Reality application. Encarnacao [13] gave an excellent survey on European efforts related to virtual reality and its application. Research on virtual reality is now being developed to include scientific visualisation [14], graphical user interface [15], and object-oriented programming language [16]. Recent developments in CAD/CAM systems that employ computer simulation for designers to analyse products must also be included.

Automotive manufacturers like Ford [17], Mercedes-Benz [18] are examining the VR technology for the virtual prototyping of cars. Oli Odegard, in his paper [19] cited about VR application in architecture/design and industrial product areas as 09% and 08% respectively in Nordic countries. Volvo has been using VR in their interior design processing of cars. Equipped with an HMD (Head Mounted Device) the designer can sit in a model of the car and try out a proposed layout of the panels and instruments before it is implemented. MIT's CAD lab has developed the 3Draw-package [20], which allows the users to sketch in 3D. Other researchers have been working on VR systems for Solid Modelling and Virtual Sculpture [21]. London based twelve firms pull together to form Europe's leading virtual reality research centres, which applied computer based simulation and industrial design with 3D modelling projects called Virtual Reality and Simulation (VRS) [22]. Many companies use VRS and work together with the Advanced Robotics Center (ARR) to improve the aspects of the virtual reality models. These companies include Roll-Royce, Nirex, Vicker Ship building and Engineering, ICI Chemicals and Polymers and British Nuclear Fuels. These companies use VRS and ARR to run impact studies, as well as vary other tests. One example is when Vickers used it for 3D walk through models of nuclear and diesel submarines [22]. Tsung-Pin Yeh and Judy M. Vance [23] developed a technique to do sensitivity analysis and design optimisation process in a virtual environment A simple cantilever beam with homogeneous material property was tested to investigate the feasibility of interactive design sensitivity and optimisation in a virtual environment. Vance [24] developed a program, called SpareVR that allow four–bar spherical mechanism design in a virtual environment. Spherical mechanisms are a sub-class of the more general category of spatial mechanisms.

Even though virtual environment technologies are still difficult and expensive to use, people are doing real work. Virtual Manufacturing (VM) provides the engineer with the capability to " Manufacture in the computer". Manufacturing environments may be simulated in a 3D virtual environment. Practical and efficient methodology may be simulated in a 3D virtual environment. Practical and efficient use of VM technology is a necessary step as more and more emphasis is placed on zero defects manufacturing [25]. In essence, VM will ultimately provide a modelling and simulation environment so powerful that the fabrication/assembly of any product, including the associated manufacturing processes, will be simulated in the computer (Virtual Manufacturing Technical Workshop, 1994). It is expected that with the use of VM, the complete manufacturing process will be visual before the product is actually put into production.

The following series of case studies represent examples of recent state of the art work that exemplifies the application of virtual environments in one or several aspects of manufacturing. Manufacturing, in this case, is taken to encompass issues relating to maintenance and training as well as the actual creation of parts and the assembly of systems. These example actual real world systems, not simply speculative fantasies [26].

The Research and Technology organisation of Boeing Computer Services is actively involved in VR technology. According to David Mizell, manager of Virtual Systems Research & Technology, Boeing uses a concept known as Augmented Reality rather than the more classic VR configuration [27]. Augmented Reality is a term, which refers to the ability to see-through a computer-generated display. The generated images are superimposed on top of reality. This is accomplished by projecting a computer image onto a half-silvered mirror, which the user looks through. This technique provides a very effective and intuitive way of "annotating" reality. The Boeing team is using a headset configured for augmented reality, which they call a HUD set (heads-up, see-through, Head-mounted display). The assembly of aircraft is a highly complex task, which is difficult to automate. Many of the skills required demand dexterity not easily accomplished by robots. In addition airplays consist of many small lots size parts and reprogramming robots for these quantities is an expensive prospect. To quote from Caudell and Mizell's paper "Someone once said that a Boeing 747 is not really an aeroplane, but five million parts flying in close formation."

Researchers at Caterpillar Inc. [28] have used VR to improve the design process for heavy equipment. Dave Stevenson and John Bettner engineers with Caterpillar in collaboration with the staff of NCSA (National Centre for Supercomputing Applications) have put together a system which allows them to quickly prototype wheel loader and backhoe loader designs. In particular the team is able to perform visibility assessment of the new design. Engineers put on a helmet-mounted display and have a full 360 degrees of vision to see how the environment looks and to evaluate obstructions. A Silicon Graphics is used to generate the real time graphics display and to simulate the operation of the equipment. The engineers can "operate" the equipment and evaluate visual obstructions in a natural manner without having to build a physical prototype. This image from the Virtual Backhoe project illustrates an "operator" driving the virtual equipment at the NCSA VR lab. Select it to view a short MPEG movie of the facility in action. The Caterpillar team was awarded the 1993 NCSA Industrial Challenge Award for VR Use.

"This technology allows us to dramatically shorten the amount of time it takes to analyse a new design concept and incorporate it into our production process," said design Engineer Stevenson as stated in ref. [28]. "It also represents a sizeable cost savings because we aren't having to build prototype machines or make last-minute design changes." He said it takes six to nine months to build full-scale models and design changes using conventional design methods. However, using the virtual reality approach, designs usually can be evaluated in less than one month. Company officials said a number of design options already been tested for new models of wheel loaders and backhoe loaders that are to be introduced by 1996, and the company said it eventually plans to allow customers to "field test" new products by putting on the special helmet.

The Ford automotive company [28] has set up a development division called Ford Alpha Simultaneous Engineering. This development organisation is trying to evaluate the use of VR for automotive assembly. According to Jim Merner, manager of the VR project, they are evaluating process installation feasibility. The vehicle parts are represented in a CAD system. The CAD file is transferred to the system with the VR equipment. A user then manipulates the virtual part and attempts to assemble it into the virtual vehicle. The equipment used for the VR experiments are a VPL eye phone and data glove running of a Silicon Graphics computer. The user puts all the equipment on and attempts the part insertion. The system checks for interference and collision between the part and the vehicle. The hope is to use the VR set-up to evaluate the human ergonomics of various assembly operations. Eventually they hope to place some more motion trackers on the person to evaluate how much bending and stooping is necessary to complete the assembly.

Matsushita's Virtual Kitchen [28] one of the most widely publicised examples of VR used by the public is a set-up created by Matsushita in Japan. To quote from New quests article: The most famous (and in danger of becoming something of a self-caricature) is Matsushita's Virtual Kitchen, a retail application set up in Japan to help people choose appliances and furnishings for the relatively small kitchen apartment spaces in Tokyo. Users bring their architectural plans to the Matsushita store, and a virtual copy of their home kitchen is programmed into the computer system. Buyers can then mix and match appliances, cabinets, colours, and sizes to see what their complete kitchen will look like-without ever installing a single item in the actual location. The Matsushita VR Kitchen is significant because it one of the only examples of VR systems set up for public use, that is not a game or in a research lab. The general public is invited to use the configuration. in collaboration with the staff of NCSA (National Centre for Supercomputing Applications) have put together a system which allows them to quickly prototype wheel loader and backhoe loader designs. In particular the team is able to perform visibility assessment of the new design. Engineers put on a helmet-mounted display and have a full 360 degrees of vision to see how the environment looks and to evaluate obstructions. A Silicon Graphics is used to generate the real time graphics display and to simulate the operation of the equipment. The engineers can "operate" the equipment and evaluate visual obstructions in a natural manner without having to build a physical prototype.

Presently there are VR applications in the fields of education, entertainment, engineering and even the medical profession, to name but a few [28]. Figure 2.1 illustrates the wide range of disciplines in which VR is being used. Presently the technology is available to create applications in many fields and the designer's imagination should take advantage of this technology. The potential of using VR in the training sector is enormous as can be seen from the early days of the NASA flight simulator to recent advancements of using VR to train surgeons in the medical profession.

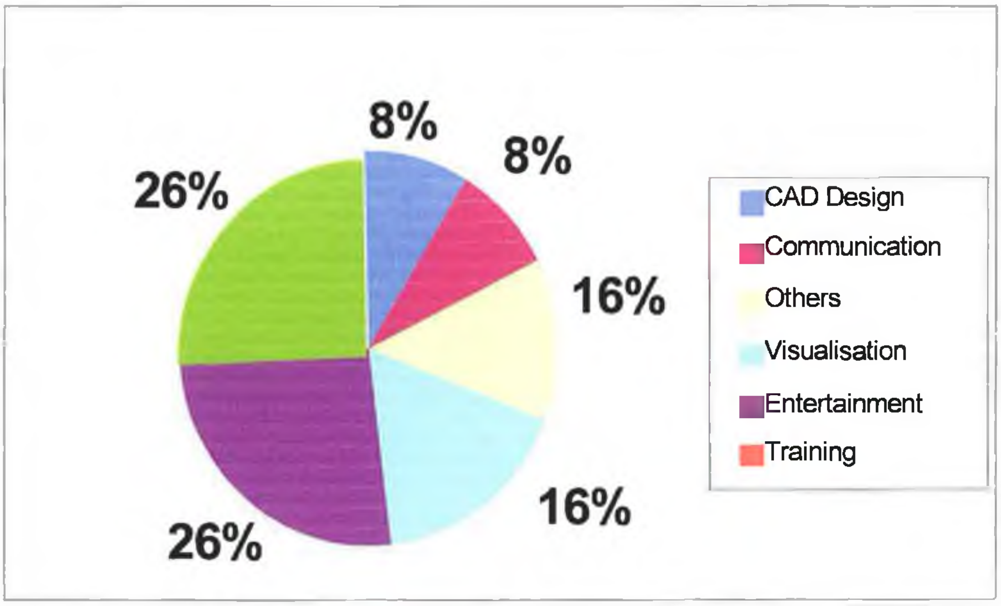


Fig. 2.1: Virtual reality Discipline Segments [27].

The following are a selection of different applications, which VR has been used to great effect [28].

Data Visualisation: Data Visualisation uses VR for viewing data in 3-D in order to gets a better idea of the meaning of it. Examples such as viewing molecules in 3-D, allow chemists to view the molecules from all angles and model the behaviour of chemical bonding. Also, physicists can model various problems in virtual reality to help understand the problems. Boeing, the American aircraft manufacturer, built a virtual reality wind tunnel, to demonstrate the unseen effects of wind passing over their models. Building aircraft models in virtual reality allows many different designs to be prototyped without the overheads and difficulty of building physical models and trying to experimentally determine their characteristics in a real wind tunnel.

Remote Surgery: The medical profession is paying particular attention in the use of VR for performing medical surgery from remote locations. The surgeon interacts with a virtual model while equipment at the remote surgery mirrors his/her behaviour. This is of particular use when there is a shortage of qualified surgeons. VR is currently being used in the training of medical staff. In a VR simulation surgery the VR patient can be programmed to respond to various stimuli. This technology is in its infancy but appears to have a lot of potential.

Astronaut Training: VR has recently been used on the Hubble telescope space mission. One of the astronauts' tasks was to attempt to polish the surface of the telescope massive lens. Space walks have been done many times before, but this mission required the manual equipment through at the lens. Using VR, the astronauts manipulated virtual equipment through the same joysticks they were to use in the mission. The virtual equipment responded to the manipulation, as if in a zero-gravity environment, teaching how inertia effects differ in space. NASA declared the experimental training for the mission a success.

Rapid Prototyping: Virtual Reality is providing to be a very useful tool for rapid prototyping. Rapid prototyping technology is primarily aimed at reducing the 'lead times' and the cost associated with new product development. One of the most essential benefits of the virtual prototyping concept is that it can offer a visualisation of an artefact to mediate an idea of design or reflect the idea [28]. When a new product is introduced various ergonomic and fundamental design effects have to be given serious consideration. VR makes use of a form of "digital clay" to create these prototype.

Vance [28] reported the following applications of virtual reality in Engineering:

Virtual Design: VR presents the opportunity to design in a 3D environment. Virtual reality tools provide the most realistic way of developing a prototype without the need to build a physical model. As a design tool VR allows users the opportunity to get inside and experiment with a design without the risk and expense of building it in the real world. In the future. Engineers will be able to mould and stretch 3D surface, create 3D holes, fillet 3D corners etc. without having to contend with a 2D display (traditional monitor). Also it can be used in analysing results such as stress, fluid, and thermal analysis among others. Visualise the results on a 3D model in the virtual design space will significantly enhance the engineer's ability to pinpoint trouble spots and areas of the design that are of interest. Coupling VR technologies with super computers for calculation purposes opens up the possibility of watching virtual crash test results.

Virtual Prototyping: Most engineering applications of VR at present are focused on the development of virtual prototypes. Ergonomic assessment of visibility, reach- ability, accessibility, clearance, comforts and aesthetics is generally performed on physical prototypes. If these kinds of assessments can be performed on a virtual prototype, significant savings will be realised in the design of new machines. The intent is not to eliminate physical altogether, but to reduce the number of prototypes that must be built before production of the new design in scheduled. Reducing the number of prototypes to answer questions such as "Will this part fit? Does this engine come together? Can I reach this knob or dial in the interior". While, Caterpillar Inc., the world's largest manufacturer of earth-moving and construction equipment, is using a CAVE (Cave Automatic Environment) to investigate assessing operator visibility. This type of assessment is very difficult to perform using existing 3D modelling tools. Virtual reality allows the designer to sit in the driver's seat and look around to evaluate the degree of visibility available. In the future, the designer will be able to reach out and alter the computer model, by moving the virtual surfaces, to produce a design that allows for increased visibility. With virtual designs, if it is easy to alter a design, more iteration will be performed, which will result in more robust designs.

Maintenance Planning in Design: Another area where virtual reality will become important is in design for maintenance planning. Manufacturers and designers have become aware of the need to plan for maintenance access to complicated designs. Concurrent engineering design principles advocate bringing design, manufacturing, marketing, sales, and maintenance experts into the design process to provide input to the design. This has resulted in additional demands placed on the design, including the desire for designs, which are easily maintained. In determining where to place individual components of a design, engineers are increasingly looking for arrangements that provide for easy maintenance. A virtual model of the design can be used to plan and verify the maintenance tasks. Design iteration can be performed on the virtual model to improve maintainability of the product. The U.S Army Tank Automotive and Armaments Command is experimenting with bringing maintenance soldiers into the design facility and soliciting their opinions on design changes needed to improve maintainability. This can be done without the use of expensive prototypes when using a virtual environment. Engineers at Lockheed used VR to plan the positioning of the corrective optics to be installed in the Hubble Space Telescope. Although this was not a planned maintenance, VR was able to contribute significantly to planning the "fix".

Assembly Planning in Design: Similarly, virtual reality can be used for assembly planning. In a virtual environment users can interact with the computer models in the same way as they would interact with the real models. Assemblies can be taken apart and re-assembled. Difficulties due to assembly tasks will be discovered early in the design process and costly redesign will be avoided. In essence, virtual reality can be used as a dry run through for the assembly operations early in the design process where design changes are less costly to implement.

Concurrent Engineering: Virtual reality provides enhanced visualisation capabilities that will improve concurrent engineering practices. Engineers are accustomed to looking at multiview drawing and visualising the three-dimensional shape of the design. Other members of the concurrent engineering design team are not as accustomed to reading these drawings and have more trouble visualising the shape and function of the final design. Even 3D computer models are sometimes difficult to understand. Viewing computer models in a virtual environment will be similar to viewing physical prototypes of the design. People can walk around and look under the model, open the doors, moves the design to verify its motions, etc. This will provide non-engineers with a computer model that more closely mimics a real model than current 3D capabilities.

Networked Virtual Design: Networked virtual reality opens up many possibilities for engineers. The U.S. government has been researching application of networked virtual battlefields for several years. Michael Zyda [28] and others have been actively researching networked VR for use in large-scale virtual battlefield. Engineers can apply this networking in another area: networked virtual design. Members of the concurrent design team in various locations can share the same virtual design space and modify, and discuss the same virtual objects. Marketing members and sales members from across the country will be able to enter the virtual environment and converse with others on the design team.

2.2.1 Background to the Literature Related to Virtual Training

Virtual Training Environment: In order for a virtual environment to be effective as a training tool, it is not enough to concentrate on the fidelity of the renderings but the accuracy of the simulated behaviour [29]. The birth of the flight simulator created the opening for the commercial use of VR as a training tool. For a virtual environment to be effective, the application should be designed to be made about the end users ability to interact with the synthetic world e.g. has the user previous computer experience. VR is now accepted as a valuable medium for communication and visualisation which gives this technology enormous potential in a wide range of disciplines. Maintenance training is one such discipline, which is taking advantage of VR'S visualisation capabilities. It is particularly appropriate to use VR-based training when there is a need to train the users, in a simulated environment for repair work which will decrease the problems relating to safety i.e. Nuclear plant repair. Researchers at Sun Micro system [30] have developed a Virtual Lathe in which the user can view the cutting action of the tool and control the tool in 3D environment. Mourant and Wilson [31] reported development of a Virtual Crane operation system for a typical manufacturing facility. Lifting operations are among the most difficult and dangerous tasks performed on the shop floor. In reality crane operation requires 40 hours of training for certification, and more importantly, experience to master. Using a virtual environment to simulate crane-lifting operations will not only improve crane operation techniques but also reduce injuries and deaths caused each year by crane accident. Keun and Vance [32] designed software to train and retrain workers in virtual environment. This software particularly focused on training workers to manipulate a robot using TELEGRIP, Chong and Hamouda [33] developed an Internet based virtual laboratory for simulation of tensile testing process on Instron 1342 machine for distance learning purpose. The main aim of the project was to reduce the testing cost and to standardise the testing performed by distance learning students. Cheung and Lee [34] developed software, which allows for the simulation and the optimisation of optics design under a preconditioned computer environment. The virtual machining module makes use of the optics design parameters together with the machine characteristics data to simulate the tool path and the surface topography of the workpiece. Besides, the selection of optimum cutting process parameters and machine capability evaluation can also be done in this module. The form and the surface roughness of the workpiece are inspected by the virtual inspection module, which simulates the measured surface roughness profile and hence determines the surface roughness of the machined surface. In medical context, "VR is used to simulate simple human anatomy. How ever even though virtual surgery is currently under development, resolution of graphics needs to improve, along with increasing the reality of internal organs [35]. A virtual world of surgery would no longer see, "...the image of the exhausted doctor sweating for hours over flesh and blood..."...replaced by a world by a world of computer imagery, simulated patients and the most minimal invasion of real bodies" [36]. A major Canadian power company used Virtual Reality to help its planners and designers create new and better control rooms [36]. They useed Superscape World Toolkit. The virtual control room contains freestanding control consoles, display screens for a distributed information system, large wall mimic displays, control panels. Users can walk through the virtual control room, manoeuvring around it at will and interacting with control and displays as they wish and as they would in the real world.

2.2.2 Background Literature of Factory Modelling and Analysis in Virtual Environment

Plenty of literature exists on the origin of VR system and its application in different fields, like ergonomic analysis, assembly modelling, computational analysis, etc. In case of factory layout modelling and analyse, a few literatures are available. It's because research in this area is new compare to other areas like prototyping, games, military training, astronaut training, and creation of science fiction movies, surgery, ship, submarine and aircraft manufacture. The main reason is the research funding according to importance. Research in factory planning in virtual environment and virtual manufacturing started after 90s. People are doing research in industrial areas but keeps secrecy of the research due to competitions.

Some of them are briefly outlined as follows:

Jones et. al, created a prototype VR system, and tested it with shop floor personnel to get the feedback from the system in the future [37]. PEROT [38], is some of the other system developed to analyse the factory layout problem in a virtual environment.

Wilson [39] reported about the Virtual Reality Application Research Team VIRART which was established in 1991 in the department of Manufacturing Engineering and Operations Management at the University of Nottingham, England. This organisation has worked with UK industrial companies and the Health and Safety Executive to build and test VR worlds, which simulate hazardous conditions that an operator may be subjected to. VIRART have also built Virtual Environments which illustrate the use of a good plant layout in which the user can travel through the virtual plant, interact with the facilities and observe the surroundings before the plant is built. The use of VR will prove to be a valuable aid to industrial and manufacturing engineers in relation to plant layout in the future.

Kelsick [40] mentioned about creation of a virtual factory to investigate the role of visualisation and virtual reality could play in the decision making process when manufacturers are faced with investing in new technology.

Neugebauer and Flaig [41] developed a VR simulation of a bottle filling station in a pharmacological process. Detailed was not revealed. Hollands and More [42] cited some examples of VR software use in modelling a car factory in virtual environment.

2.2.3 Background Literature of Simulation and Manufacturing System Evaluation

Whilst simulation is widely used in simulation in system design, literature suggests that it is more widely used in systems evaluation. Here, existing approaches to manufacturing are modelled using simulation software; they can then be explored (and modified) to evaluate the potential effectiveness of any changes to the system. There are many examples of simulation being used in this way, such as Park and Getz [43] who used the simulation package ARENA and AUTOMOD to evaluate tank farm batch sizes, determine good production schedules, analyse an AS/RS material handling system, and design a Pharmaceutical Manufacturing facility. The remainder of this section will introduce applications of simulation and systems evaluation in the following areas: electronics industries; aerospace industries;

Flexible Manufaturing Cells (FMC) and Flexible Manufacturing Systems (FMS); resource management; and AGVs.

Electronics industries: As in the case of systems design, electronics industries are often cited as users of simulation in systems evaluation. Mc Guigan [44], for example, addresses the problem of accurately modelling the lot selection process in semiconductor wafer fabrication. Liljegren [45] describes two simulation efforts at Motorola used to evaluate current procedures and policies at the indivisual tester level as well as the overall system of converting wafers to usable products. The testing process is characterised by long recursive flows through multimillion-dollar test equipment. Mauer and Schelasin [46] also discuss simulation to evaluate various performance characteristics in semiconductor manufacturing.

Aerospace industries: Aerospace industries are also well represented: Bier and Tjelle [47] present a simulation prototype at the Boeing Company as a tool to determine how control parameters affect inventory, performance, and time needed until effects are realised; Scott [48] explores five aspects of developing simulation models to analyse crew operations on aircraft assembly lines for the same company; Rolen and Kilgore [49] discuss the use of simulation for both planning and control of aerospace through work-instruction level models; and Buxton and Gatland [50] simulate the effects of WIP on customer satisfaction at Delta Air Lines.

Flexible Manufacturing Cells (FMC) AND Flexible Manufacturing Systems (FMS): FMC and FMS are prime candidates for evaluation using simulation because of the scope for change that they offer through their flexibility. Simulation provides an ideal way of evaluating the implications of changing the operation of cells and system. Nordlund and Sadowski [51], Manivannan et al. [52] and Dullum and Davis

[53] all applied simulation to CIM to analyse system efficiencies/capacities in a closed-loop manufacturing cell, to evaluate a smart card -based system, and to evaluate tool delivery systems in an FMC. Morito et el. [54] discussed the continued development of a simulation model and associated software for a real-life commercial module-type FMS, which shows that increased flexibility achieved by having several alternative machines (which helps reduce makespan), leads to improved machine utilisation and reduced down time.

2.3 Summery of the Literature Survey and Possible Scope of Work

From the Literature cited and described in the previous section, the following points may be noted:

(i) Most applications of virtual reality have been implemented in prototype design of industrial products and manipulation of those products in virtual environment before the real production occurs. Also training in virtual environment for machine operating, virtual battle used by military and navy, and virtual air combat training by Air Force of different countries have used virtual reality techniques.

(ii) Industrial robot has been widely used in manufacturing playing an important role in the automation of the manufacturing process.

(iii) Also a quite a good number of prototype design have been done in automobile and aircraft manufacturing industry using virtual reality technique to assess the ergonomic concept and aesthetic view of the end product.

(iv) Very few studies were done in the area of factory planning and analysis of the existing layout of a factory using virtual reality software.

(v) No studies have been carried out to analyse the existing factory layout using factory layout technique and virtual reality software.

(vi) Very little study was found in implementation of Computer Integrated Manufacturing System (CIM) concept in a factory built in virtual environment by taking the real data.

Various scopes of work identified in the previous section mainly defined the objectives of this project. This thesis is about application of two types of virtual reality software to assess their user friendliness to assist the user to do the followings and implementation of Computer Integrated Manufacturing (CIM) concept using a software to analyse the total information system of a manufacturing factory created by one of the virtual reality software package earlier.

2.4. Objectives of the present project `

Objectives of the present project are

1. The use of 3D Studio MAX software to model a factory in 3D environment and to assess the applicability and user friendliness in the 3D Studio MAX system to assist the design and planning of production facilities and analysis of the existing layout of the factory in 3D environment using factory layout solving techniques.
2. The use of Superscape VRT 5.5 Software to construct a virtual toy making factory. The purpose of building such virtual manufacturing environment is to :
   (i) Rapid prototyping through design and test facilities.
   (ii) Modelling, dimensioning, reforming, orienting and colouring.

(iii) Walk through around a factory floor with rapid switching of viewing points.

(iv) Visualisation of several stages in a manufacturing process.

(v) Ergonomic assessment of "fit" between users and product.

3. Use of CIM (Computer Integrated Manufacturing) concept in the virtual factory using a commercial manufacturing system simulation software package called SimCAD.

2.5 Brief Description of the Project

The work of the project started with a Pentium PC with 100 MHz speed, 16MB of memory and 750MB hard disk space. Using 3D Studio MAX packages, soon it was realised that this computer would not be suitable for modelling and analyse in three dimensions, as animation was very slow. Therefore, the Pentium PC was upgraded to 64MB memory and hard disk space was upgrade to 1GB.

A virtual factory using solid modelling and animation based simulation package (3D Studio Max) was modelled. The objective of creating the virtual factory environment was to explore potential use of 3D solid modelling and animation package for industrial application. So that it can aid engineers in analysis the virtual factory's layout with a view to (i) identify production process bottlenecks, and (ii) proper utilisation of space and other facilities. The animation package was found to be good only for visualising operations of various machinery and other facilities (packaging, transport, and storage) of the factory. The problem faced by using 3D Studio Max is that the user can not control objects in the virtual environment. The user cannot move around, and interact with the simulated process. So virtual reality software called Superscape VRT 5.5 was purchased. The advantage of this software over the previous one is that the user can move around, and interact with the simulated process in a natural and intuitive manner. But again it was found that simulation and walk through using mouse was very slow, as speed of the computer was 100 MHz. So a new Pentium PC with 64MB memory, 200 MHz speed and hard disk space with 2GB was purchased.

Another problem faced in the project is that no published work reveals the detailed technique or process by which virtual reality was used. None gave any clue of step by step application of virtual reality technology.

Given these constraints it is probably better to develop own application techniques as the need arises specially, for computational engineering research project like this.

2.6 CONCLUSION

This chapter has explained the involvement od Virtual Reality (VR) in design, prototyping, assembly, virtual training and factory modeling in virtual environment. Also introduction of simulations and system evaluation in the following areas: electronics industries, aerospace industries, Flexible Manufacturing Systems (FMS), Resource management, and AGVs have been discussed. Lastly objectives of the present project have been defined after identifying the various scopes of work.

Chapter 3

VIRTUAL REALITY

3.1 Introduction

This Chapter introduces the components of Virtual Reality (VR) and different types of Virtual Reality. Virtual Reality can take two forms, immersive and non-immersive. These two media vary greatly and each is identified because of society's perception of VR as a form of space age technology. The effects of using immersive VR can be traumatising as well as expensive and it is for this reason that a non-immersive desktop PC based VR system is used in this project.

3.2 Components of Virtual Reality

A VR system consists of two main components [55]:

i. Hardware.

ii. Software.

Both of these play an important role in the successful implementation of a VR set-up and in the degree of realism achieved. A brief description of these two components follows.

3.2.1 Hardware

The hardware in a VR system consists of (1) Main Processor (2) Input Devices and (3) Output Devices.

The main processor is also called the Reality Engine because it produces the sensations of reality. The user interacts with the virtual world, created by the computer, using various types of input devices such as gloves (for gestures), voice commands and traditional keyboard input. The virtual world in turn responds to the user's actions by using appropriate output devices such as, a visual display, sound response, and tactile feedback system. The following is a description of the three sub-components of the hardware that comprises the VR system (Fig. 3.1).

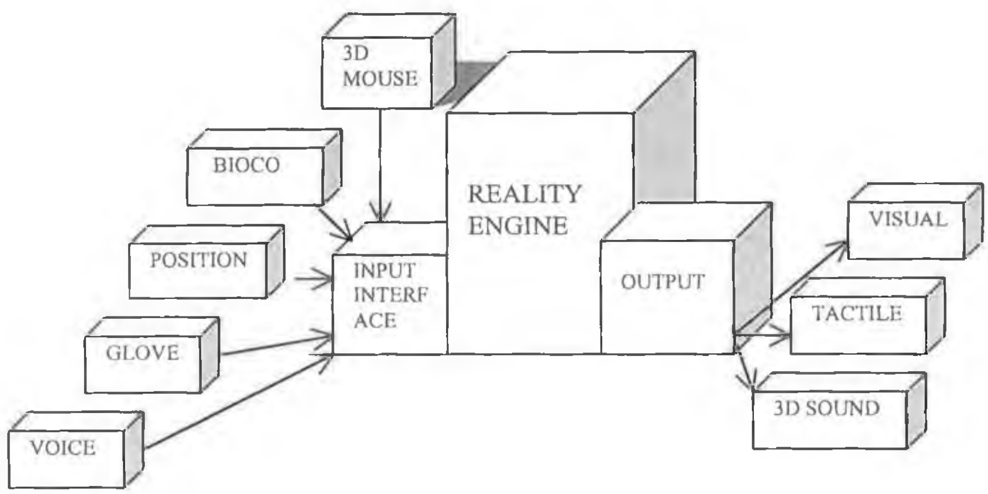


Figure 3.1: The integration of the various elements of a generic VR system.

Reality Engine: This is the main processor that performs the task of creating the virtual environment and handling the interactions with the user. It provides the computing power to run various aspects of a virtual world simulation. The first task of the reality engine is usually the display of the virtual world (may be in Stereo mode) and it utilises a majority of the CPU time. This display processor is often the bottleneck in the performance of a VR system. Also the degree of realism achieved depends on the speed with which images are updated when the user interacts with the virtual world. A measure of the speed of a reality engine is the number of shaded polygons it can render per second. The second task of the reality engine is to interface with different input and output devices and to provide feedback to the user with a minimum lag time as possible. Depending on the architecture of the VR system this secondary task can be delegated to other processors thereby allowing the main processor to handle the visual rendering alone.

***Input Devices*:** The principal objective of a Virtual Environment (VE) is to allow a more realistic interaction with a graphical image. Input devices, therefore, play an important role in allowing the user to interact with the virtual world. Traditional 2D devices like the mouse can still be used (for picking type operations) in a Virtual Environment (VE). However it is the new generation of 3D devices, which provide the real tools to reach out into the 3D virtual world. Input devices that can be used in a virtual environment can be divided into the following categories.

Position Tracker: These devices are used in position and orientation tracking of a user's head and/ or hand as shown in (Figure 3.2). An example is the tracking of the user's head position, and updating the virtual world scene based on this position and orientation. Another use of the tracker is to track the user's hand position in space so that interaction with objects in the 3D world is possible. Tracking sensors based on mechanical, ultrasonic, magnetic and optical systems are available.

Digitizer: These devices have been adapted from the mouse/trackball technology to provide a more advanced form of data input. Included in this category is the 6 DOF mouse and force ball. The 6 DOF mouse functions like a normal mouse on the desktop but as a 6 DOF device once lifted of the desktop. Force ball uses mechanical strain developed due to the forces and torque the user applies in each of the possible three directions.

Glove: This consists of a wire cloth glove that is worn over the hand like a normal glove (Figure 3.2). Fibre-optical, electrical or resistive sensors are used to measure the position of the joints of the fingers. The user can therefore use gestures to communicate with the VE. The Glove is typically used along with a tracking device that measures the position and orientation of the glove in 3D space.

Biocontrollers: Biocontrollers process indirect activity such as, muscle movements and electrical signals produced as a consequence of muscle movement. As an example, dermal electrode placed near the eye, to detect muscle activity, could be used to navigate through the virtual worlds by simple eye movements.

Voice Input: Voice input provides a more convenient way for the user to interact with the VEs by freeing his/her actions in the VE. Such a facility is very useful in a VR environment because it does not require any additional hardware, such as the glove or biocontrollers, to be physically attached to the user (Figure 3.2).

Output Devices: Output devices are used to provide the user feedback about his/her actions in the VE. The way in which the user can perceive the virtual world is limited to the five primary senses. The primary senses consist of sight, sound, touch, smell and taste. Of these only the first three have been incorporated in commercial output devices.

Visual: Two types of devices are available for visual feedback. The first is the head mounted display. This uses two liquid crystal display (LCD) screens to show independent views (one for each eye). The human brain puts these two images together to create 3D view of the virtual world. Though head mounted displays provide immersion, they currently suffer from poor resolution, poor image quality and high cost. The second and much cheaper way is to use a stereo image display monitor and LCD shutter glasses. In this system two images (as seen by each eye) of the virtual scene are shown alternately at a very high rate on the monitor. Infrared transmitter co-ordinates this display rates to the frequency with which each of the glasses is blacked out. The user perceives 3D images.

Sound: After sight, sound is the next most important sensory channel for virtual experiences. It has the advantage of being a channel of communication that can be processed in parallel with visual information. The most apparent use is to provide auditory feedback to the user about his actions in the virtual world. However, 3D sound, in which the different sounds would appear to come from separate locations, can be used to provide a more realistic VR experience.

Haptic: This type of feedback could either be touch or force. For the sense of touch feedback, various systems including using electrical signals (on the fingerstrips) are being currently used to simulate different type of textures. Another approach has been to provide resistance as the user tries to manipulate objects in the virtual world.

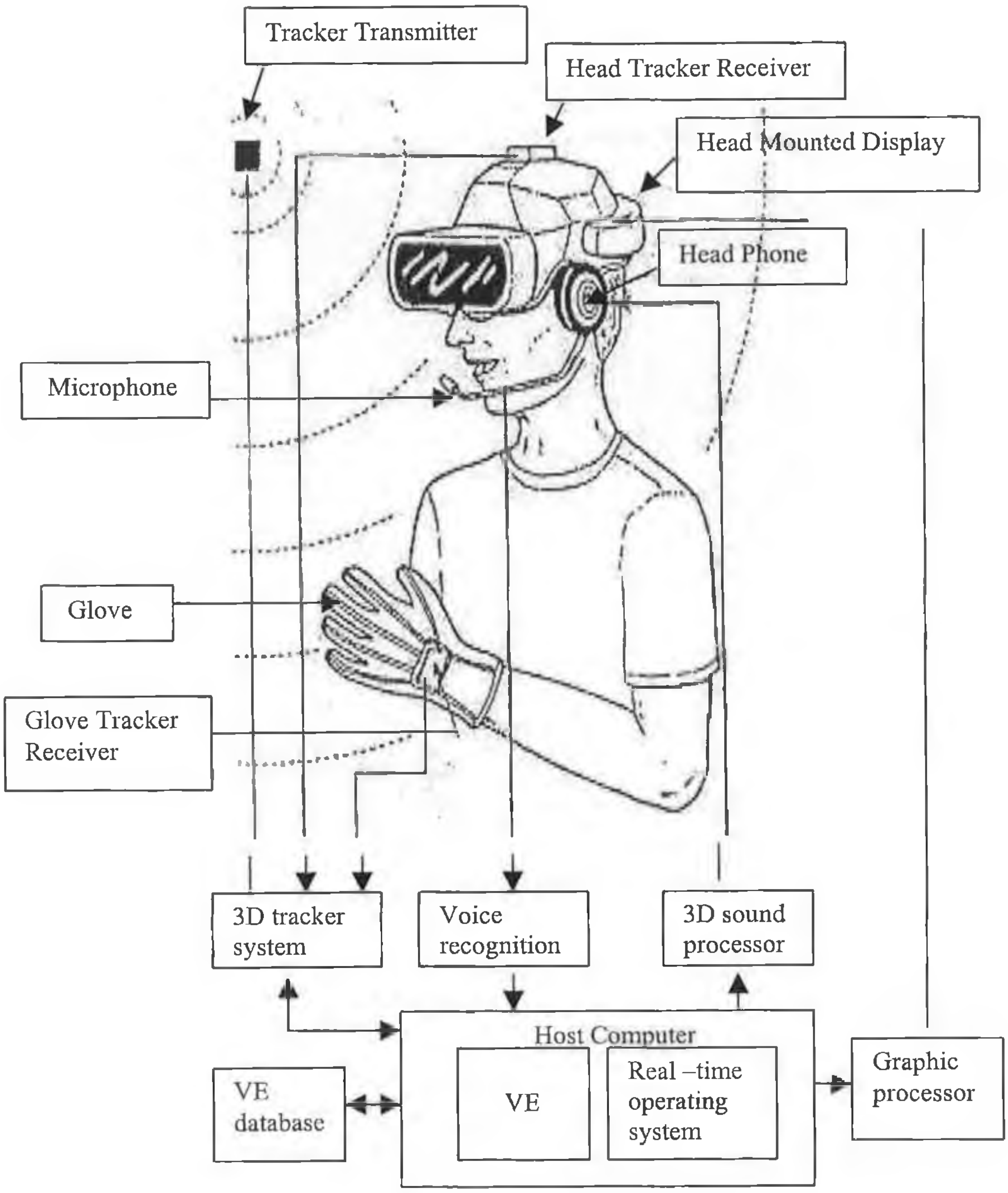


Figure 3.2: The integration of the various elements of a generic VR system.

3.3 Software

Most VR software system consists of a simulation manager and a virtual database [55]. The simulation manager executes the main event loop of the VR program and maintains the virtual world database (Figure 3.3). The main event loop consists of a cyclic process that the input devices are queried, the user actions are processed and finally some feedback is provided to the user using the output devices. In addition the simulation manager maintains the current state of the virtual world in a virtual world database. This database contains information about all the objects in the virtual and their attributes. Examples of attributes include colour, texture and physical properties of the objects in the virtual world and their attributes. The state of virtual world can be modified as a result of the user issuing a command or interacting with the objects in the virtual environment in some manner. The event loops consists of:

1. Input processor.
2. Application software.
3. Output processor.

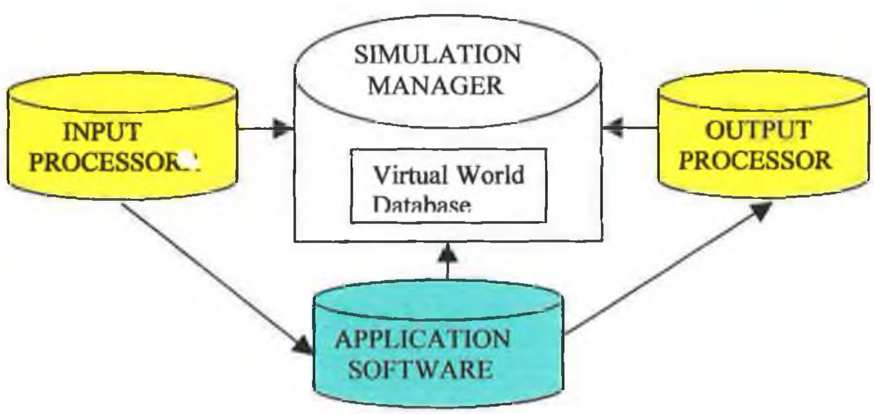


Figure 3.3: VR System Software.

Input Processor: The input processor is the software that obtains data from the devices used in the VR system. The input processor provides the simulation manager with the current position and orientation of all input devices with a minimal lag time. The simulation manager can then act upon this information and pass this information to the application software so that appropriate action can be taken.

Application Software: This is the software that runs within the VE to perform a particular task. For example, in a virtual CAD system, the solid modeller will continuously check the geometry being created by the user for interactions.

Output Processor: The output processor displays the results of the user interaction with the virtual world primarily through the visual display. Depending on the other hardware available on the system other feedback mechanisms like sound and force feedback can also be used.

3.4 Different Types of VR Systems

A major distinction of VR system is the mode with which it interfaces to the user. This section describes some of the common modes used in VR systems. Today, Virtual Reality has many different ways to be implemented. Some of these systems are known as Window on Immersive systems, World system/Desktop VR system, Telepresence, and Augmented reality.

3.4.1 Immersion VR

Immersion VR is a system in which the user is surrounded by a virtual environment. The user can hear, visualise and interact with the artificial environment. In order for a person to participate in a full immersive VR system a considerable amount of hardware is necessary. Varied definitions exist in relation to immersive VR and a selection is presented below.

"Immersive Virtual Reality: A computer system used to create an artificial world in which the user has the impression of being in that world and with the ability to navigate through the world and manipulate objects in the world" [56].

"Immersive Virtual Reality allows you to explore a computer generated world by actually being in it " [57].

A Head Mounted Display (HMD) is a major piece of equipment in immersive VR. A HMD tracks the user's head movement while allowing the user to observe the virtual environment. A HMD consist of two small screens and optics, which spread the images from the screens over a wide angle. A typical HMD is shown in Fig. 3.4. The display portrays a slightly different image in front of each eye. Because our eyes are set apart, each sees a slightly different view of every scene, thus obtaining stenographic vision.

The head position is tracked and the virtual world updates in the HMD display, to compensate for each new viewing angle created by the user. The current technology available relating to HMD's is poor, due to poor resolution. Although HMD's provide a strong sense of presence, the illusion is far from optimal [58] and recent commercial models have yet to display a true graphical representation of an environment. Data gloves are the next most popular accesories for immersion in a virtual environment. A typical data glove is shown in Fig. 3.5.

A data glove is worn on the user hand and can be seen as a computer generated hand with the aid of a HMD. The user's hand movement can be tracked via the HMD and objects can be programmed to be activated via the glove. A typical VR glove relies on optical fibres to convert hand movements into signals to the computer. When a hand is flexed, the fibres in the glove are bent and stretched at the joints. This flexing informs the computer of the movement of the fingers and updates the virtual environment accordingly. Every hand gesture is pre-programmed for a specific result. Bodysuits and data-gloves are other accessories, which can be adopted into an immersive system for enhanced interactivity. The result of using such equipment gives the user the perception of actually being in the environment. Immersion VR systems are the most demanding in terms of the technology required offering a satisfactory system response in viewing interactivity.

Immersive VR gives the effect of placing a person into a simulated environment that looks and feels, to some degree like the real world. This technology holds with it, a lot of potential, due to its power of immersing the user in an environment with no external distractions. In immersive VR, simulated objects appear solid and can be picked up with the use of a data glove. The future of Immersive VR will introduce and refine sense such as smell into a virtual environment and objects or virtual people may respond to voice commands [59].

Fig. 3.4: A typical VR Head Mounted Display (HMD).

Fig. 3.5: A typical VR Data Glove.

3.4.1.1. Immersion VR Side-Effects

Simulation sickness is a term often associated with a condition experienced by astronauts in controlled simulations of their working environment. A major problem associated with immersive VR systems is that a time lag exists between what the user observes and what the user expects to observe [60]. Currently the most serious problem with HMDs, is the time lag experienced by the user when the viewpoint changes and the virtual environment needs to be rendered at a different perspective. This time lag may cause a feeling of nausea. Long lags between any user action and the resulting computed change in the display will often destroy the illusion and tend to lead to 'simulator sickness'. Presently, only a few thousand polygons per second can be generated, but it is expected that nearly a billion polygons per second may be needed for near realism [61].

Experts claim to trace the time lag effect which causes discomfort to the user, to a corruption of a mechanism called the vestibulo-ocular reflex, which the brain uses to co-ordinate the input from the eyes and the inner ear. If a virtual reality system processes visual information too slowly, the two sets of signals get out of synchronisation, for example, the inner ear will signal that a user's head is turning, but it takes a split second for the visual imaginary to catch up, a factor called latency.

Eyestrain is another reported result from using a HMD, which could be a consequence of constant refocusing of the eyes to different images in the virtual world. Ramsey carried out an investigation, assessing VR induced symptoms. He said that "Immersion in a virtual environment for many people is accompanied by a feeling of malaise, similar in form and content to motion sickness, with 60-80% of subjects reporting symptoms during and post immersion" [62]. An increase in heart rate by users has also been observed in immersion conditions. Also, adrenaline levels rise in response to immersion in virtual environments. Ramsey concluded that for most individuals, the experience of immersion in an interactive virtual environment was “not a pleasure one”. It is unknown, however at what stage in the immersion process the side effects occur and how long they will last. Research is presently being carried out into this area, and there is a promise of home VR entertainment in the future.

3.4.1.2. Cybersickness

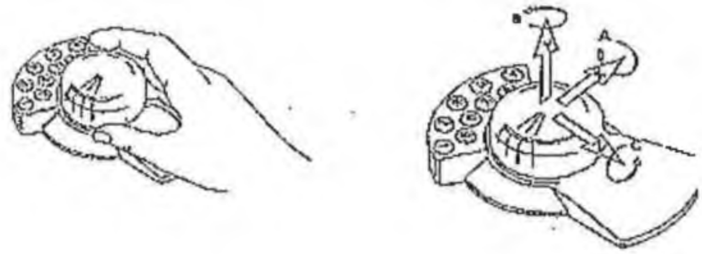
Cybersickness is the term accredited with the major problems of using a HMD. Sega, a computer games company, recently had plans to market a $200 VR game. Preliminary tests were completed on the game and the hardware used, the results of which contributed to the project being selved. The users who tested Sega’s prototype HMD suffered adverse symptoms from nausea to sore eyes. Now, as a wave of virtual reality products are destined to make there way into the marketplace, the manufacturers of HMD’s fear that eye injuries or ‘flashbacks’ followed by injury claims from consumers may stall the virtual reality market.

3.4.2 Window on world system/Desktop VR system

The system uses a conventional computer monitor to display the visual world (Fig.3.6). The monitor is thus a medium through which the visual world is viewed. This sometimes is called Desktop VR or a Window on a World (wow) [63]. The system is more economical. For certain application, such as CAD, the advanced capabilities of immersive system are not essential. This is because the 1 certain 3D CAD systems would be to provide the designer with a 3D environment to work in (create and visualise designs) rather than to completely surround the designer in a realistic virtual environment. The desktop systems let users view and interact in a 3D environment using a stereo display monitor and stereo glasses. The user can navigate around 3D objects using various devices like mouse, space balls and gloves.

Fig. 3.6: Desktop VR system.

A space ball is a more complex pointing device, which gives the user more freedom to explore a virtual world. Figure 3.4 shows a typical spacemouse. This spacemouse is a six-degree of Freedom (DoF) Magellan. The Magellan has a "cap" that the user grasps. The cap rests on a pivot, which allows the user to tilt, twist, push, pull and translate the cap. When released, the cap returns back to its initial resting state.



(a) (b)

Fig: 3.7: A six degree of freedom input device, (a) the Magellan Space mouse and (b) axis labelling for the spacemouse.

The six DoF isometric input devices such as the Magellan are commonly used to manipulate (translate and rotate) graphical objects in a three dimensional world.

3.4.3. Telepresence

Telepresence uses sensors and other electronic peripherals. Surgeons carrying out microsurgery and fire fighters that can send in robots to inaccessible places (Fig.3.8) currently use this technology. The classic example of a telepresence environment is the teleoperation of a robot in a hazardous or remote environment. One can imagine coupling one's visual system with camera that track your head and eye movements so that he can see what one would see oneself if one were in fact in that remote place.

3.4.4. Augmented reality

Augmented reality is created when part of the computer world is combined with images of the real world (Fig.3.9). This is referred to as augmented reality. VR images are 'overlaid on top of images, merging telepresence with immersive VR. For example an aeronautical engineer may inspect the surface of a wing joint while at the same time viewing an overlay of an infrared stress-scan which may show defects not visible to the naked eye.

Fig. 3.8: Telepresence

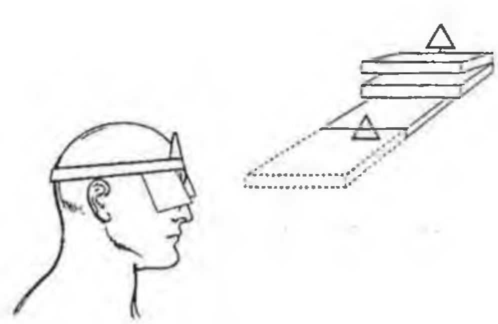


Fig. 3.9: Augmented Reality

3.5 CONCLUSION

This chapter has explained the different concepts relating to VR and the problems, which are presently associated with this technology. Desktop VR is being used for the developed application because of these problems and due to the cost of an immersive system. A number of immersive VR can be realised. These include;

Technological

For a virtual world to be effective a number of conditions have to be met. Virtual world designers need to have the following.

(i) More computer speed.

(ii) Less time lag.

(iii) Less obstructive input/output device.

(iv) Better display technology.

Building worlds

Creating models take a long time and skill, which requires significant time to learn. Better Software tools to create objects and handle interaction processes are necessary. As VR technologies evolve, the present limitations of VR will reduce. VR will enhance user and computer interaction in the future in the way people access information and visualise different processes.

Chapter 4
SYSTEM HARDWARE & SOFTWARE

4.1 Introduction

This chapter identifies and describes the software and hardware selected to create a realistic presentation of production facilities in virtual environment. Superscape VRT was selected as the most suitable VR software. It allows the virtual world designer to attach intelligence to objects in a virtual world by adding a programme that will mimic the characteristics of each object. A virtual world can be modelled using VRT or imported from an external CAD application in order to make up a series of objects. To obtain a realistic model, some of the machines were initially modelled using AutoCad Release-13. These machine models were then imported into 3D Studio MAX. One moulding machine was modelled in Superscape VRT and intelligence was then programmed into various parts of the model using the Superscape Control Language (SCL), which has close similarities to the C programming language.

4.2 The Virtual Reality Software

4.2.1 Introduction

The potential for using VR technology as a means of simulating various environments is growing and the creation of virtual worlds is only limited to the imagination of the virtual world designer. Software companies have realised the potential of VR and are striving to make it more accessible to PC owners. Superscape VRT is a commercially available Virtual Reality system from Superscape and was selected as the most appropriate VR software for this project. Superscape introduced the first PC-based Virtual Reality software product, which offers the user the ability to design, and attach intelligence to objects in the virtual world. Superscape VRT is a single user environment but recent developments offer optional networking capabilities to provide some degree of multi-user participation (upto 15 users). Worlds that are designed using VRT with the intention for desktop VR use can later be modified in order to view the world with VR glasses, thus giving a limited degree of immersion. Superscape offers a variety of powerful features including the ability to edit and create all aspects of the virtual environment. Also incorporated is a comprehensive selection of object attributes both static and dynamic, which allow objects to behave in various pre-programmed ways. VRT provides its own C-like interpreted language, SCL (Superscape Control Language) which allows the user to attach scripts to objects. SCL permits the user to create complex sophisticated behaviour within virtual world.

4.2.2 VRT Hardware and Software

Superscape VRT 5.5 is one of the fastest software solutions for building intelligent virtual environments on a PC. VRT uses a point and click interface in order to accomplish a user-friendly environment in a 3-D world. It consists of a suite of editors that are used to build a desired world. It also offers two browser platforms, Viscape and Visualiser. Viscape is a real-time 3-D web browser and is available as a plug-in for Netscape Navigator. Visualiser is available as a stand-alone window application for use by end-users. Basically, the world designer will use all the editors on offer in the world development process, but the end-user can view the world by down loading Viscape from the Internet. VRT 5.5 is designed to be installed on Intel based PCs with Pentium processor or better, running Windows 95, Windows NT 3.51 (NT 4 recommended. The minimum and recommended requirements for running VRT 5.5 are shown in table 4.1 [64].

Table 4.1: Minimum and recommended requirements for running VRT 5.00.

Component	Minimum	Recommended
Processor	P5 66 MHz	Fastest PC available
RAM	16 MB	64 MB
Hard Disk	500 MB	1 GB
Graphics card	SVGA 640x 480	SVGA 1280x1024
Sound card	None	Sound Blaster 16
Monitor	SVGA 30 cm	SVGA 48 cm
Input device	Mouse	Spacemouse

VRT stores all information relating to objects in the world in a mathematical description rather than as a picture, thus enabling the complete world to be stored, as a small amount of computer data. Invisible bounding cubes are used in VRT in much the same way as blocks in AutoCAD. These enable objects to be ordered correctly in the world, and henceforth simply moving the bounding cubes can move a series of objects. Facets are used which give the effect of a surface between points. Facets are one-dimensional or two-dimensional surfaces created by connecting two or more points together. These points are firstly created in a virtual space and the facets are then created using the points. The invisible bounding cube will then be created around the complete set of facets. Superscape is the most popular VR software package, with dVISE/ dVS in second place as can be seen from table 4.2. Also table 4.3 shows that Superscape is the most popular VR software package.

Table 4.2: VR users in the United Kingdom (Advanced Interface Group (AIG).

Software	1995 Survey	1994 Survey
Superscape VRT	17	13
Dvise/Dvs	10	3
GL/OGL/Performance/Inventor	7	2
3D Studio	6	3
VRML/Webspace	5	0
World Tool Kit/Sense 8	6	7
JACK	3	0
Renderware	3	6
Multi Gen	2	0
PHIGS	2	0
Rend386	2	3
World view	2	0
Audio Lab	1	1
Avril	1	0
AVS/Explorer	1	0
DIVE	1	2
Quicktime VR	1	0

Table 4.3: VR users in the Republic of Ireland (University Research level).

Software	1997 Survey	1998 Survey
Superscape VRT	2	5
3D Studio	3	4
VRML/Webspace)	1	2
World Tool Kit/Sense 8	1	1
JACK	0	0
DIVE	0	0
Quicktime VR	0	0

4.2.3 The Superscape Control Language (SCL)

Superscape VRT offers its own C-like language called the Superscape Control Language (SCL). SCL programs can be attached to objects within the virtual world to assign different behaviours. Thus, in effect, gives the particular item intelligence. All the syntax relating to SCL is based on the C-programming language. A simple SCL program consists of a list of commands that are executed sequentially. For interaction to take place, the object with the attached SCL program has to be activate. The simplest form of activating an object is to click on the object in the virtual environment world with the aid of a mouse, For example a simple SCL program may consist of just two lines.

```
If (activate (me, 0))
togvis (me)
```

This SCL program is an attribute, which can be attached to an object and will change the visibility of the object if it is activated by a mouse click. SCL programs are made up of arguments, statements and instructions. If a piece of information is passed to an instruction then this is known as an argument. Arguments are always enclosed in brackets immediately after the instruction itself. A complete line of instructions and arguments is known as a statement, which are always terminated by a semicolon. The first line of the previous short program checks to see if the mouse has activated the object (me). If the object has been activated, the' if' instruction lets the next statement be performed, which will toggle the visibility of the object (me). The 'me' in the second line of the program could also be changed to a different object number. Then, when the (me) object is activated, a different object will have its visibility changed, thus applying a higher degree of intelligence.

4.3 The 3D Studio Max Software

4.3.1 Introduction

Virtual environments built within genuine Virtual Reality (VR) technologies, are increasingly seen as having a number of serious applications in industrial area. Another trend seen in recent years has been the inclusion of high quality graphics and animation in manufacturing systems simulation tools. Using animation, the various entities within a process can be seen moving around the simulated systems, the status of the resources within the system are clearly displayed, and the interaction between subprocesses easily visible. Now animation has become so useful that a survey has shown that the majority of industrial engineers think that graphics/animations are very important. The ability to move the position from where the observer views the simulated process potentially allows various interactions and characteristic within the system to be seen that might otherwise have been hidden [65].

3D Studio Max, an animation based simulation software (PC based) was selected for design, evaluation, and verification of the complex motion of mechanical systems and production facilities visualisation of an existing bi-cycle parts manufacturing industry which is situated at Dhaka, Bangladesh.

3D Studio Max is a commercially available animation based simulation software. It is a PC- based software selected for this project, which offers the users the ability to design, facilities to add, subtract and combine, and can add material characteristics to object. Modelling, editing, lighting, rendering and animation tools are always available in the command panels and toolbars. Designer can draw 2D and convert it to 3D by using tool bars and designer can view in front view, in left view, in top view, and in perspective view. This software helps the designer to change an initial profile of a model, thus updating the previous model and its current drawing. Also viewing the model at the same time in different ways.

The Useability of the 3D Studio Max system was assessed for how easy or difficult it was for the user to perform specific operations. 3D Studio Max gave a good feel and quite realistic effect of the actual real factory. The user found some design operations easy to perform. In visualisation of the manufacturing process " flying into the machine and recognising where you are " was found to be difficult. Possibly the most important feature is that any changes made by the user within one part of the world (e.g. design modification) influenced the activities or results in another (e.g. production visualisation).

The Relation between multiple systems could be shown in a natural way. The primary advantage of designing product in virtual environment is that it provides a good medium for visualisation of the prototype. Virtual prototyping is a method to be used to evaluate different design alternatives very quickly. In contrast to physical prototypes, a virtual prototype is made very fast, can be manipulated and modified directly and the data is reusable.

4.3.2 3D Studio Max Hardware and Software

3D Studio Max is a commercially available advanced 3D modelling and animation based simulation software. It is a PC- based software selected for this project, which offers the users the ability to design, facilities to add, subtract and combine, and can add material to object. Modelling, editing, lighting, rendering and animation tools are always available in the command panels and toolbars. Designer can draw 2D and convert it to 3D by using tool bars and designer can view in front view, left view, top view, and in perspective view. This software helps the designer to change an initial profile of a model, thus updating the previous model and its current drawing. Also viewing the model at the same time in different ways. Animated graphical simulation enhance our understanding of abstract concepts, aid analysis, increase human productivity and reduce design cost. Creation of a virtual factory using 3-D solid modelling and animation based simulation system can provide a fast, effective method of visualising and 'experiencing' new designs which can be easily modified to consider design alternatives.

3D Studio Max 1.2 is designed to be installed on Intel based PC's with Pentium processor, Windows 95, Windows NT 3.51 (NT 4 recommended. The minimum and recommended requirement for running 3D Studio Max 1.2 is shown in table 4.4 [65].

Table 4.4: Minimum and recommended requirements for running 3D Studio Max.

Component	**Minimum**	**Recommended**
Processor	P5 66MHz	Faster PC available
RAM	32 MB	64 MB
Hard Disk	100 MB	200-300 MB Depending on scene
Graphics card		PCI or VLB-based graphics card at 1024x768x256 colors
Sound card	None	Optional but recommended
Monitor	SVGA 30 cm	SVGA 48 cm
Input device	Mouse	

In order to create a realistic virtual world, 3D Studio offers the following suite of command panels:

Modelling and editing panel: The cornerstone of 3D Studio MAX is an advanced 3Dmodelling and animation environment. One can perform 2D drawing, 3D modelling, and spline-based animation within the unified workspace. Modelling, editing and animation tools are always available in the command panels and tool bar.

Lights & Camera: Designer can create light objects using the light category of creating panel. Ambient light is found in the Environment dialog by choosing Rendering/Environment. The lights can cast shadows, project images, and create Volumetric effects for atmospheric lighting. 3D Studio Max also supports real-world camera controls for lens length, field of view, and motion control such as truck, and pan.

Materials: 3D Studio Max contains a sophisticated Material Editor that floats in its own window above the scene. One can use the Material Editor to create highly realistic materials by defining hierarchies of surface characteristics.

Animation: User can begin animating his scene at any time by clicking the Animation button. Button can be clicked again to move back and forth between modelling and animation. User has extensive control over his animation with the 3D Studio Max Track View. This is a window into time where one edit animation keys, set up parametric animation controllers or display and adjust motion curves for all of your animated effects.

Rendering: The 3D Studio Max render include advanced features such as analytical antialiasing, motion, volumetric lighting, and environmental effects.

4.3.3. Modelling objects in 3D Studio Max

The latest technology in modelling is utilised in this project by combining 3D Studio Max software and AutoCAD with Superscape VRT for object drawing. 3D Studio Max is a three-dimensional modelling and animation based package. It has the facilities to add, subtract, combine, and can add material to object, to perform 2D drawing, 3D modelling, and spline-based animation within the unified workspace. Modelling, editing and animation tools are always available in the command panels and toolbars.

Designer can draw 2D and convert it to 3D by using tool bars and designer can view in front view, left view, top view, and in perspective view. This software helps the designer to change an initial profile of a model, thus updating the previous model and its current drawing. Also viewing the model at the same time in different ways. Those are the advantages that 3D Studio Max has over AutoCAD Release-13.

4.4 CAD Software

Computer Aided Design (CAD) relates to using a computer to display and manipulate designs made of geometric representations. The computer provides the users, viewing capabilities that allow the design to be viewed in any desired position or perspective view. More recent developments of CAD allow the designer to modify existing models by using parametric design techniques, instead of a complete new design for any small alternations that may be required. CAD is now a common feature in engineering departments, which can out perform traditional methods by up to twenty times the number of hours to produce some design. CAD also excelled in the manufacturing environment, and is currently being used to design parts and entire manufacturing processes [66,33,67].

4.4.1. Parametric Modelling

The latest technology in modelling is utilised in this project by combining AutoCAD software and 3-D Studio Max with Superscape VRT. AutoCAD Designer is a parametric, feature-based solid modelling tool within the AutoCAD Development system (ADS). The Designer gives the modeller the ability to sketch in the industry standard 2-D AutoCAD environment and then automatically create a 3-D parametric solid model. Previous 3-D draughting packages, while excellent for their time, lack the capability for the designer to alter previous designs significantly. Parametric capabilities offer the designer the option to change an initial profile of a model, thus updating the previous model and its current drawing. With this type of technology at hand for designers today, the next logical step for a designer would be to visualise a model in a virtual environment. If a model can be easily manipulated using software such as AutoCAD and easily imported into VR software such as VRT 5.6, then the potential cost savings are immense. It is thought that the prototyping industry will be the first to benefit, and that the technology will ultimately reach all major design disciplines.

4.4.2. Parametric

Parametric is the use equations that solve engineering problems using a set of geometric and dimensional values in a design. Applying Parametric to model defines the shape and the size of that model. Editing these parameters causes the design to change. A part can initially be drawn in much the same way as a freehand sketch. A profile can then be applied to this sketch and Designer applies constraints that it considers applicable to the profile. These constraints can vary from all radii to have the same radius, to certain lines to be parallel. The design process usually changes. The Designer enables the dimension parameters in a model to be changed and the dimensioning scheme so that drawing and documentation (e.g. Bill of Materials) can take place concurrently with the evolution of the design.

4.4.3 Feature-based design

Features in Design are industrial standard objects such as hole and chamfer. Traditional solid modelling techniques involved in creating a hole in a solid, meant that firstly the solid part was extruded and a cylinder was put in a hole position. The cylinder would then be subtracted from the original solid to give the impression of a hole. An obvious disadvantage of this design technique is that the hole size and position could not be changed later. Designer, with the aid of its parametric capability enables an actual hole to be drilled in a solid and all modifications relating to the size and position can be altered. Even the type of the hole applied can be modified i.e. C'bore, C'sink. A feature-based system allows you to create and edit models faster than you could with traditional methods. Every part in a system could be designed using the above technology and all the parts would be assembled into their respective positions with appropriate constraints. When you constrain components, you indicate how one component relates to another. As you constrain, you eliminate degrees of freedom, or types of movement, for those components. Interference's may occur in any design problem but an assembly display of the final solution will show these faults. Each part can be selected from the assembly and updated as a single drawing. Every assembly or sub-assembly that the component appears in will then update to the new drawing revision number ready for inspection of the updated design.

4.5 Model Conversion Process

4.5.1. Conversion of an AutoCAD model to a 3D Studio Max Virtual Model

3D geometry modelling CAD systems such as AutoCAD are widely used in engineering design. AutoCAD is suitable as a graphics editor for geometric modelling, especially for 3D geometric modelling. Although AutoCAD is powerful for geometry modelling, it can't be used as the tool for complex system motion verification. AutoCAD do not have the dynamic simulation capabilities like 3D Studio Max. AutoCAD provides some primary 3D objects, such as box, cone wedge, ball etc., which are often used in 3D modelling. In order to create a realistic virtual model of the machines, an AutoCAD model was imported into 3D studio as a 3DS file. Similarly virtual model was imported into AutoCAD as a DXF (Data Interchange Format) file for modification. A DXF file is an ASCII (American Standard Code for Information Interchange) coded file, of an AutoCAD drawing for importing and exporting to and from other software packages [68]. Fig.4.1 (a) illustrates the process of converting a 3D Studio virtual model into Auto CAD model and Fig.4.1 (b) illustrates the process of converting an AutoCAD model to a 3D Studio Virtual model.

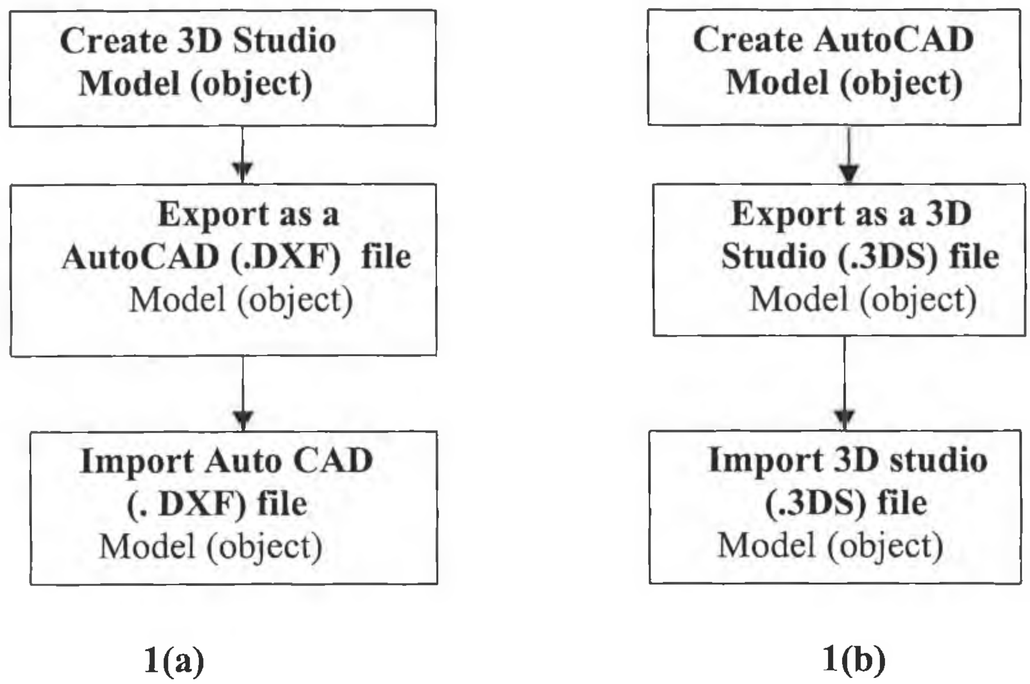


Fig.4.1: (a) Conversion process of a 3D studio virtual model to an AutoCAD model (b) Conversion process of an AutoCAD model to a 3D studio Virtual model.

4.5.2 Conversion of an AutoCAD model to a Virtual Model in Superscape VRT 5.5

VRT includes a module that will import DXF files, in which solids that are created as drawing file are converted in VRT, to a series of facets. Fig. 4.2 illustrates the process of converting a realistic AutoCAD model into a Superscape VR model. 3-D Studio files were used to change solids in the CAD application to surfaces as problems occurred when importing solids to VRT i.e. 3D Studio Max is a CAD application which may be used to convert solids into surfaces.

The data converter module is mainly for converting data into three-dimensional VR formats. The conversion process involves a substantial amount of importing blocks into VRT. Therefore the missing information is generated by the data converter which is often obtained by guesswork but can later be corrected by the user. In most cases, however, a VRT data file bearing a close resemblance to a 3D representation of the original CAD model is produced. The VRT converter is recommended for use on single object in order to obtain the best result i.e. each individual object should be run through the VRT converter. Therefore the amount of times the above cycle would have to be carried out is equal to the amount of parts that make up the AutoCAD model. All block definitions are converted directly into shapes. These shapes are then checked against any restrictions applied by the designer and the converter attempts to correct them. One major problem with the conversion process is that facets may be created facing the wrong way (inside out).

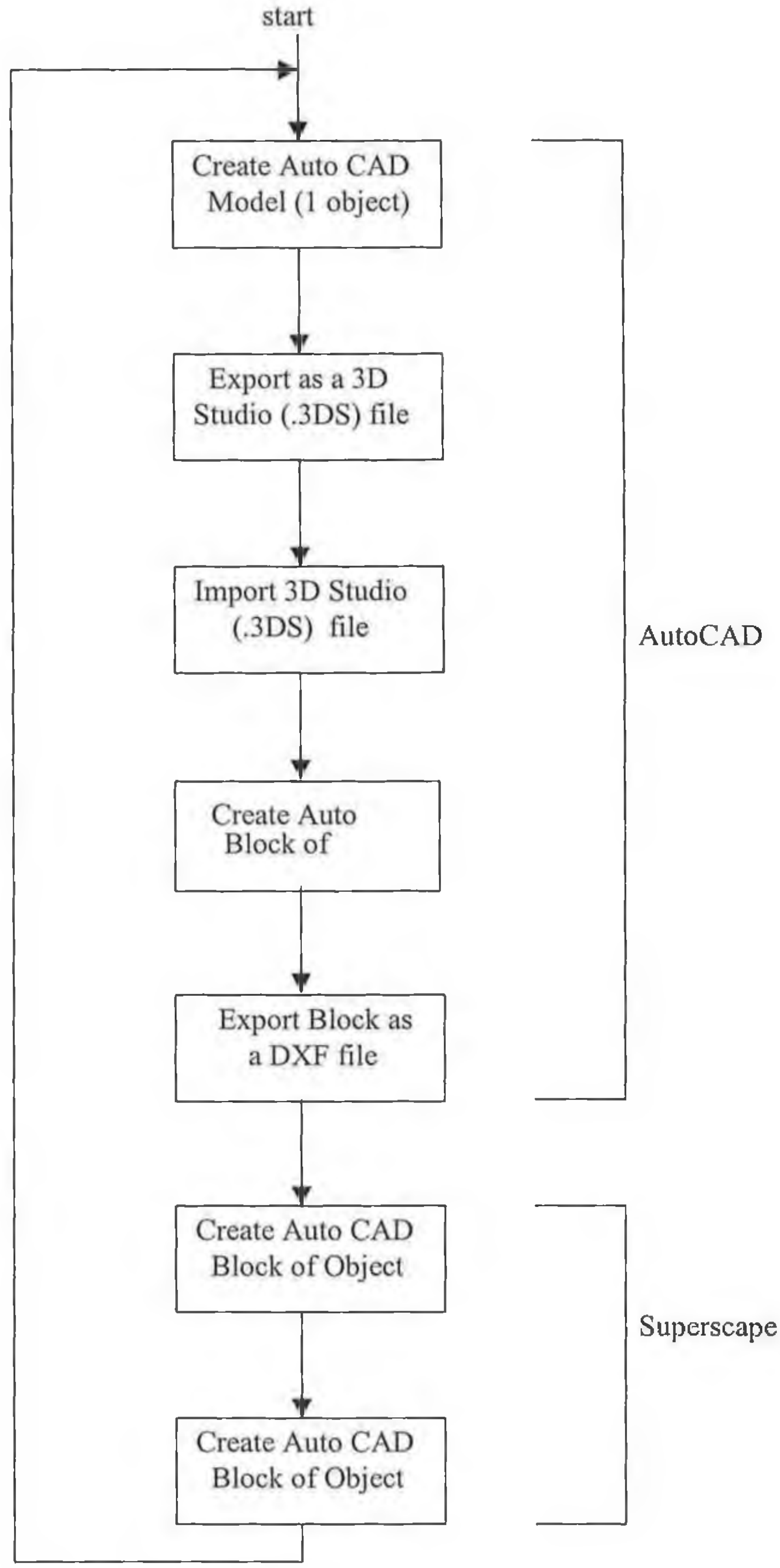


Fig. 4.2: Conversion process of the AutoCAD model to a Superscape virtual model.

This causes rendering problems and the designer has to 'flip' the facets in the correct direction. All the shapes are then stored as world objects with their associated information. Once all the shapes are imported into the virtual world, the parts that make up the different virtual machines can then assembled into their correct positions with the aid of VRT's collision detection and position commands.

4.6 Conclusion

3D Studio Max, an animation based simulation software was selected for design, evaluation, and verification of the complex motion mechanical systems and production facilities visualisation of the existing bi-cycle parts manufacturing industry which is situated at Dhaka, Bangladesh. A picture is worth a thousand words, according to an old Chinese proverb; if this is so, a graphical animation should be worth at least a thousand pictures. Animated graphical simulation enhance our understanding of abstract concepts, aid analysis, increase human productivity and reduce design cost. Creation of a virtual factory using 3-D solid modelling and animation based simulation system can provide a fast, effective method of visualising and 'experiencing' new designs which can be easily modified to consider design alternatives.

Superscape VRT was selected as a suitable software package to model the virtual factory producing toy car. This software is inexpensive for the end user in order to view the factory. The virtual moulding machine was developed using Superscape directly. The intelligence was attached to the various parts of the machine.

Chapter 5

BACKGROUND CONCEPT FOR DESIGNING AND ANALYSING A VIRTUAL FACTORY

5.1 Introduction

Traditional design method and mock-ups for production facilities planning can be time consuming and costly. One perceived advantage of Virtual Reality in production facilities planning application is a 'feel good' factor resulting from the fact that everyone is able to relate to and understand what they are seeing. The realistic visualisation of the plant enables an engineer to evaluate the layout in an intuitive and natural-like way. This chapter focuses on some important topics in industrial and production-engineering field for the designer to have knowledge before creating virtual factory environment and to assess the value of Virtual Reality (VR) for visualisation and planning production facilities.

5.2 Background Concept

The VR technology can play a substantial role in the interactive design and analysis of complex production systems and processes. The three-dimensional nature of VR, and the mechanisms for interacting with objects in the VR environments, makes the enormous amount of technical data available much more accessible to decision-makers. Travelling through, and manipulating objects within the virtual facility offers a much more natural and direct interaction than working indirectly through programs providing only two-dimensional representations of the problems.

In design and analysis of production systems economic and operational aspects of the system should be considered concurrently. Economic choice not only refers to which equipment and machines are to be used to manufacture products, but also includes architectural issues, such as placement of supporting structures, provision for material handling devices and arrangement of open work. VR could help in visualising the movement of materials, equipment, tools and workpiece within the facility and it's capability to easily accomplish the change in the arrangement of equipment, machinery and other logistic supports. This will help in securing human safety in real working environment. One of the most significant aspects of the technology is its ability to improve decision-making processes from both qualitative and quantitative perspectives. In both cases it allows people to play " what if ", and test alternative scenarios with relative ease. Qualitatively, users can get a feel for the effect of the new process design. For instance, suppose a factory has one particular crowded shop floor into which they must install a new machine. With a VR representation of the current production facility, an operator could locate a new virtual machine into the shop floor seeing how much twisting, turning and repositioning he would have to do to correctly position the machine; he would also be able to judge the rearrangement of equipment needed to accommodate the movement of a new type of product in that shop floor.

One needs not be a trained technician to enter a virtual environment, how to "grab" pieces of computer-generated equipment and move them to new locations on the simulated shop floor is all that is needed to know. Another potential benefit of VR stems from the richness and flexibility of the computerised environment. The user can effectively become "Superhuman", thereby increasing his/her efficiency for the task at hand. Consider the case mentioned above, where a machine must fit into an already crowed area. The user has effectively infinite control, for he/she can move any object as he/she pleases. Advantages and applications of virtual production planning are given below.

5.2.1 Application of Virtual Production Planning

The typical applications of virtual production planning are:

(i) Planning and verification of production/manufacturing process.

(ii) Determination of production sequence.

(iii) Analysis of different alternatives of production and assembly.

(iv) Planning and verification of material logistic.

(v) Aisles planning.

5.2.2 Advantages of Virtual Production Planning

The typical advantages of virtual production planning are as follows.

(i) More precise planning results compared to conventional tools.

(ii) Exchange of knowledge among different experts in planning team.

(iii) Taking into account various influential factors such as workplace, accessibility and production tools.

(iv) Reduction of planning time and errors.

(v) Documentation of company know-how.

(vi) Planning results can be used for the purpose of training and education.

(vii) Data reusable.

5.3 Systematic Planning Techniques

Computer programs are nothing more than lengthily sets of detailed instruction. For programs to work properly there can be no ambiguity in the instructions and no unforeseen steps in the procedure. Planners quickly discover that the successful use of computers rests first on their use of systematic planning techniques. But the typical planner today is not systematic. In fact, his most commonly used approach might be called “instinct and experience”. The planner makes a survey and looks for similarities to past projects. He draws on his experience to formulate solutions. “I think” and “I feel” are common phrase in the development of a plan. Another approach uses the “cookie cutter”. Concepts featured in the latest journals, or presented in recent professional forums, become the proposed solutions for the project at hand. Or, a standard facilities plan is applied, over and over, to each new situation [69].

Leading professionals have long recognised the need for systematic planning. Their concern with techniques and structured approaches predates our current interest in computers by many years. Richard Muther, in his book Systematic Layout Planning (SLP), addresses the heart of facilities planning with the nine-step procedure shown in Figure 5.1. Each box in the pattern covers one or more planning techniques. Taken in sequence, to guide the development of layout plans with clear rules and conventions. The pattern of procedures rests on the three “fundamentals” of relationships, space, and adjustment.

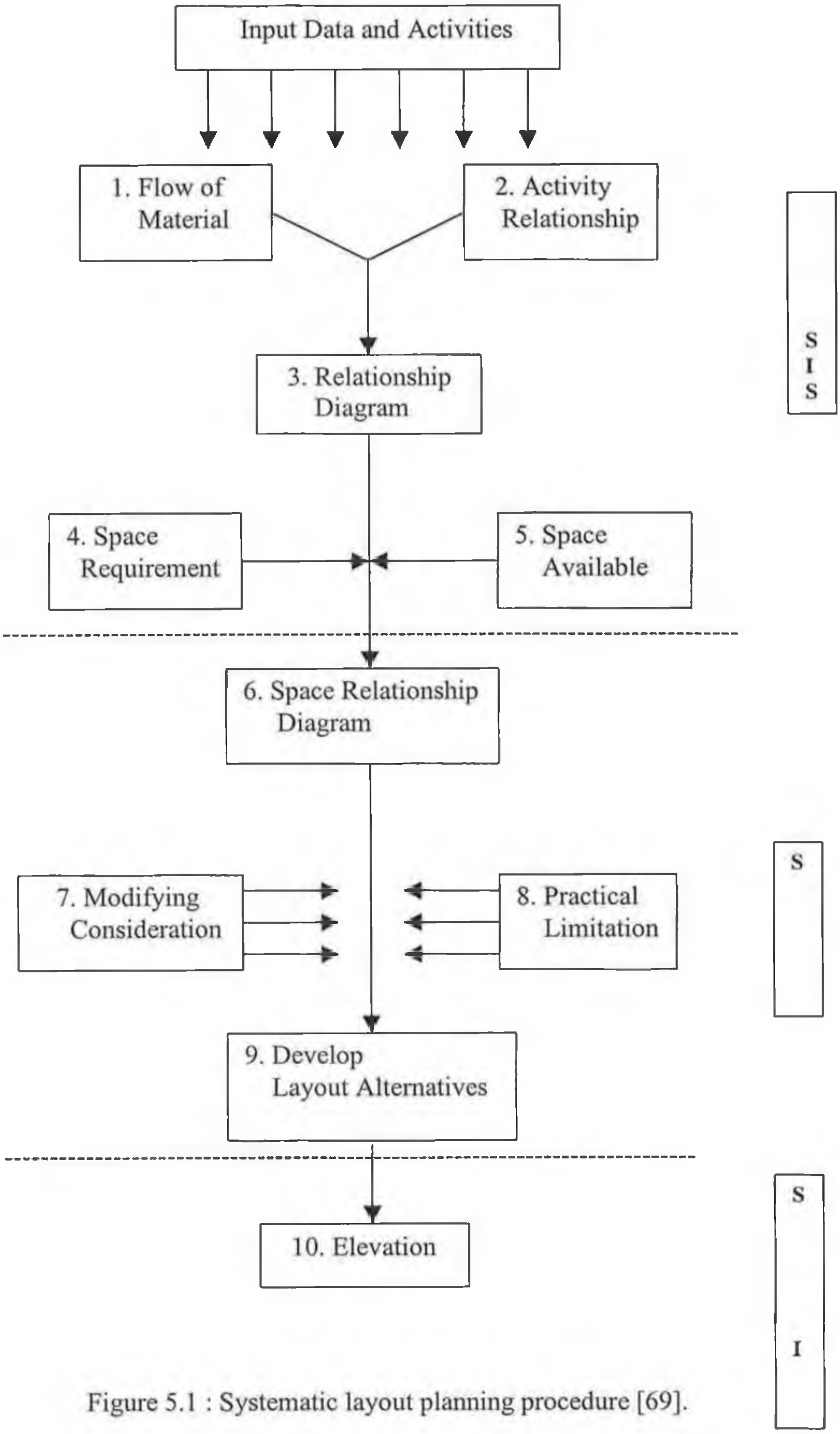


Figure 5.1 : Systematic layout planning procedure [69].

Few see that once the appropriate information is gathered, a flow analysis can be combined with an activity analysis to develop the relationship diagram. Space considerations, when combined with the relationship diagram, lead to the construction of the space-relationship diagram. Based on the space-relationship diagram, modifying considerations, and practical limitations, a number of alternative layouts are designed and evaluated. In comparison with the steps in the design process, we see that SLP begins after the problem is formulated. The first five steps of SLP involve the analysis of the problem. Steps 6 through 9, including the generation of alternative layouts, constitute the search phase of the design process. The selection phase of the design process coincides with step 10 of SLP.

5.4 Information Gathering

For the plant layout analyst to perform effectively, one must obtain certain information pertaining to the product, process, and schedule. The data requirements may not coincide with data availabilities in some cases. However, we shall assume such data exist; otherwise, the necessary management information system to obtain these data must be developed [70].

Data regarding product design decisions can significantly affect the layout. However, the process designer feels the effect of product design decisions. Whether a part is made of aluminium or plastic will influence processing decisions can indirectly affect the layout. Thus, product design decisions can indirectly affect the layout. Product design decisions can also have a direct effect on the layout. The

Storage of Rim Strip

To rim forming machine

Forming of rim

To Butt welding machine

Butt-welding

To sizing machine

Sizing

To grinding machine

Grinding

To abrasive machine

Abrasive

To punching machine

Punching

To marking machine

Marking

To electroplating section

Electoplating

Inspection and Packaging of electroplated rim

To store

Storage for packed rims

Figure 5.2 (a): Flow process chart for the production process of rim.

Storage for M.S.Wire/Coil

Coil to upsetting Machine

Forming and upsetting of nipples

Sorting out upsetted under sized and over sized nipples to put into nipple automation

Threading of upsetted nipples

Threaded nipple to electroplating section

Electroplating of threaded nipple

Inspection and packing of nipples

Polypacked nipples to storage

Storage for poly packed and complete packed nipple

Figure 5.2(b): Flow process chart for the production process of nipple.

Storage of spoke wire

Coil to spoke and checking formed spoke

Forming of spoke and checking formed spoke

Electroplating of formed spoke

To inspection and packing section

Inspection and packing of spoke

To storage

Storage for poly packed and complete packed spoke

Figure 5.2 (c): Flow process chart for the production process of spoke.

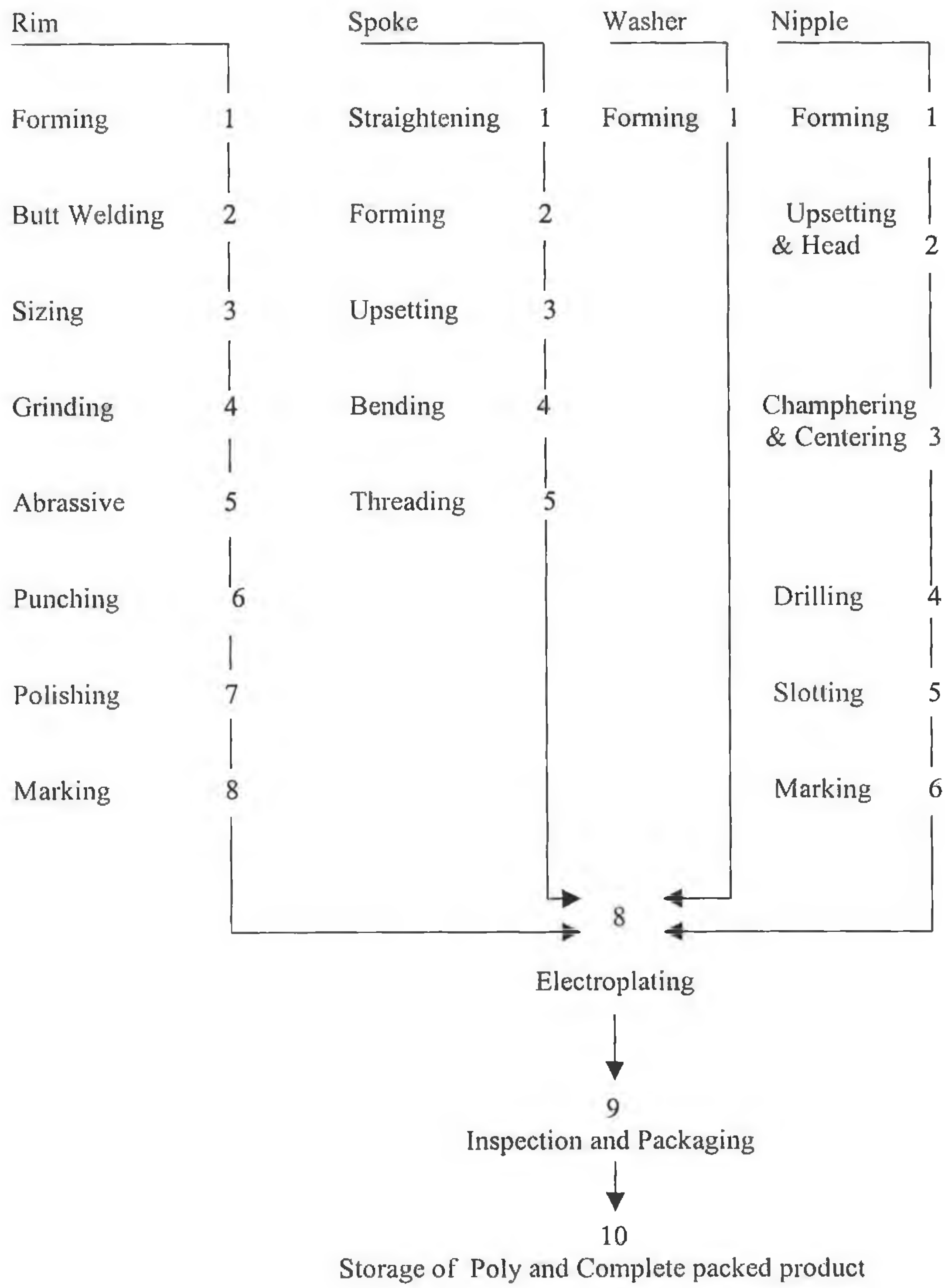


Figure 5.3: Operation Process Chart of a Bicycle Parts Manufacturing Factory.

design of the product affects the sequence of assembly operations, and this sequence can influence the layout. Therefore, it is important to have available data concerning the design of the product. Basic product design data can be obtained from production drawing, flow process charts, parts lists, bills of materials, and prototypes of the product. As an illustration, flow process charts are given in Figure 5.2 (a), (b) and (c). Notice depending on the type of product involved, that the layout could be governed by the flow lines from an assembly chart.

Process design decisions determine whether a part will be purchased or produced, how the production of a part will be achieved, what equipment will be used, and how long it will take to perform each operation. This information is typically summarised on a route sheet (Figure 5.3) or operation sheet. A separate route sheet is normally required for each part. Therefore, operation process chart (Fig.5.3) is the primarily basis for the layout.

Scheduling design decisions provide the answers to the questions, how much to produce and when to produce. Depending on the product mix (number of different products) for the firm and the required production rate, the decision may be made to produce each product on a continuous basis or an intermittent basis. The plant layout analyst is often involved in this decision.

5.4.1 Flow Planning

Flow improvement is important for plant layout improvement. It emphasises only the elimination of waste time. A simple way to evaluate the status of the flow in a plant is to examine the conditions on the production floor.

Any of the following items are a signal that the flow needs improvement [71]:

1. Many units on carts, shelves, or conveyors waiting to be assembled.
2. Parts on the floor in bulk containers waiting to be assembled.
3. Rejected parts or other items on floor that have not been disposed of.
4. Numerous rework benches or a large amount of rework being performed on production benches.
5. Expensive machinery that is idle.
6. Workshop machinery placed near to production machinery causing problem during production operation.
7. Trash on the floor.
8. Anything in the aisles except people.
9. Manual material handling system.

Planning effective flow involves combining the flow patterns with adequate aisles to obtain a progressive movement within factory floor. As noted, effective flow planning is a hierarchical planning process. The effective flow within a facility is contingent upon effective flow between departments, which depends on effective flow within workstations [71]. This hierarchy is shown in Figure 5.1.

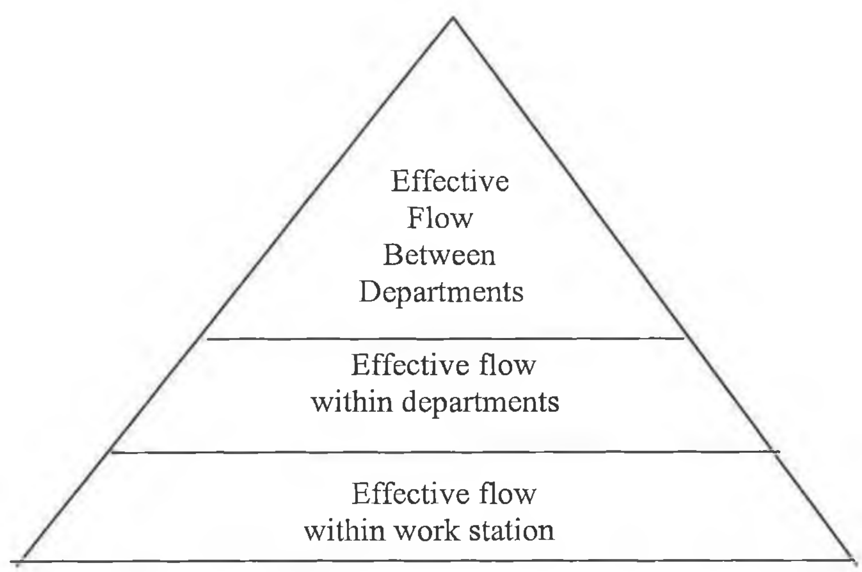


Fig.5.4: Flow planning hierarchy

5.4.2 Flow Within Workstations:

Motion studies and ergonomic considerations are important in establishing the flow within workstations. For example, flow within a workstation should begin and end their motions together and should not be idle at the same instant except during rest periods. Symmetrical flow results from the co-ordination of movements about the centre of the body. The left and right hands and arms should be working in co-ordination. Natural flow patterns are the basis for rhythmical and habitual flow patterns. Natural movements are continuous, curved, and make use of momentum. Rhythmical and habitual flow implies a methodical, automatic sequence of activity which also allow for reduced mental, eye and muscle fatigue, and strain.

5.4.3 Flow Within Departments:

The flow pattern within departments is dependent on the type of department. In a product and/or product family department, the flow follows the product flow. Product flow typically follows one of the patterns shown in Figure 5.5. End to End, back to back, and odd-angle flow patterns are indicative of product departments where one operator works at each workstation. Front-to-front flow patterns are used when one operator works on two workstations and circular flow are used when one operator works on more than two workstations.

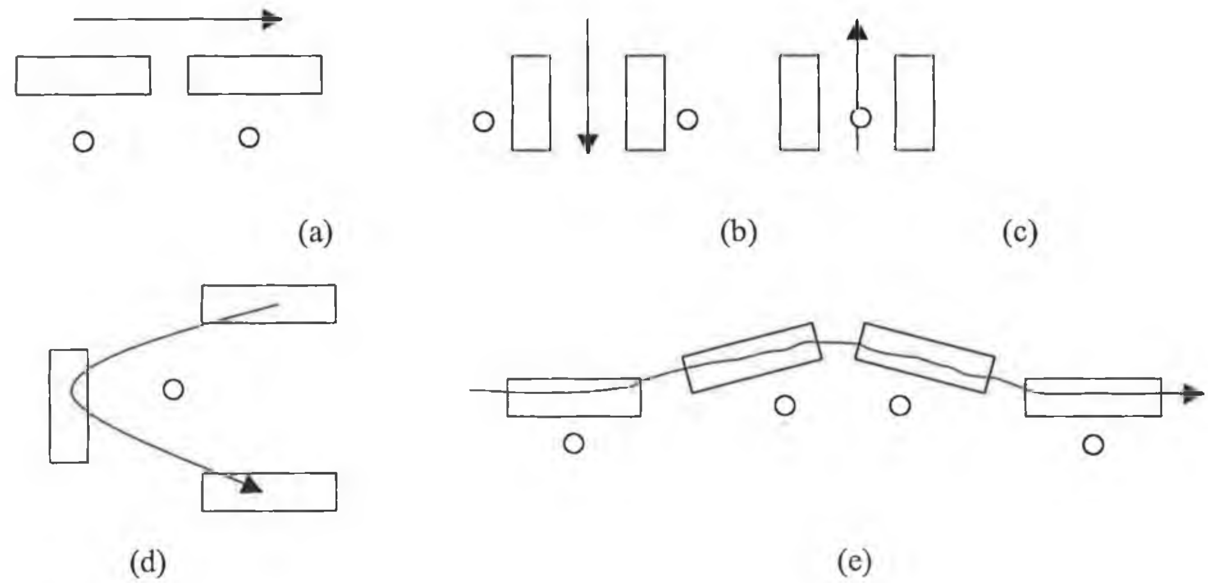


Fig. 5.5: Flow within product departments (a) End-to-end. (b) Back-to-back.
(c) Front-to-front. (d) Circular. (e) Old-angle.

In a process department, little flow should occur between workstations within departments. Flow typically occurs between workstations and aisles. Flow patterns are dictated by the orientation of the workstations to the aisles. Figure 5.6 illustrates three workstation-aisle arrangements and the resulting flow patterns. The determination of the preferred workstation-aisle arrangement pattern is dependent on the interactions among workstation areas, available space, and size of the materials to be handled. Diagonal flow Patterns are typically used in conjunction with one-way aisles. Aisles that support diagonal flow pattern often require less space than aisles with either parallel or perpendicular workstation-aisle arrangements. However, one-way aisles also result in less flexibility. Therefore, diagonal flow pattern are not utilised often. Flow within workstations within departments should be enriched and enlarged to allow the operators not only to use their muscles but also their minds.

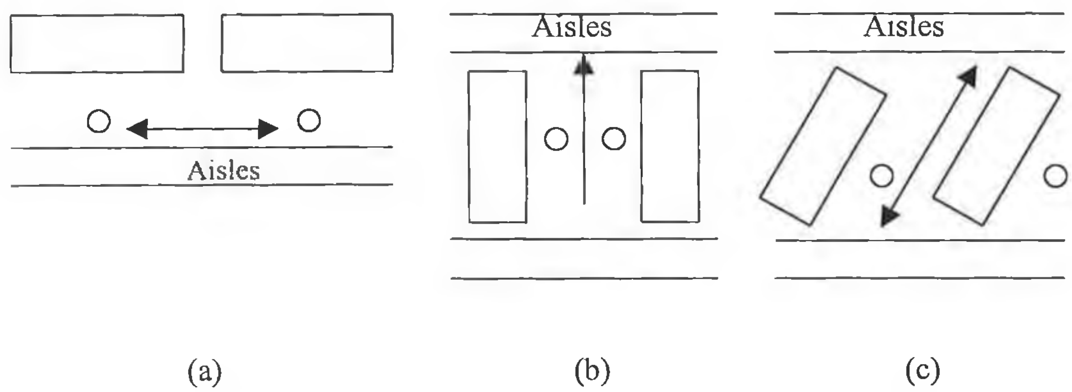


Fig:5.6: Flow within process departments.(a) Parallel.(b) Perpendicular.(c) Diagonal.

The following principles have been observed to frequently result in effective: maximise directed flow paths, minimise flow, and minimise the costs of flow. A directed flow path is an uninterrupted flow path progressing directly from origination to destination. An uninterrupted flow path that does not intersect with other paths. Figure 5.7(b) illustrates the congestion and undesirable intersections that may occur when flow paths are interrupted. A direct flow path can be seen in Figure 5.7(a). A direct flow path progressing from origination to destination is a flow path with no backtracking. Planning for effective flow within the hierarchy requires the consideration of flow patterns and flow principles.

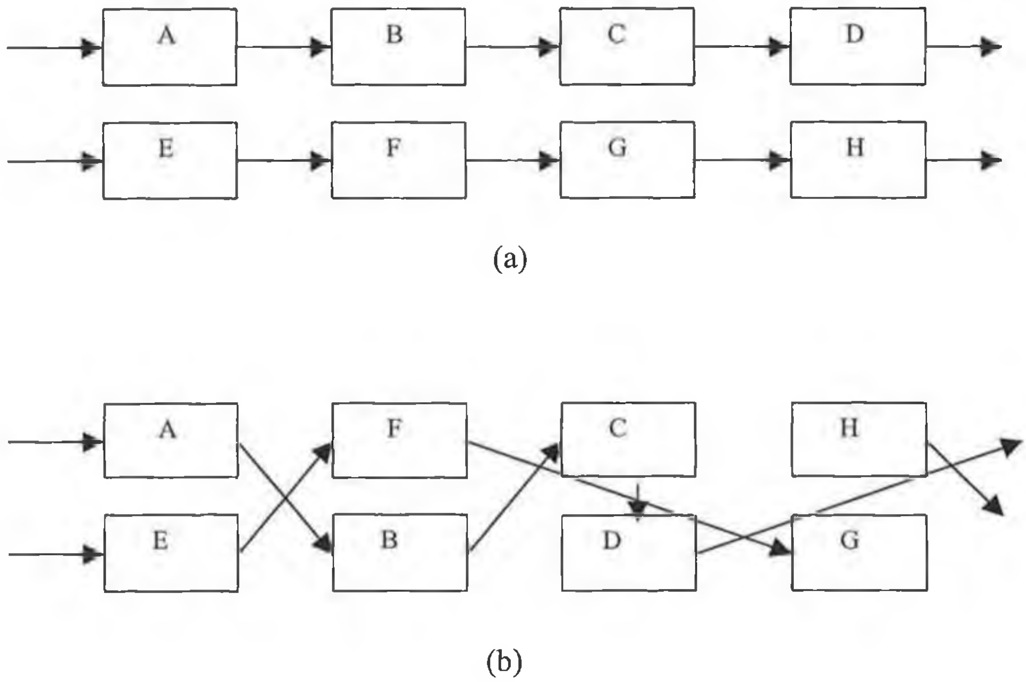


Figure 5.7: Shows the impact of interruptions on flow paths. (a) Uninterrupted flow paths. (b) Interrupted flow paths.

The principle of minimising flow represents the work simplification approach to material flow. The work simplification approach to material flow includes:

1. Eliminating flows by planning for the delivery of materials, information, or people directly to the point of ultimate use and eliminate intermediate steps.
2. Minimising multiple flows by planning for the flow between two consecutive Points of use to take place in as little movement as possible, preferably one.
3. Combining flows and operations wherever possible by planning for the movement of materials, information, or people to be combined with a processing step.

The principle of minimising the cost of flow may be viewed from either of the following two perspectives.

1. Minimising manual handling by minimising walking, manual travel distances, and motions.

2. Eliminate manual handling by mechanising or automating flow to allow workers to spend full time on their assign tasks.

5.5. Requirements for Virtual Factory Modelling

In order to build the virtual factory, which is similar to a real factory, there might be many requirements in modelling the elements of manufacturing systems. Among a number of requirements, the author emphasise that the following are most important to develop a modelling system for virtual factories.

(i) *Visualisation:* The most important requisite is that a virtual factory should be visualised with reality. With good visualisation, one can easily understand the constitution of a virtual factory and observe how each system elements works in the manufacturing system.

(ii) *Detailed descriptions:* Each element (i.e. machinery, equipment workbench, etc), needs its detailed description not only for its visualisation, but also for calculating a number of its attributes, for example, when a workpiece needs to be placed into a box, the shape and dimensions of the workpiece and the box have to be known in order to check whether the box can contain the workpiece or not.

(iii) *Flexibility:* The modelling system should present a flexible way of modifying a virtual factory in order to cope with the change of machines, layout and other facilities.

(iv) *Production planning requirements:* When planning the production sequence of a product, the planner has to take the product features into account, but also has to consider the other production facilities such as availability of storage and test facilities, supply of materials, handling of parts as well as the necessary production tools.

(v) *Aisle arrangement:* For a factory layout, the framework is its aisle system, whose symmetry often indicates the quality of the factory layout itself. Most factories, however, need and use connecting aisles to accommodate movement of materials between the main aisles. Table 1 below describes recommended Aisle widths for various types of flow [71].

Table 5.1: Describes recommended Aisle widths for various types of flow [74].

Type of Flow	Aisle Width (feet)
Tractors	12
3-ton Forklift	11
2-ton Forklift	10
1-ton Forklift	09
Narrow aisle truck	06
Manual platform	05
Personnel	03
Personnel with doors opening into the aisle From one side	06
Personnel with doors opening into the aisle from two sides	08

For people wearing indoor clothing, an aisle or hallway 24 in (610 mm) wide is the minimum width to avoid brushing against structures or equipment. For two people to pass, 54 in (1372 mm) is recommended; 44 in (1118 mm) is minimum. If one person stands against the wall while the other passes, 36 in (914 mm) is sufficient, but such a design is limited to space constrained systems such as ships or passenger aircraft [72].

A few recommendations for safety and efficiency are:

1. Locate aisles centrally within a building so as to minimise walking distances to them.

2. Locate aisles or paths for minimum distance between traffic-generating sources.
3. Provide traffic guidance markings on walls or floors (for example, direction to rooms).
4. Make intersecting aisles converge at 90°.
5. Avoid blind corners, if feasible.
6. Do not permit doors to open into narrow corridors. A door opened suddenly in front of a passer-by could be hazardous.
7. Keep aisle clear of equipment and supporting columns.
8. Avoid one-way aisle if possible. These are inefficient and difficult to enforce.

Some erroneous assumptions that lead to this wasteful use of space for aisles are as follows:

1. The only economical way to move materials and components is in large containers that cannot be moved without a lift truck or hand lift truck.

2 Every aisle corner must be wide enough to accommodate two lift trucks travelling in opposite directions and turning the corner at the same time. Thus width of the turn dictates the width of the entire aisle system.

3. At every point on the aisles, a forklift truck must have space to make a right-angle turn into the process area in order to pick up and set down skid-size containers.

4. Machine operators and assembler who are located between their machines or lines and the aisle must have extra aisle space to protect them from stepping back into the path of a forklift.

5. Aisles must handle not only heavy lift-truck traffic, but also high volumes of people. All employees travel to and from their workstations in the aisle systems.

6. Aisle clearance for two lift trucks travelling in opposite directions must be very liberal to help avoid collisions.

7. In the future, the largest machines in the factory might need to be moved, or new, oversized machines might be brought in, so aisles must be wide enough to accommodate movement of such machines.

Planning aisles that are too narrow may result in congested facilities having high levels of damage and safety problems. Conversely, planning aisles that are too wide may result in wasted space and poor housekeeping practices. Aisle widths should be determined by considering the type and volume of flow to be handled by the aisle. The type of flow may be specified by considering the people and equipment types using the aisle. If the anticipated flow over an aisle indicates that only on rare occasions will flow be taking place at the same time in opposite directions, the aisle widths for main aisles may be obtained from Table 5.1. If, however, the anticipated flow in an aisle indicates that two-way flow will occur frequently, the aisle width should equal the sum of the aisle widths required for the types of flow in each direction.

Curves, jogs, or nonright angle interactions should be avoided in planning for aisles. Aisles should be avoided unless the aisle is used for entering or leaving the facility. Column spacing should be considered when planning aisle spacing. When column spacing is not considered, the columns will often be located in the aisle. Columns are often used to border aisles, but rarely should be located in an aisle.

(vi) *Space utilisation:* A very large plant can be one of the best or one of the worst, depending on how its space is utilised. Experienced professionals can easily scan a factory, recognise opportunities for improvement, and establish targets for better use of space. Proper space utilisation eliminates excess work-in-process inventory and the corresponding investment. Improved space utilisation also has some theoretical benefits that produce major economic results. For example, it improves communication among workers themselves, and between employees and supervisors [73].

Since lower-level management personnel are usually naïve about the advantages of improved use of space, they often misconceive that improved space utilisation means uncomfortable working areas for employees. But, in truth, working areas actually increase, as excessive inventory, conveyors or wide aisles, and wasted, unused space disappear. Also, these same managers often feel that if half the factory space is vacated, there are no savings since the space would be idle. Executive management, on the other hand, is often instantly able to envision dramatic savings associated with improved space utilisation. For instance, it can see that:

1. Inventory, machines, etc., from other company plants and/or warehouses can be moved into the vacated space, and the other facilities can be sold or subleased.

2. New products or acquired product can be moved into the vacated space.

3. Proper space utilisation eliminates excess work-in-process inventory and the corresponding investment.

4. Smaller spaces minimise the unnecessary movement of staff-including both indirect personnel such as material handlers, supervisors, equipment repair employee; and direct workers who waste time moving about in areas that are larger than necessary to perform production operations.

5. Improved space utilisation also has some theoretical, intangible benefits that produce major economic results. For example, it improves communication among workers themselves, and between employees and supervisors. As well, the following unexpected changes typically occur: improvement of 90 percent in the number of defects, a 75 percent improvement in equipment downtime.

(vii) *Functional Layout:* Functional layout refers to the arrangement of rooms and work areas by functional criteria. Facility layout specialists determine optimum arrangements based on analysis of functional requirements. Other principles of arrangement include functional grouping (for example, all activities related to a particular industrial process are located in one area) and sequence of use (for example, lining up workstations in the order of workflow) [73].

(vi) *Human factor involvement in production facilities design and planning:* Safety of workplace has to be taken into consideration.

(viiii) *Civil Engineering Knowledge:* Building structure, window position, door height, column spacing, stair design etc. should be considered.

(ix) *Architectural concept:* This deals with aesthetic aspects of factory building, which includes room decoration, office furniture selection and placement, sitting arrangement, entrance decoration, reception room decoration, building out a look design. All innovation and creativity must remain the prerogative of the architecture.

The basic requirement for virtual production facilities planning is, first of all, the availability of all objects in virtual environment. If this requirement is fulfilled simple production facilities planning is possible.

5.5 Conclusion

This chapter described some of the important activity relationships and space requirements, which are essentials of a facilities plan and also has emphasised the importance of their function in facilities planning. Among the activity relationships considered, flow planning, aisle arrangement, human factor, civil engineering knowledge, architectural concept, production planning requirement have been discussed which would be required (i) to build a factory (ii) to plan production facilities (iii) to visualise different facilities of factory. The use of these concepts could change dramatically, building size and shape, material flow analysis and location of production, support, and administrative areas while designing a 3D virtual factory.

Chapter 6

MODELLING AND ANALYSING OF VIRTUAL FACTORY LAYOUT

6.1 Introduction

This chapter is largely focused on what desk-top VR techniques have been applied in designing and planning of production facilities (which includes process, storage, test facilities, factory office, training centre for virtual machine etc.) and solving plant layout problems using 2D and 3D views. The effectiveness of working systems is largely dependent upon the planner in the work preparation of the factories. In order to raise the flexibility as well as to continuously adopt the factory working environment to changing marginal conditions and other influential factors in an economical way, new and innovative planning tools are required. The basic principles of this planning are the structural and geometric construction of the different sections of production facilities as well as all restrictions that arise from the limited space and the restricted accessibility. A new technique called Virtual Reality (VR) has been applied in the area of production facilities planning. Virtual environments built within genuine Virtual Reality (VR) technologies, are increasingly seen as having a number of serious applications in industrial area.

Another trend seen in recent years has been the inclusion of high quality graphics and animation in manufacturing systems simulation tools. Using animation, the various entities within a process can be seen moving around the simulated systems, the status of the resources within the system are clearly displayed, and the interaction between subprocesses easily visible. Now animation has become so useful that a survey has shown that the majority of industrial engineers think that graphics/animations are very important. Using Virtual Reality techniques, it is possible to generate the three dimensional graphics in real-time, concurrently with simulation generation, allowing the user to move around, and interact with the simulated process in a natural and intuitive manner. The ability to move the position from where the observer views the simulated process potentially allows various interactions and characteristic within the system to be seen that might otherwise have been hidden. Virtual Reality allows the incorporation of the original objects from CAD files, and building plans to allow for very realistic and convincing scenes to be created. One of the most significant aspects of the technology is its ability to improve decision-making process from both qualitative and quantitative perspectives. In both cases, it allows people to play "what if," and test alternative scenarios with relative ease. Qualitatively, users can get a feel for the effect of the new process design.

In the first part of this section a bicycle parts manufacturing factory has been modelled using 3D Studio Max Animation package. In this part plant layout problem solving technique has been applied to solve the existing factory layout problem using 3D and 2D views. In the second part of this section, a simple toy factory, which makes a sports car (for four to six year old children), has been modelled. The factory model has been designed to visualise shop floor virtually and to analyse the system using Desktop Virtual Reality System (Superscape VRT 5.5).

6.2. Virtual Factory Modelling Using 3D Studio Max

A picture is worth a thousand words, according to an old Chinese proverb. If this is so, a graphical animation should be worth at least a thousand pictures. Animated graphical simulation enhances our understanding of abstract concepts, aid analysis, increase human productivity and reduce design cost. This section describes an experience of building a virtual factory using solid modelling and animation based simulation package. Creation of mechanical systems using 3-D solid modelling and animation based simulation system can provide a fast, effective method of visualising and 'experiencing' new designs which can be easily modified to consider design alternatives. Using animation, the various entities within a process can be seen moving around the simulated system, the status of the resources within the system are clearly displayed, and interaction between subprocess easily visible.

Computer simulation is now-a-days becoming popular in evaluation of complex motion of mechanical systems. First of all its economical impact in design for manufacturing is considerable. It can be easily imagined that it is desirable to use a simulation system to have an opportunity of watching a new mechanical system on a computer screen first, when it is just finished in design stage. One of the most alternative subjects in the computer applications to manufacturing is to construct a factory on a computer memory and to operate it as if it were real. This idea is called a virtual factory. A virtual factory built in a computer will be conveniently applied to a lot of purpose. At the design stage of a factory, designers can evaluate the feasibility such as space, storage and other facilities. At the stage of operations, a visual factory built in a computer is considered to be a replica of the real factory and it can be used for factory management. The development of a virtual factory is expected to be valuable for the education of manufacturing, as well as for industry.

This section describes one approach to a virtual factory by means of a three-dimensional modelling system and animation based simulation. The section also discusses how 3-D solid modelling and animation based simulation can aid engineers in analysing the virtual factory's layout with a view to (i) identify production process bottlenecks (ii) proper utilisation of space and other facilities by applying plant layout problem solving techniques.

6.3. Virtual Factory

6.3.1. Description of the virtual factory (Bi-Cycle Parts Manufacturing)

The virtual factory is made up of four different sections. One section consists of two spoke forming machines, a nipple upsetting machine, two nipple-threading machines, and one washer-forming machine. The other section consist of a rim (bicycle parts) forming machine, a butt welding machine, a sizing machine, a abrasive machine, and a grinding machine. The third section consists of electroplating equipment for nipple, washer, spoke and rim. The fourth section is the packaging and storage section for finished products. To visualise the different machining process and other activities on the factory floor several viewingpoints have been set. Thus it is possible to view different machines in operation and observe existing layout of different sections of the factory. The user has the facilities to modify different facilities design in dimensional and aesthetic qualities and could test the machinery's and other production facilities for better positioning thus making space available for future allocation of new production machinery's and other machine tools.

The system development was divided into two main parts:

(i) Construction of a virtual environment: This part provide experience of creating virtual object and placing them in the virtual environment with associated real world properties in order to illustrate how models are created. The machines like lathe, drilling and milling were created in 3D Studio MAX. All production machines were created in AutoCAD Release 13 and then imported to 3D Studio Max using the DXF format. The main boundary wall of the factory was created and then aisles were created. Columns were placed to generate the constraints that are faced in real life situations. Partition walls were placed. Then workshop and production machines were located on the factory floor.

(ii) Use of virtual environment: This part encourage to explore different attributes of the virtual environment within two broad categories which are factory walkthrough and visualisation of different sections of the factory.

6.3.2 Factory Walk Through

This feature demonstrates how the participant can navigate through VE and examine it from different viewing points. Several viewing points were set up at different locations around the factory. Appropriate directional control inputs were responsive according to the type of object being manipulated. Two different types of object manipulation were represented in the virtual environment:

(i) Egocentric view in which eye height was set at approximately 1.6m (Fig. 6.1).

(ii) Excocentric in which view is placed in the ceiling above the factory floor allowing to see both the production line and design room(Fig.6.2).

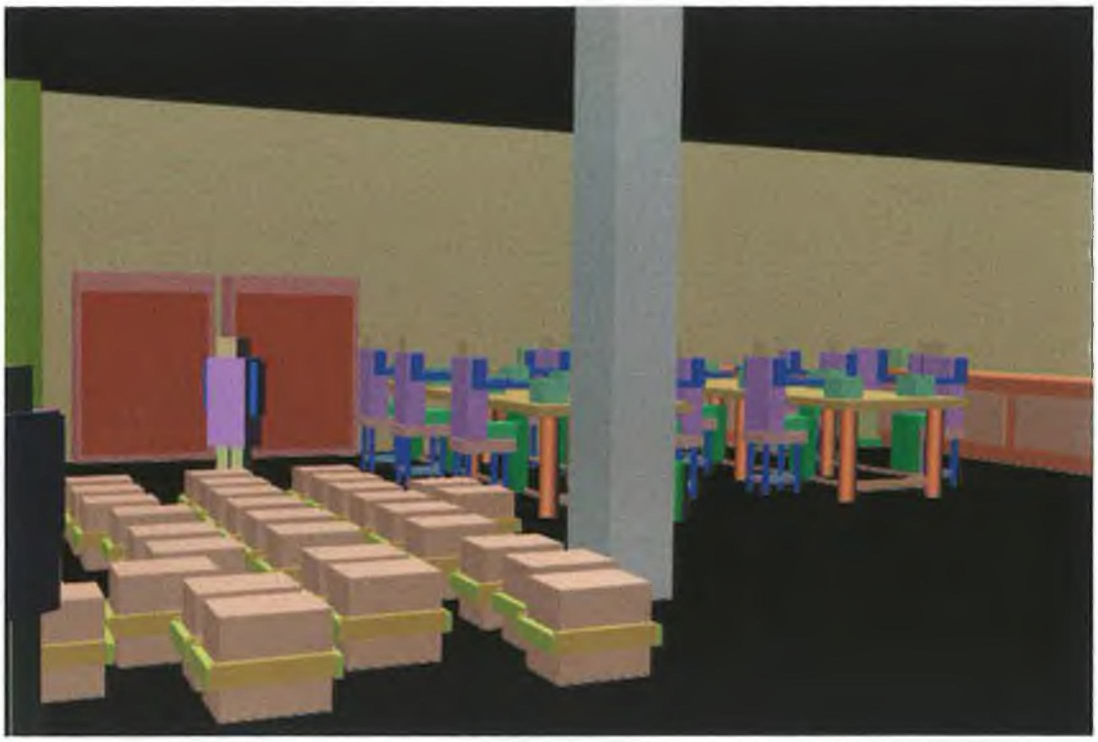


Fig.6.1: Egocentric view as the participant walks around the factory.

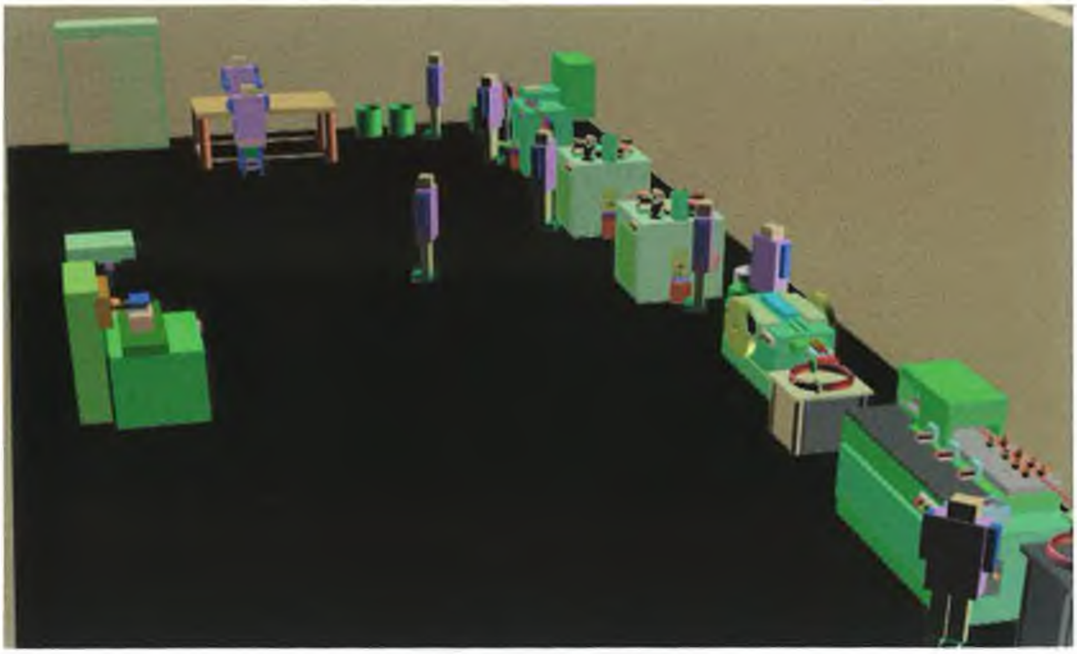


Fig. 6.2 : Exocentric view. Here the view is placed in the ceiling above the factory floor allowing the participant to see both production line and the design room.

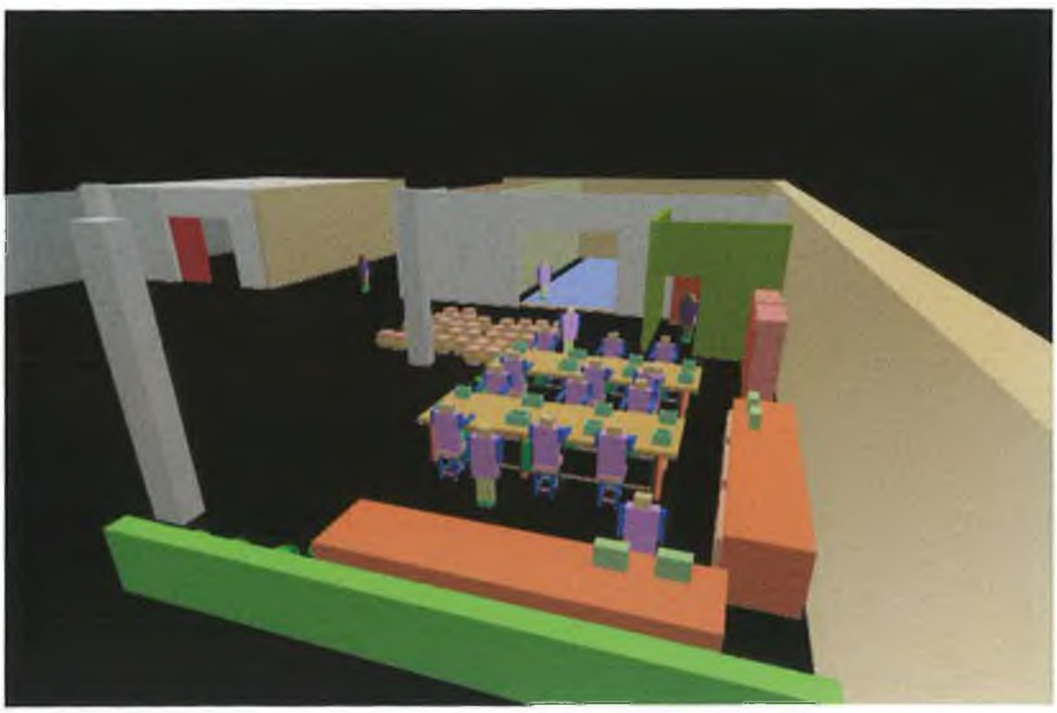


Fig. 6.3: Exocentric view. Here the view is placed in the ceiling above the factory floor allowing the participant to see both packaging section and the design room.

6.8. Visualisation of different facilities of the factory

This feature demonstrates the effect of simulation operations and visualising interactions between different objects and related functions. It was possible to

- Observe operations from unusual viewpoint (Fig. 6.2).
- Observe packaging and storage sections for end products, to identify any bottlenecks (Fig. 6.3).

Fig. 6.3 shows layout of packaging and storage section of end product. Thus it is also possible to view different process in operation and various layout from different viewpoints.

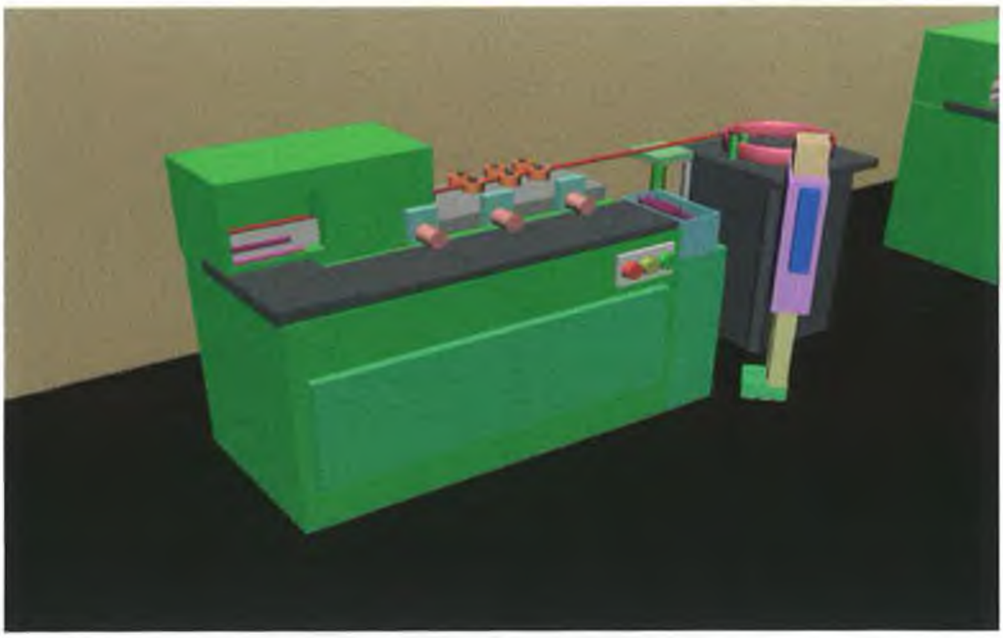


Fig.6.4: Looking from unusual viewpoint the participant can observe the process.

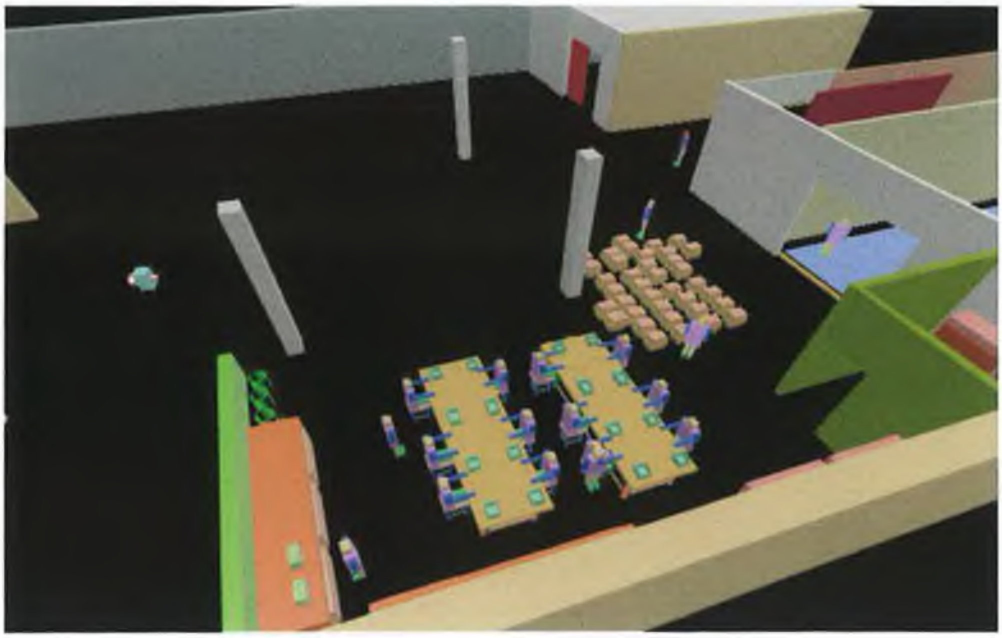


Fig. 6.5: Looking from unusual viewpoint the participant can find out bottlenecks in packaging section.

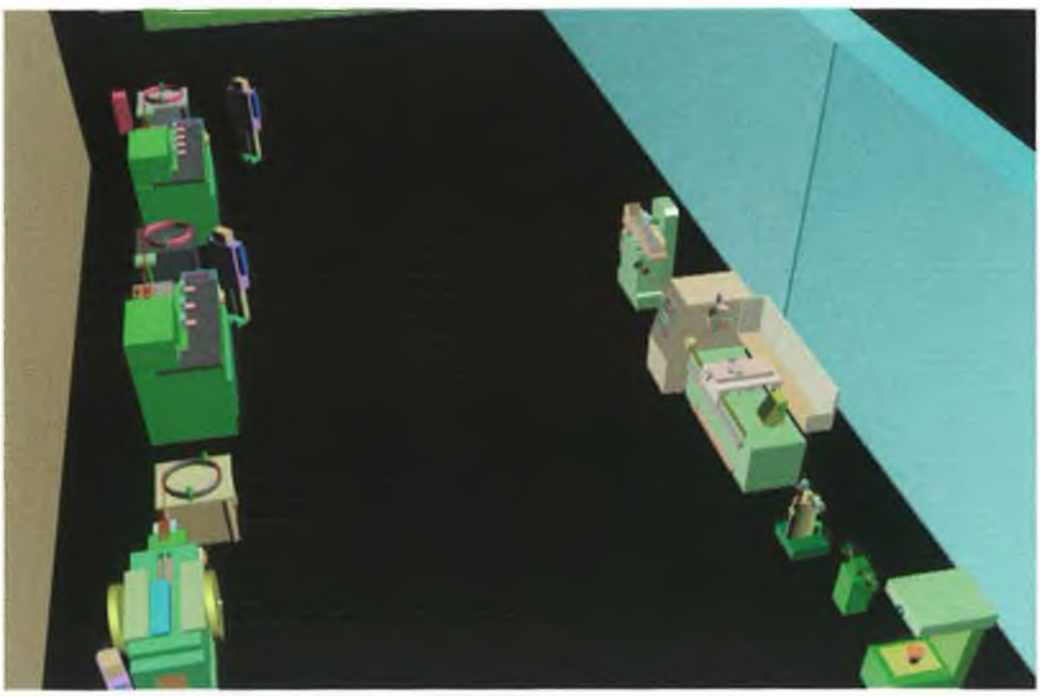


Fig. 6.6 : Visualising layout of machinery from unusual viewpoint bottlenecks can be realised.

6.5. Identifying bottlenecks on the factory floor

To find bottlenecks in the virtual factory, designer need to view various sections of the factory. Visualising different sections of the factory floor the following bottlenecks were identified.

(i) Visualising the packaging and storage section (Fig. 6.5) it can be quickly realised that existing storage area of the end products in front of warehouse entrance blocks movement of people and materials. As a result designer can quickly relocate the storage area of end products stored in wooden boxes.

(ii) Visualising 3D picture and 2D plan (Fig. 6.6 & 6.8.), it can be observed that there is no systematic flow path of materials among the four sections. This leads to excess handling of materials, as workers have to carry materials in an unplanned flow path.

(iii) Machineries and equipment relocation: Machineries like milling machine, surface grinding, double ended grinder, drilling machine and lathe (Fig. 6.2) can be relocated to another suitable place in order to have more empty space for production section. The empty space can be utilised for setting up new production machineries in future.

(iv) No aisle has been implemented in the existing layout of the factory.

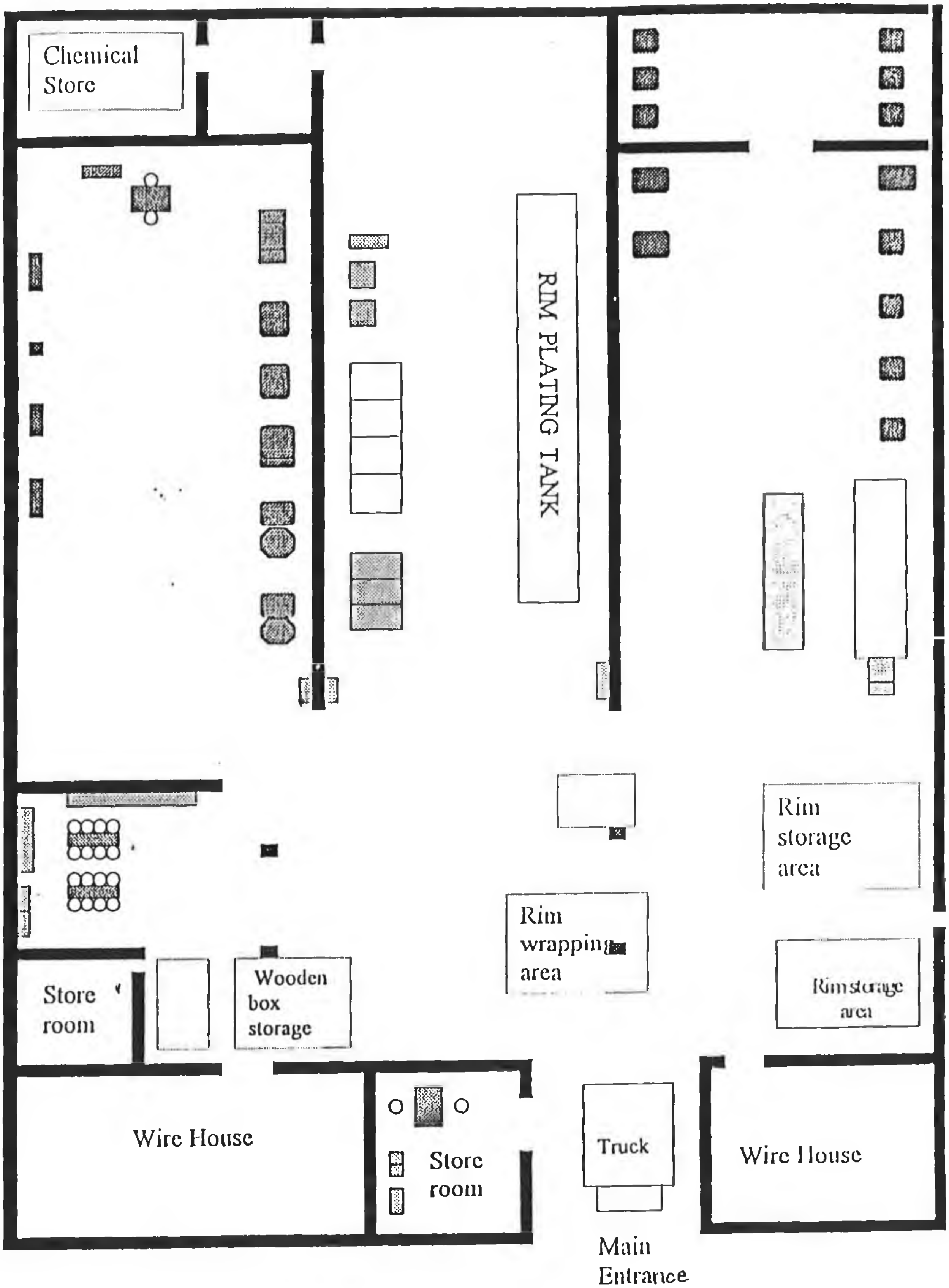


Fig.6.7: Old layout without aisle.

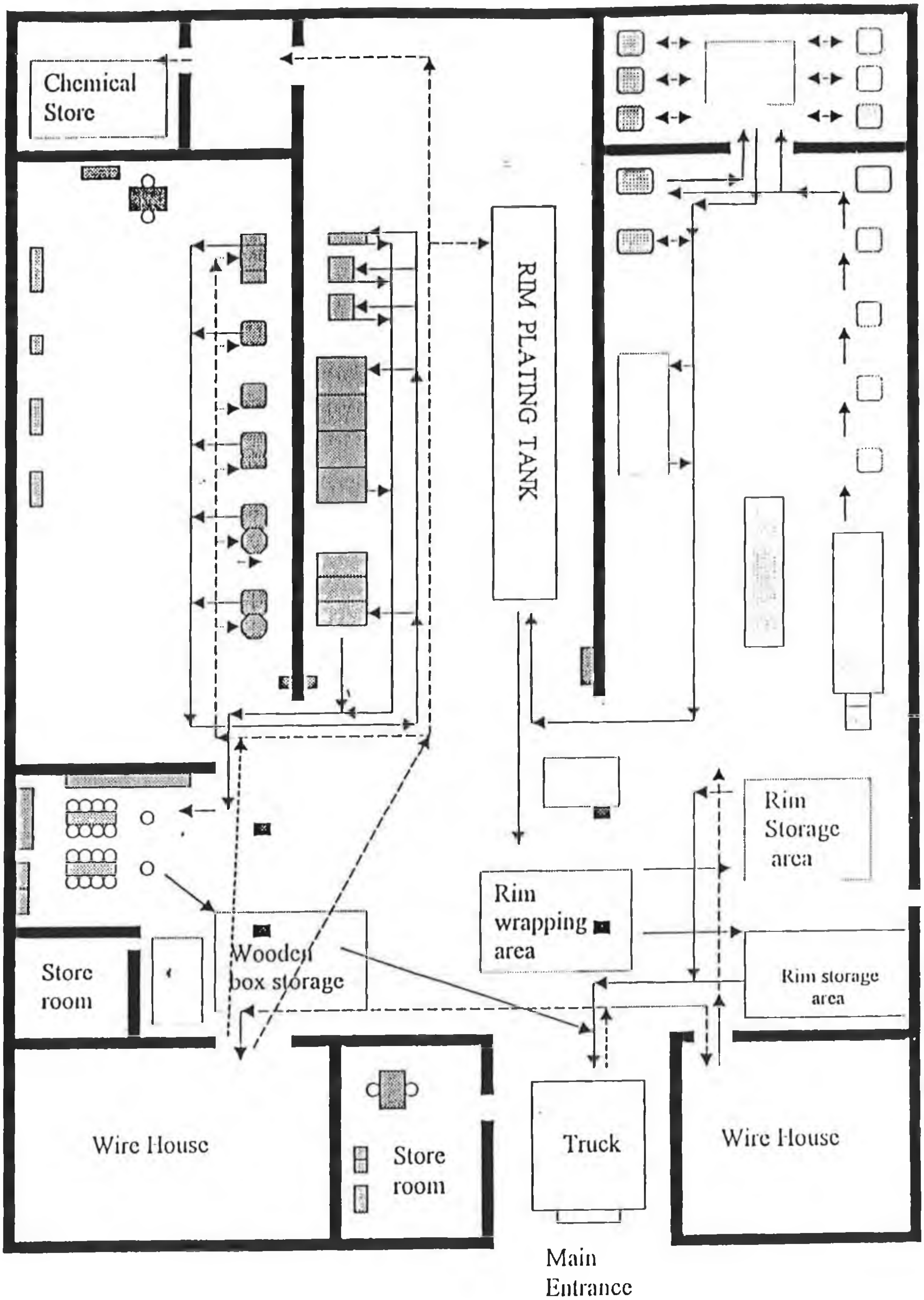


Fig.6.8:Material flow diagram before modifying the existing layout.

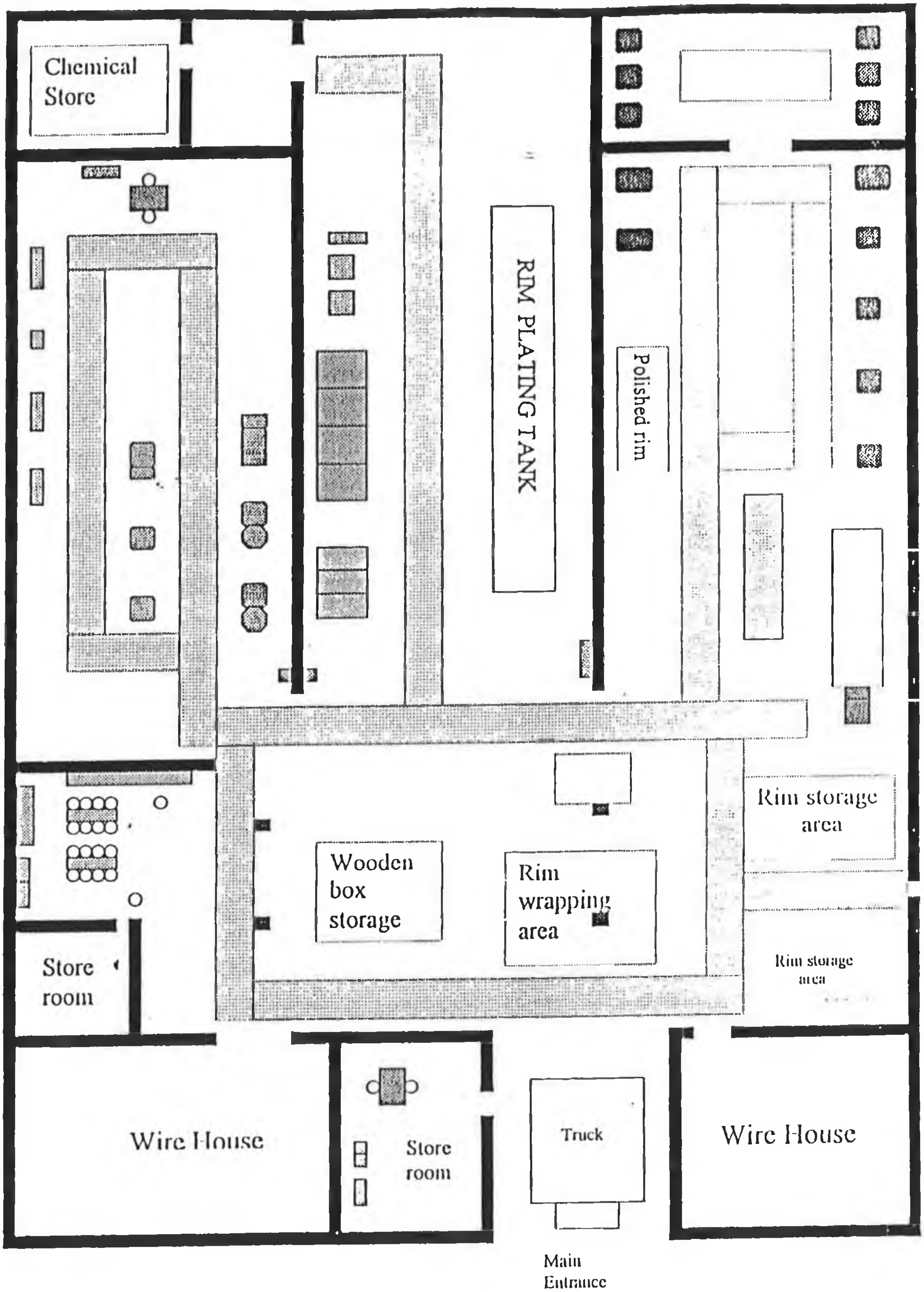


Fig.6.9:New layout with aisle.

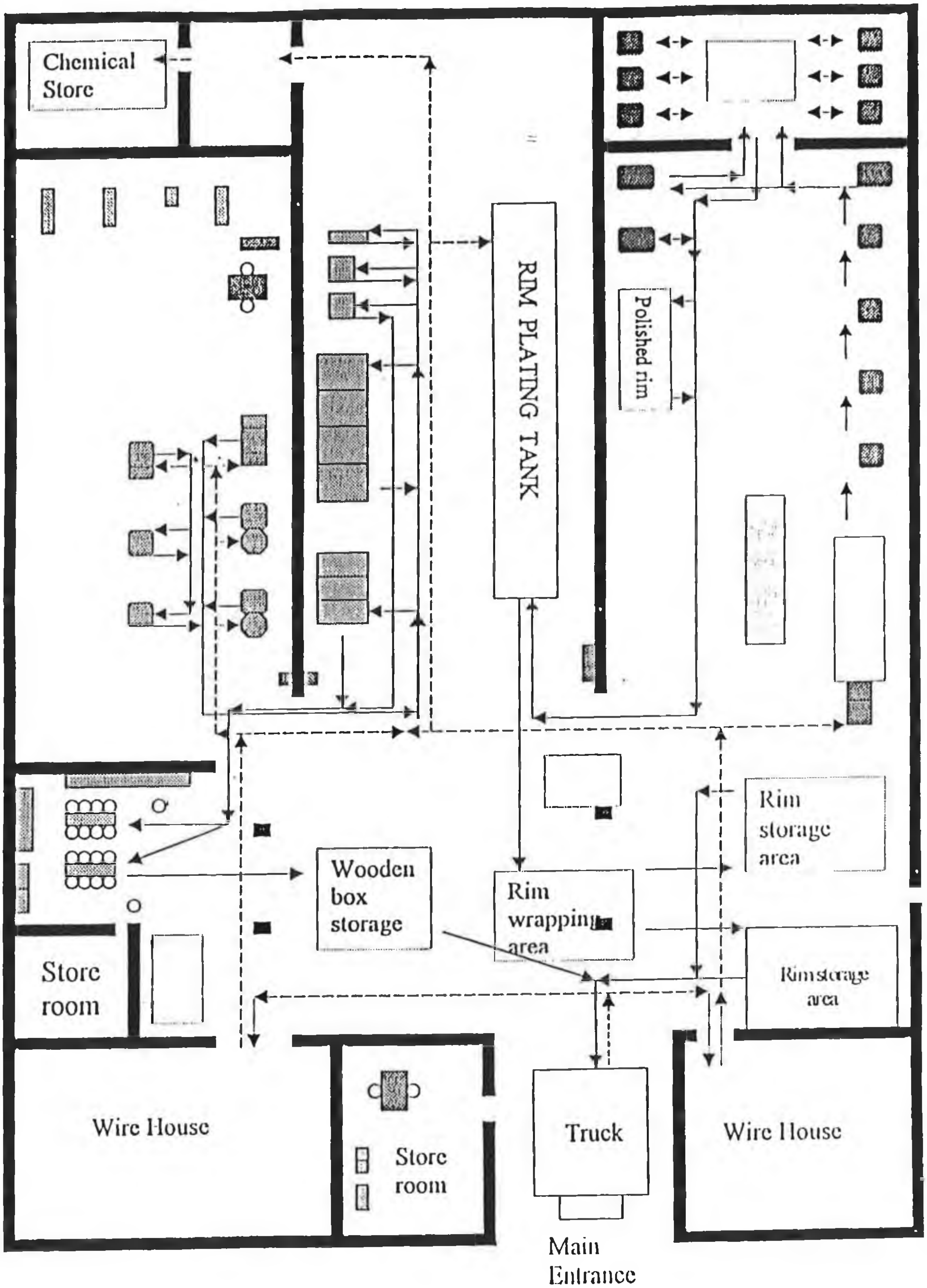


Fig.6.10:Material flow diagram in the new layout after introducing aisle.

6.5.1 Modification to the Existing Facilities

(i) Introducing aisle in the factory.

(ii) Rearrangements of production machineries.

(iii) Rearrangement of packaging section.

(iv) Rearrangement of finished product in open space.

6.5.2 Benefit to the Modification

(i) New aisle system has reduced material carrying distance (Fig.6.10).

Table 6.1 shows the difference of material handling distance before and after Implementing the aisle system.

Table 6.1: Difference in material handling distance before and after implementing the new layout system (meter).

Machine Type	Distance from the ware house to the machine before implementing aisle system	Distance the ware house to the machine after implementing aisle system
Nipple Forming m/c - 1	27.13	19.21
Nipple Forming m/c - 2	25.31	21.19
Washer forming Machine	31.25	22.41/23.02

(ii) Changing the layout of production machines in nipple, spoke and washer section gives more space for setting up new production machineries in future (Fig.6.9). Relocating the machines and carrying out the analysis permits creation of new layout. The area of the store room for packaging material has been increased to 23.72 sq. m from 17.77 sq. m, thus giving more space for material and worker movement and storage areas.

(iii) Using new aisle collisions among trolleys and boxes can be avoided when transporting the end products and production related materials from one place to another.

(iv) Finished products are stored in a organised way (Fig.6.9).

(v) Those modifications are subject to cost effectiveness in terms of production facilities and new space allocation.

6.6. Use of Analytical Methods to Obtain a Good General Layout

During the last 35 years, several computer-based heuristics have been developed that try to approximate natural search or spatial thought processes [74]. These layout packages fall into two general categories: those based on improvement heuristics and those based upon construction heuristics. This section describes the application of the former type, which can help in constructing and improving the functional layouts.

Here the concept of CRAFT (Computerised reallocation of facilities technique) has been applied to improve the existing layout of a factory. CRAFT (Computerised reallocation of facilities technique) is one of the oldest and simplest programs. It was developed by Armour and Buffa (1963), and is available for the use on desktop computer. CRAFT is not generated to produce an optimal (nor are any heuristics), but it will either produce a better layout than the initial one.

In this analytical method distances are measured between the middle of the work centers rather than from actual entry or exit points. As a result this method is the most useful at a macro level of design, where we want work centers located in a reasonably efficient manner with respect to all other work centers. In addition to CRAFT, there is other computerised layout programs. Two popular software are

CORELAP (Computerised relationship layout planning) and ALDEF (Automated layout design program). These programs differ from CRAFT in two ways. First, each is based on construction heuristics. That is, they construct layouts rather than improve on existing layout. A key issue in constructing the facility layouts is how to evaluate the goodness of alternative layouts. In this layout analysis, the flow of materials is the dominant factor. So Flow Matrix and Flow Cost Matrix have been taken into consideration as described below.

Flow Matrix: A Flow Matrix is a matrix of the estimated amounts of flow between each pair of work centers [74]. The flow may be materials (expressed as the number of loads transported) or people who move between centers. Each work center coressponds to one row and one coloumn, and the element f_{ij} designates the amount of flow from work center (row) i to work center (coloumn) j. Normally, the direction of flow between work centers is not important, only the total amount, so f_{ij} and f_{ji} can be combined and the flows represented using only the upper right half of a matrix, as illustrated in Table 6.2(a). In this table $f_{BE} = 30$ means that there are approximately 30 units of flow between work centers B and E each day. This may be frequency of pallets of material or trips by employees between the work centers.

Table 6.2a: FLOW MATRIX, daily flow between work centers [74].

Work Center

	A	B	C	D	E	F	G	H
A		25	32	0	80	0	30	5
B			20	10	30	75	0	7
C				0	10	50	45	60
D					35	0	25	90
E						20	80	0
F							0	150
G								50
H								

Flow-Cost Matrix: A basic assuption of facility layout is that the cost of moving materials or people between work centers is a function of distance traveled. Often we assume that the per unit cost of material and personnel flows between work centers is proportional to the distance between the centers. So for each type of flow between each pair of departments, i and j, we estimate the cost per unit per unit distance, c_{ij} . Notice for example, that the cost , c_{AD} may be different from the cost c_{BE} because different forms of transportation may be used. The cost per unit distance for the total flow between work centers i and j, which we will designate C_{ij} , is $C_{ij} = c_{ij} f_{ij}$. (if there are several forms of flow between a pair of work centers, then C_{ij} would be the sum of the costs for all flow types). The matrix of C_{ij} values is called the flow-cost matrix. Table 6.2(b) is the flow matrix for Table 6.2a, where all c_{ij} = \$1 per 100 feet, except that $c_{BC} = c_{DG} = c_{DI}$ = \$2, and $c_{BE} = c_{GH}$ = \$3. So for example, c_{BE} =\$3 x 30 \$90 per 100 feet. For every 100 feet of distance separating departments B and E, the company would incur \$90 of flow cost per day[74].

Table 6.2(b): FLOW -COST MATRIX, daily cost for flow between work Centers (Dollars per Day per 100 ft) [74].

Work Center

	A	B	C	D	E	F	G	H
A		25	32	0	80	0	30	5
B			20	10	30	75	0	7
C				0	10	50	45	60
D					35	0	25	90
E						20	80	0
F							0	150
G								50
H								

Suppose we have a flow-cost matrix where c_{ij} is the cost per unit distance of all flows between work centres i and j. For any given layout, let d_{ij} be the distance between work centres i and j. The cost associated with the flow between i and j is $C_{ij} d_{ij}$ and the total flow cost (TFC) for the flows among all the work centres is

$$\text{TFC} = \sum_i \sum_j C_{ij} d_{ij}$$

Where $C_{ij} = c_{ij} f_{ij}$

Here C_{ij} = Cost per unit distance for total flow between work center i and j

c_{ij} = Cost per unit per unit distance between two dept. or centers

f_{ij} = Flow between two work centers

d_{ij} = Distance between two work centers

if several forms of flow between a pair of work centers exist then the formula for the total flow cost (TFC) becomes

$$\text{TFC} = \sum_i \sum_j c_{ij} f_{ij} d_{ij}$$

If travel cost per meter are the same for all people then $C_{ij} = c_{ij}$

Again if all flows are equally costly per unit distance then TFC formula becomes

$$\text{TFC} = \sum_i \sum_j C_{ij} d_{ij}$$

In this layout analysis assume travel costs per meter s are the same for all people or in other words assuming all flows are equally costly per unit distance.

where the summations are taken over all work centres pairs [74].The TFC provides a concise way to compare specific layouts. Our task is to find the spatial arrangement of the work centres that makes the TFC as small as possible. Here the d_{ij} variable is indirect, determined by the spatial arrangement of the work centres [74].

The Relationship diagram

In this layout analysis, the flow of materials is the dominant factor. The from-to chart also referred as a travel chart is used to measure the material flow from on department to another department per day. Distance-based scores are inherently cost-minimising approaches to layout planning. It is assumed that distances between activities should be minimised, especially on frequently travelled routes.

Table 6.3 : Shows estimated number of workers and materials moving between departments per day.

To From	A	B	C	D	E	F	G	H
A	-	35	20	10	15	15	-	-
B	-	-	15	05	130	10	5	8
C	-	-	-	70	100	10	8	5
D	-	-	-	-	95	10	-	-
E	-	-	-	-	-	120	5	5
F	-	-	-	-	-		10	-
G	-	-	-	-	-			5
H	-	-	-	-	-			-

Where A = Main Store.

B = Spoke, nipple and washer forming section.

C = Rim forming and polishing section.

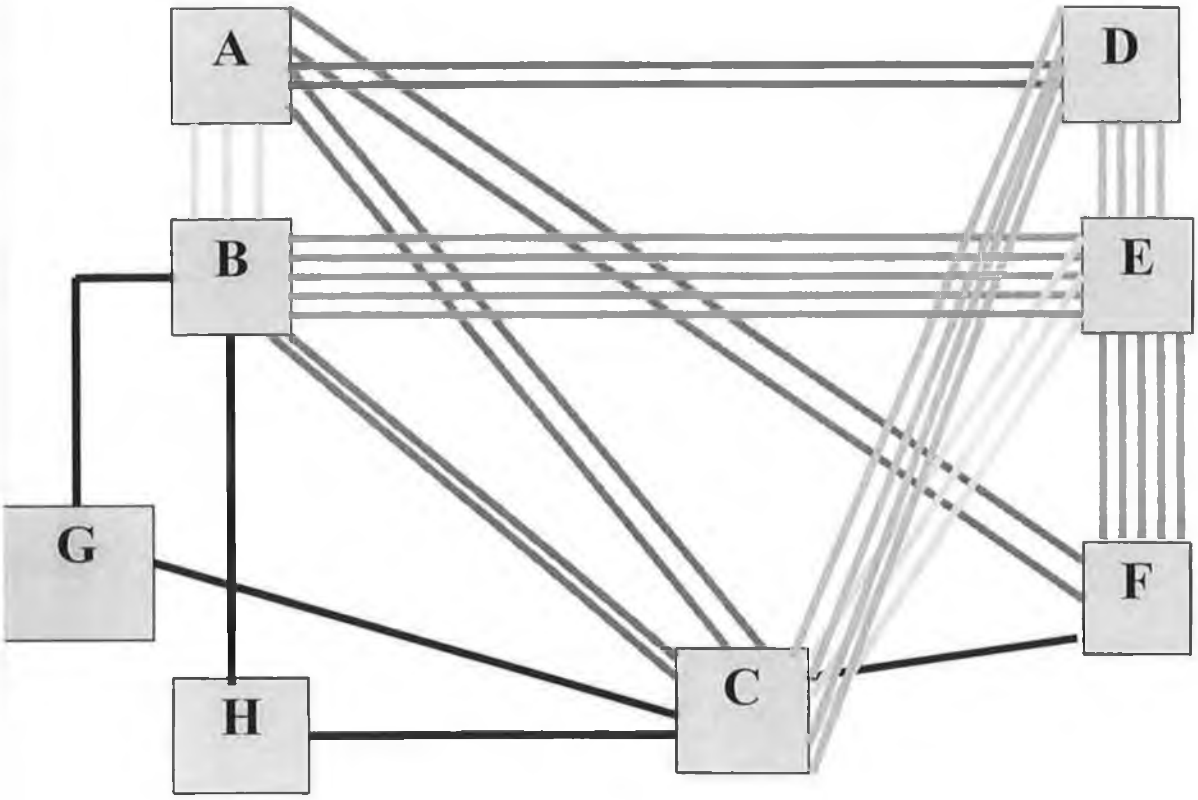
D = Polishing section.

E = Electroplating section.

F = Packaging section.

G = Wire house-1.

H = Wire House-2.



Ordinary (Frequency of people movement below 9)

Important (Frequency of people movement 10-19)

Very Important (Frequency of people movement 20-25)

Absolutely essential (Frequency of people movement 90-119)

Extremly desirable (Frequency of people movement 120+)

Figure 6.11: Activity relationship diagram.

Table 6.3 and Fig 6.11. shows that the flow between E and B is the largest (130). So location of B has to be close to E. Similarly the flow between E and F is the second largest (120). Thus F has to be close to E. Flow between C and E is 100. So C has to be near E. Similarity D and E have 100 flow between them and the location of D has to be near E. Position of A, G and H are to be located away from production areas. All the sections can be arranged in the following manner [74].

Closeness rank of the departments are shown as below,

RIM	ELECTRO	PACKING	WIREH-1
1 C	2 E	3 F	4 G
5 D	6 B	7 A	8 H
POLISH	SPOKE	MAIN STORE	WIREH-2

Table 6.4 shows distance (in meter) between departments after implementing the aisle system.

To From	A	B	C	D	E	F	G	H
A	-	33.50	37.70	50.80	42.00	22.10	14.33	08.14
B	-	-	32.85	48.25	31.55	23.73	41.92	31.84
C	-	-	-	13.85	47.95	34.45	30.33	45.65
D	-	-	-	-	37.37	47.56	44.05	42.98
E	-	-	-	-	-	37.78	42.76	42.98
F	-	-	-	-	-	-	33.53	19.51
G	-	-	-	-	-	-	-	23.63
H	-	-	-	-	-	-	-	-

Combining the data from number of times people carry materials per day between departments (Table 6.3) and the distance between departments (Table 6.4), we obtain the material handling distance travelled per day for the new layout with aisle system as shown in Table 6.5.

Table 6.5: Material handling distance travelled per day for the new layout after Implementing the aisle system.

To From	A	B	C	D	E	F	G	H
A	-	1172.5	754.00	508.00	630.00	331.50	14.33	8.14
B	-	-	492.75	241.25	4101.50	237.30	209.60	254.72
C	-	-	-	960.50	4795.00	344.50	242.56	228.25
D	-	-	-	-	3358.10	475.60	44.05	42.98
E	-	-	-	-	-	4533.60	213.80	214.90
F	-	-	-	-	-	-	335.30	19.51
G-	-	-	-	-	-	-	-	118.15
H	-	-	-	-	-	-	-	-

Now using the formula TFC = $\sum_i \sum_i C_{ij} d_{ij}$ to find the total daily travel with layout (Fig.6.9) we get 24881.40 person-meter.

Table 6.6 shows distance (in meter) between departments before implementing the aisle system.

To From	A	B	C	D	E	F	G	H
A	-	40.85	38.26	51.98	48.47	27.14	14.32	17.37
B	-	-	32.85	48.69	31.55	23.92	41.92	31.78
C	-	-	-	13.72	47.95	34.14	30.33	41.76
D	-	-	-	-	37.78	47.56	44.05	42.98
E	-	-	-	-	-	37.78	42.75	46.26
F	-	-	-	-	-	-	33.53	19.51
G	-	-	-	-	-	-	-	23.63
H	-	-	-	-	-	-	-	-

Again combining the data from number of times people carrying materials per day between departments (Table 6.3) and the distance travelled per day for the old layout with aisle system as shown in Table 6.6.

Table 6.7: Material-handling distance travelled per day for the old layout with aisle system.

To From	A	B	C	D	E	F	G	H
A	-	1429.75	765.20	519.80	727.05	407.10	14.32	17.37
B	-	-	492.75	243.45	4101.50	239.20	209.60	254.24
C	-	-	-	960.40	4795.00	341.4	242.64	208.80
D	-	-	-	-	3584.35	475.6	44.05	42.98
E	-	-	-	-	-	4533.6	213.75	231.30
F	-	-	-	-	-	-	335.30	19.51
G	-	-	-	-	-	-	-	118.15
H	-	-	-	-	-	-	-	-

Similarly for the layout (Fig. 6.7) the daily travel value is 25568.16 person-meter. Comparing the TFC value of the two layouts, the TFC value of the first one (Fig. 6.9) is low. So the new layout is chosen as the better layout.

6.7. Evaluation of the Virtual Factory

After visualising different sections of the factory using viewpoints it is considered that the factory walkthrough and visualisation facility both are useful for design and planning activities in virtual environment. Visualisation gives information about the minimal needed workspace or the optimised production sequence for products or planning production facilities. In virtual factory, various variants can be simulated, stored and repeated. It is also possible to visualise the moving parts of materials. This path can be used in a real material-handling path.

Useability of the 3D Studio Max system was assessed for how easy or difficult it was for the user to perform specific operations. The user found some design operations easy to perform. In visualisation of the manufacturing process " flying into the machine and recognising where you are " was found to be difficult. Possibly the most important feature is that any changes made by the user within one part of the world (e.g. design modification) influenced the activities or results in another (e.g. production visualisation). The problem faced by using 3D Studio Max is that the user can not control objects in the virtual environment. The user cannot move around, and interact with the simulated process. Simulation is done using animation time which is presetted. Walkthrough can be done by moving the Free Camera. This Free Camera can be created in the virtual environment and movement of the camera can be done smoothly in one direction only.

6.8 Virtual Factory Modelling using Superscape VRT 5.5

6.8.1 Description of the Virtual Factory

The virtual factory considered in this work is for producing toy vehicles for 3-6 year old children. The plastic body of the product is manufactured using injection moulding. To visualise the different machining process and other activities on the factory floor several viewing points have been set. Thus it is possible to view the injection moulding process in operation, and follow the component along the production line. Similarly it is possible to observe existing layout of the factory. The user has the option to modify different design of facilities in dimensional and aspects and could test the machinery's and other production facilities for better positioning thus making the operator's working environment safe and space available for future allocation. A number of attributes of virtual environments applicable to manufacturing, include: (i) modelling, dimensioning, reforming, orienting and colouring (ii) rapid prototyping through design and test facilities. (iii) design for manufacturability with interactive design and production facilities (iv) Walk through around a factory floor, with rapid switching of viewing points (v) guidance and exploration, for operation (vi) visualisation of several stages in a manufacturing process and (vii) ergonomics assessment of "fit" between users and product. The system development was divided into two main parts: (i) Construction of a virtual environment: This part provides experience of creating virtual objects and placing them in the virtual environment with associated real world properties in order to illustrate how models are created, and (ii) Use of a virtual environment: This part encourages the participants to explore different attributes of the virtual environment within two broad categories: (a) factory walkthrough, and (b) visualisation of a product development process, and storage facilities.

The system development was divided into two main parts:

(i) Construction of a virtual environment: This part provide experience of creating virtual object and placing them in the virtual environment with associated real world properties in order to illustrate how models are created. The injection moulding machine, conveyor, factory structure, windows, doors etc. were created in Superscape VRT 5.5. The main boundary wall of the factory was created and then aisles were created. Columns were placed to generate the constraints that are faced in real life situations. Partition walls were placed. Then machines and furniture were located on the factory floor.

(ii) Use of virtual environment: This part encourage to explore different attributes of the virtual environment within two broad categories which are factory walkthrough and visualisation of different sections of the factory.

6.9. System Development

6.9.1 Factory walkthrough

This feature demonstrates how the participant can navigate through the VE and examine it from different viewingpoints. Several viewingpoints were set up at different locations around the factory, some of which enable movement control of virtual objects. A 3D mouse has been used to control the movement of the participant and also of the virtual objects around the factory environment. Appropriate directional control inputs were responsive according to the type of object being manipulated. Two different types of object manipulation were represented in the virtual environment:

(i) 'Human walking' (egocentric view) in which the eye height was set at approximately 1.6 m i.e. viewing point has been set to represent the approximate height of a person and movement control restricted to 2 degrees of freedom (DOF)-forward/back and left/right obeying natural physical laws- for example, doors must be opened before passing through, the participant's 'body' is fixed to the floor and can only be raised by climbing (Fig. 6.12).

(ii) 'Ghost mode' in which the participant has complete freedom of movement around the virtual environment in all 6 DOF (Degree of freedom), defying all natural boundaries (e.g. movement through hard surfaces such as walls (Fig. 6.13).

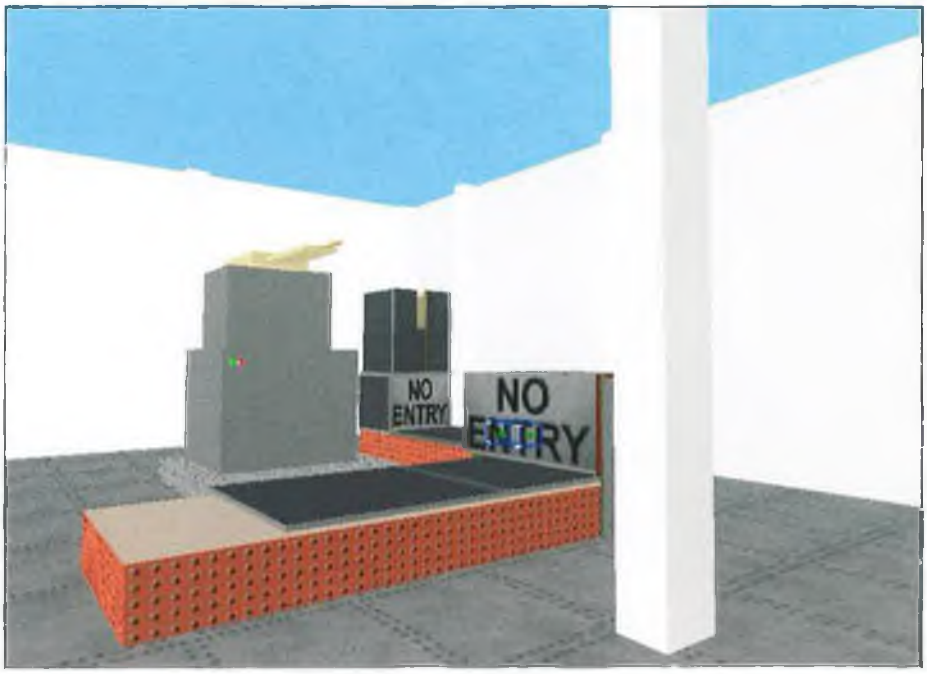


Fig. 6.12: Viewing point of " Machine operator" as he walks to the moulding machine.

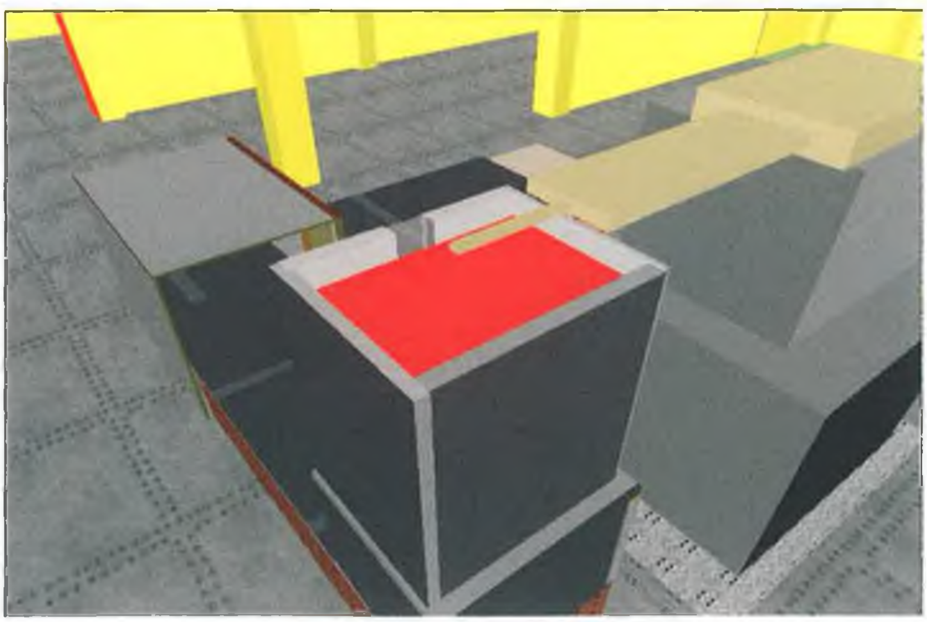


Fig.6.13 : Looking from above the participant can observe the material flow.

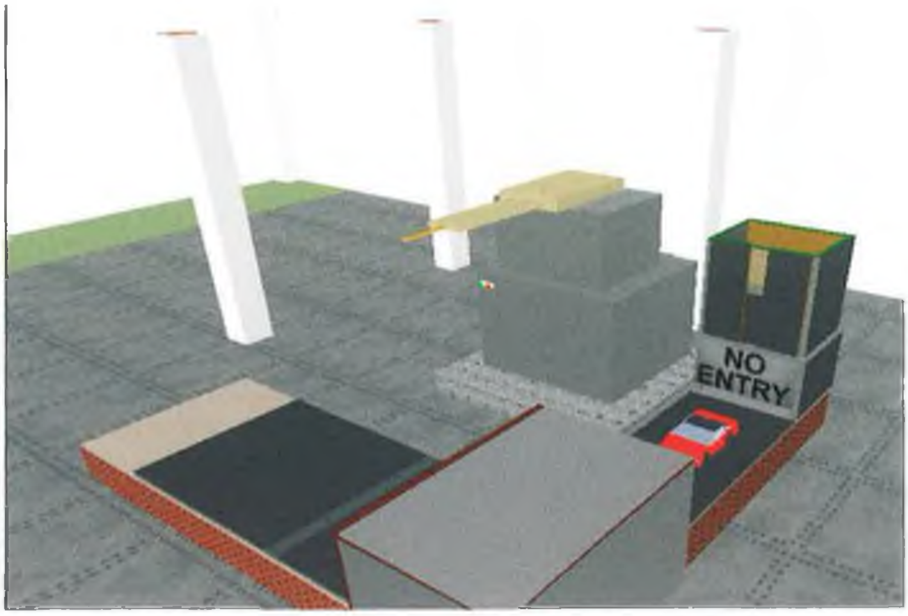


Fig.6.14: Over view of factory world, with viewpoint in "ghost mode", showing process layout.

Fig. 6.15: Looking from unusual viewing point the participant can observe the whole process and see the design room.

The User Navigation Tools and Operation of the Virtual Factory: Navigation around the virtual factory is achieved via a movement bar located at the middle bottom of the screen. The movement bar is presented in Fig. 6.16. In order to navigate around the virtual factory, the user intends to move forward in the virtual factory he/she will click on the " Move Forward" button (fig.6.16) and drag the mouse away from the icon in the direction he/she desired to travel. The further the mouse is displaced from the icon, the faster the forward motion will appear to the user. In order to stop the motion, the mouse button will have to be released. The "Looks" up/down icons give the effect of rotating the user head up/down and give the appropriate visual response.

The developed virtual factory begins with a big automatic door (Fig.6.17). On a mouse activation on the main door of the virtual factory in z-axis to open/close as shown in Fig. 6.17. This door has an SCL attribute, which indicates opening and closing commend. The user will be in the reception area after opening the main entrance door. Then the user can navigate around the reception area using the mouse. When the user enters the main factory floor through the second door, he/she can view the injection moulding machine. The user can also start the machine by pressing the green button and then can navigate the machine from different angle using the navigation tool and the mouse mentioned earlier. Different viewing points have been set for the participant to view the machine, conveyor, end product and other facilities. Pressing the red button, which is beside the green button, can stop the machine. Similarly storage section and loading and unloading section can be viewed using the mouse and the "forward arrow". Appendix D gives SCL of different virtual objects of the virtual factory. Appendix E gives instruction for operating the virtual factory by the new user.

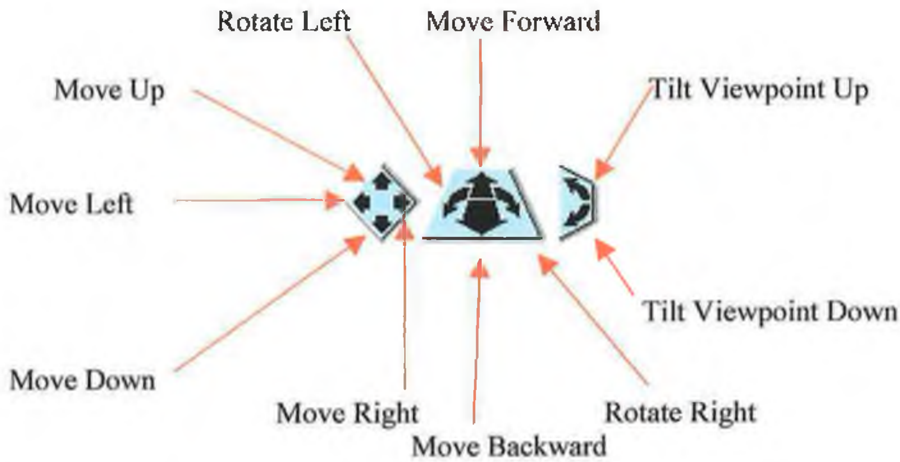


Fig.6.16: Navigation Arrows.

6.9.2 Visualisation of Different Facilities of the Factory

This feature demonstrates the effect of simulation operations and visualising interactions between different objects and related functions. It is possible to:

(i) switch on the moulding machine to start operation.

(ii) observe the process in operations from unusual viewingpoint (e.g. watching the hopper filling with plastic beads as viewed from above the machine) (Fig. 6.13)

(iii) observe finished parts moving down the conveyor lines, identifying any bottlenecks (Fig.6.12& 6.13).

6.10 Usefulness of the Virtual Factory to Industrial Application

The objective of creating the virtual factory environment was to explore the potential use of the Desktop VR system for industrial application. A factory could be represented in a virtual environment such that the operators could virtually see, hear, and feel the system and components to determine status. After visualising different sections of the factory using viewing points (Fig. 6.17) it is considered that both the factory walkthrough and the visualisation facilities are useful for design and planning activities in virtual environment. Visualisation gives information about the minimal needed workspace or the optimised production sequence for products or planning production facilities. Walkthrough ability and interaction with virtual models before applying findings to real life could be extremely useful. In a virtual factory, various variants can be simulated, stored and repeated. It is also possible to visualise the moving parts of materials. This path can be used as a real material-handling path. Similarly end product storage system can be visualised early.

Applicability of the Superscape VRT 5.5 system was assessed for its user friendliness for the user to perform specific operations. The Superscape gave a good feel and quite realistic effect of the actual real factory. The authors found some design operations easy to perform. In visualisation of the manufacturing process "flying into the machine and recognising where one is" was found to be difficult. The relation between multiple systems could be shown in a natural way. The primary advantage of designing a product in virtual environment is that it provides a good medium for visualisation of the prototype. Virtual prototyping is a method to be used to evaluate different design alternatives very quickly [75]. In contrast to physical prototypes, a virtual prototype is made very rapidly, can be manipulated and modified directly and the data is reusable as shown in Figure 6.18. VR provides extraordinary powers to apply engineering design to visual representation and interactions although they are in the early stages of dissemination and refinement.

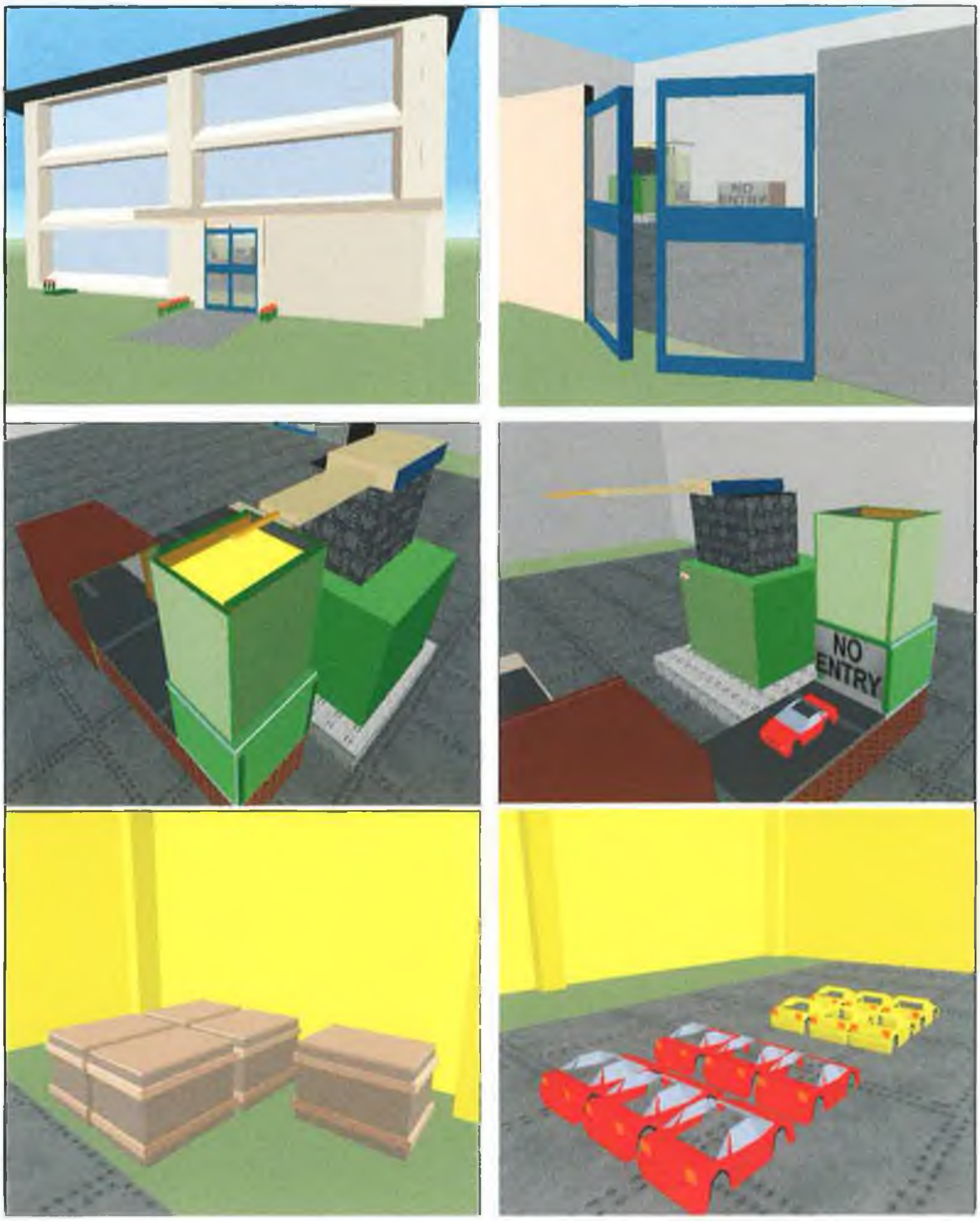


Figure 6.17: Participant can switch from walkthrough to factory entrance, to process visualisation, to assembly area and to storage area by windowing or changing viewing points.

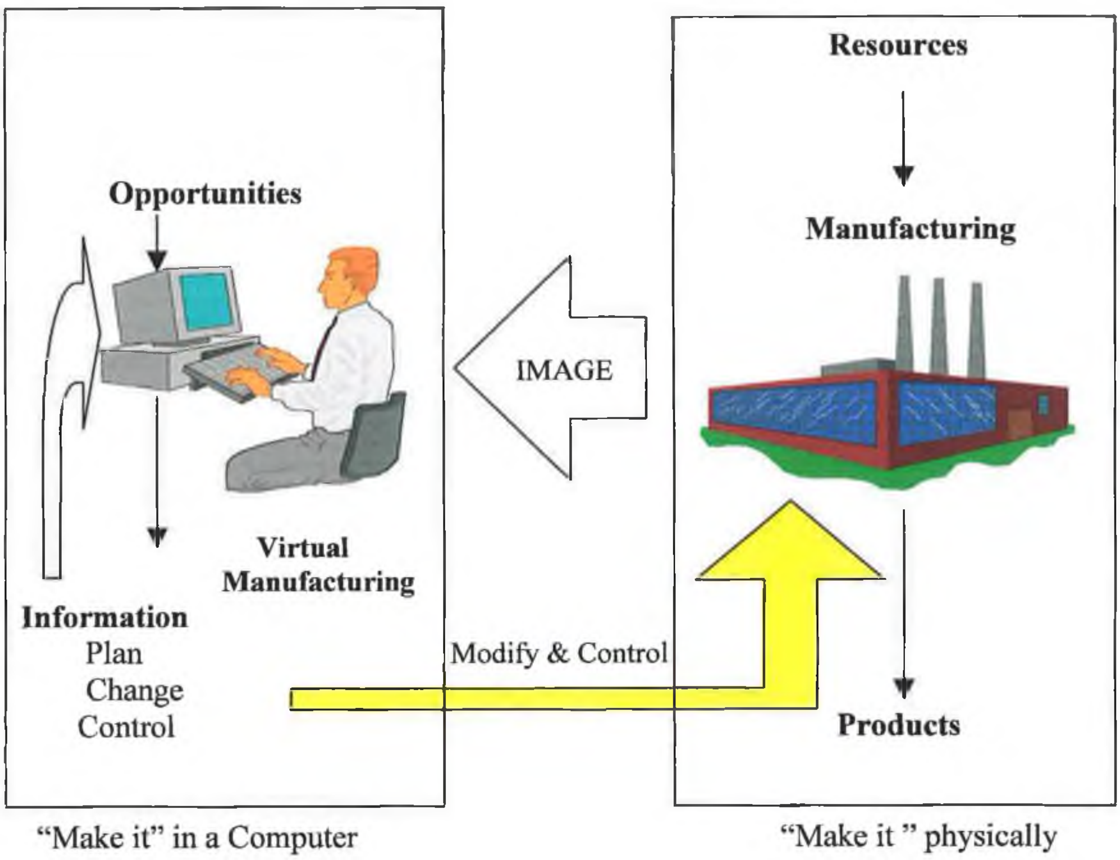


Figure 6.18: Shows advantage of "Make it" in a Computer over "Make it " physically.

6.11 Discussion

The VR can provide high levels of interactivity and involvement that many CAD systems do not. Though the VR systems are at an early stage of development, it can offer added value to existing concurrent engineering practice. The VR has the ability to navigate freely around a virtual environment in real time, which provides an obvious attraction for use within concurrent engineering. The system will assist the product designer to visualise the product concept, represent alternative solutions, understand consequences of production, bottlenecks in production planning, facilities planning and communicate all these to others. The designer can move freely around the VE examining the object from different angles, the user can interact with objects to explore and test its functional behaviour. The designer and others can view a simplified model of the product which does not carry all the exact detail specification in the design model and can examine it visually very quickly from alternative angles and viewing points. It is also possible to explore some of the functional features of the design such as opening doors or operating control panels. Using VR, the process planners can give decision upon the operation sequence as to how the products are to be made and which equipment should be used. VR can play as a visualisation tool in gaining a better "feel" for the component than from drawing. Also, the process schedule decisions can be made about the optimum use of machines to manufacture the product. Similarly visualisation of material flow via different production routes and identification of bottlenecks can be achieved by VR simulation of the process. Again using VR, a visual representation of the physical positioning of the objects within a specified space will allow the user to explore access space available, safety analysis of the operator, and space need for setting new machines or other facilities. Virtual reality will help engineers add motion, functionality and intelligence to solid models so that these can be evaluated in a simulated environment.

6.12. Conclusions

In this section, construction, walkthrough and visualisation of two virtual factories has been described. Various bottlenecks of the bi-cycle parts manufacturing factories were identified and modified using scientific factory layout problem solving techniques. The old and the new layouts were compared and the new layout was chosen as the better layout. Aisle was introduced in the new layout. After implementing of the aisle and the CRAFT (Computerised Reallocation of Facilities Techniques) concept, optimum layout has been achieved which has increased total productivity of the factory in terms of (i) by shortening material handling distance (ii) allocation of more space for setting up new production machineries.

Designer can build up a virtual factory just like building a miniature model of the real factory. Thus 3-D solid modelling and animation based simulation system provides a fast, effective method of visualising and experiencing new designs which can be easily modified. Designer can design and see different types of layout before making final decision to choose the best from them. Virtual environments have great potential to allow some thing to be done in industry in the future.

Chapter 7

PROCESS DEVELOPMENT AND SIMULATION OF BI-CYCLE PARTS MANUFACTURING FACTORY

7.1 Introduction

This chapter presents the process development for a bi-cycle parts manufacturing factory using the process modelling and simulation software SimCad. Detailes about the introduction of SimCad Software has been given in Appendix F. Models were created graphically by placing different process shapes in the layout window to represent process model. The primary interface to the software is either pulldown menus or the button tool bar. The operation of the simulation model is controlled from a toolbar at the top of the screen, which starts, stops, and resets the model. The majority of the activity however, takes place in the 'Simulation Window'. It is here that items are placed in drag-and drop predefined items on to the simulation screen. Once the required elements are on the screen, visual push and pull rules are added, via the mouse. Once a basic model has been assembled on the screen, the next step is to add more details to the elements in the model.

Standard SimCad reports can be viewed on the screen either in tabular or graphic format. In addition, several graphical elements are available for summarising statistics from a model. Pie charts and histograms provide a meaningful, easily read format for data from a simulation model run.

7.2 Modelling Methodology

Different types of process icons are available for building various types of process models. Firstly graphically represented processes were selected from the tool bar containing different processes and were linked using connection lines as shown in Fig. 7.1.

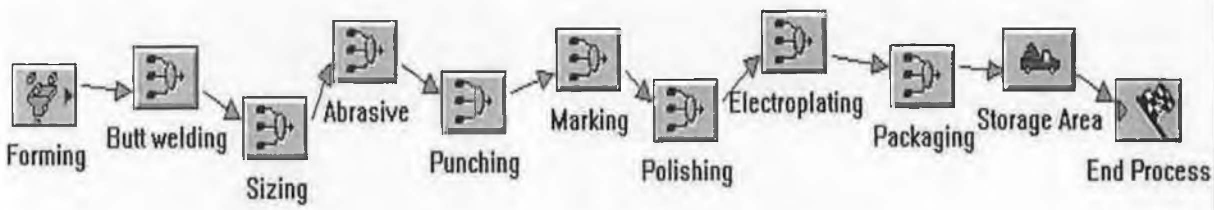


Fig. 7.1

7.2.1 Flow Properties

This section explains different terms used in the Process General Properties Dialog Icon (Fig. 7.2).

The terms in the Process General Properties icon are explained as follows:

The Process Name: It contains the name of the process, as it will be displayed on the simulation model.

Total Objects in Process: It is the maximum number of objects the process queue will store in addition to the number of stations. This number can not be 0, as the minimum number entered should be at least equal to the number of stations specified, in which case the queue length of the process is 0.

Number of Stations: It is the number of processes required to complete the job. SimCad is not capable of tracking the load on each of these workstations.

Percent Rework: It is the percentage of objects to be inserted back in the process queue after the object processing is completed. This number is used to simulate incomplete work to be completed, or object not properly completed and needed to be re-done.

Initial Process Load: It defines the initial number of objects that the process will have when the simulation starts.

Initial Object Type: It defines the object type of the object created to support the 'Initial Process Load' feature. The object type is also used to define the type of object created when the process Queue is loaded when the simulation is running.

Process Set-up Time: It is the amount of time the process requires to initialise itself before it is ready to accept work. The process set-up time takes effect only at the start of the simulation.

Minimum Time Spent: It is the minimum amount of time an object requires to be processed. This number is used as the default for all connections into the process.

Maximum Setup: It is the maximum amount of time an object requires to be processed. This number is used as the default for all connections into the process.

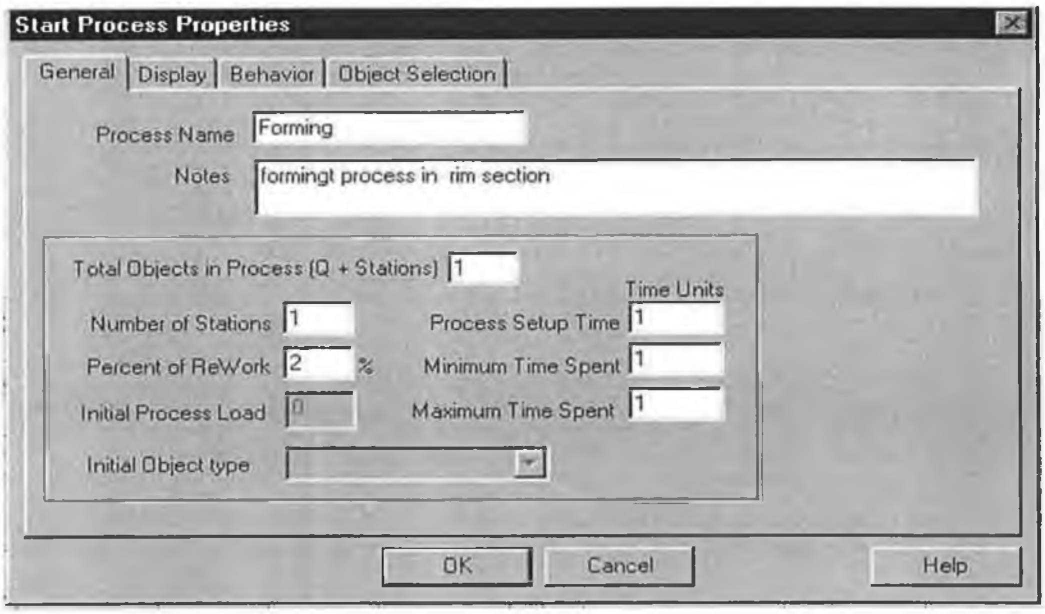


Fig. 7.2: General Dialog Icon Under Start Process Properties.

The following data in Table 7.1 (a) was used in the SimCad simulation.

Data in Table 7.1 (a) was taken from bi-cycle wheel manufacturing factory [76].

Table 7.1(a): Rate of Rim Production by different Machines of Rim Section [76].

Process Name	Number of Machine	Average Rate of Rim Production Per Hour	Time for one rim
Forming	1	135	2.25
Butt Welding	1	71	1.83
Sizing	1	240	4
Grinding	1	86	1.43
Abrasive	1	45	0.75
SpokeHole Punching	2	93	0.77(per machine)
Polishing	6	93	0.258(per machine)
Marking	1	120	2

Tale 7.1(b): Data for Process General Properties.

Process Name	Total Object in Process	Number of Station	Process Set up Time	Min. Time Spent	Max. Time Spent	Percent of Rework
Forming	1	1	1	1	1	2
Butt Welding	1	1	1	2	3	0
Sizing	1	1	1	1	1	0
Abrasive	1	1	1	2	3	0
Punching	1	1	1	1	2	2
Marking	1	1	1	1	2	2
Polishing	7	6	1	2	4	0
Electroplat-ing	1	1	1	1	1	1
Packaging	6	5	1	1	2	0
Storage	0	1	1	-	-	0
End Process	0	1	1	-	-	0

Note: Initial Process Load is Zero for all processes.

The data given in Table 7.1(b) have been inserted for each process in the Process General Properties Dialog Icon. The data in Table 7.1(b) were generated from Table 7.1(a).

Necessary data were put from Table 7.1(a) to the Process General Properties Dialog Icon (Fig.7.6) for all processes involved in the production of a rim.

For the creation of bi-cycle wheel rim and for simulation, the following step by step procedure was used.

Procedure for data input for Forming Process:, The data input for forming process (Referred to in Fig. 7.1) is given as follows:

In General Dialog Icon under Start Process Properties (Fig. 7.2) data was inserted in the following way.

- 'Forming' is written beside 'Process Name'- Forming represents the name of the process, as it will be displayed on the simulation model (Fig 7.2).
- 'Forming Process in Rim Section' is written beside 'Notes'- This is the process description ,which need to be tracked for information (Fig. 7.2).
- 'Zero' is typed beside 'Rework'- Zero represent no percentage of items to be inserted in the process queue after the object processing is completed. This is used to simulate incomplete work to be completed or items not properly completed (Fig. 7.2). There is no rework for forming process.
- '5' is typed beside 'Process set-up time'- '5' represents the amount of time (minute) the process requires to initialise itself before it is ready to accept work (Fig. 7.2).
- '1' is typed beside 'Number of station - '1' represents one forming process (Fig. 7.2).

- '1' is typed beside minimum time spent'- '1' represents the minimum time an item requires to be processes (Fig. 7.2).
- '1' is typed beside maximum time spent'- '1' represents the maximum time an item requires to be processes (Fig. 7.2).

Under the Object Selection Icon data was inserted in the following way.

- '30' was typed beside 'Objects are created'- '30' represents the total items of the bi-cycle wheels to be manufactured. (Fig 7.3).
- 'Formed Rim' was typed beside 'Object type to Create'-This represents items name to be created (Fig.7.3).

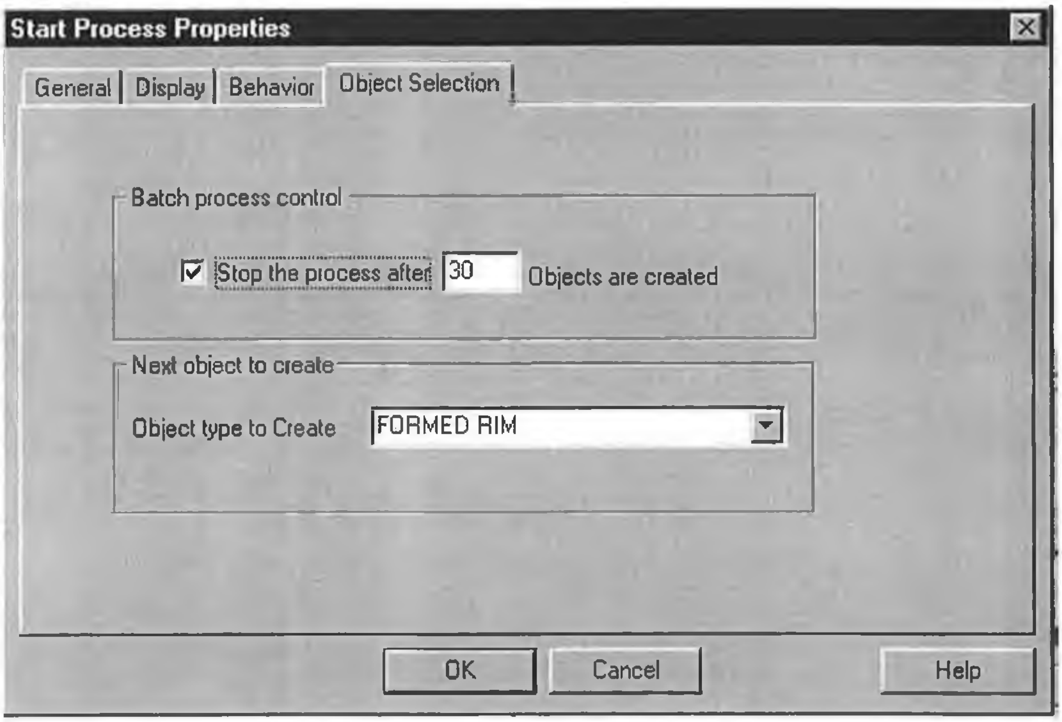


Fig. 7.3: Object Selection Dialog Under Start Process Properties.

7.2.2 Procedure for data input for Processes from Butt Welding to Packaging

As already shown in Fig.7.1, graphical processes for butt welding to packaging have been put on the screen and connected by connection lines.

The following procedure was followed for data input for each of the processes from Butt Welding to Packaging.

Butt Welding: In the process properties dialog of join process (Fig. 7.4 and Fig. 7.5) the following steps were used.

- Under behaviour dialog 'Next Object Selection' one to one connections were typed for all the processes (Fig.7.4).

- Under object selection (Fig. 7.5), beside 'object type to create' BUTT-WELDED RIM' is typed. Similarly for sizing, abrasive, punching, marking, polishing, electroplating beside object type to create 'SIZED RIM', 'ABRASIVED RIM', 'PUNCHED RIM','MARKED RIM', 'POLISHED RIM', 'ELECTROPLATED' were typed.

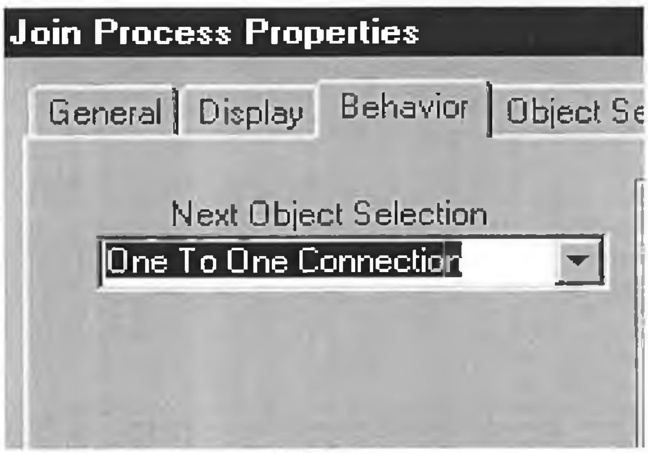


Fig. 7.4: Join Process Icon.

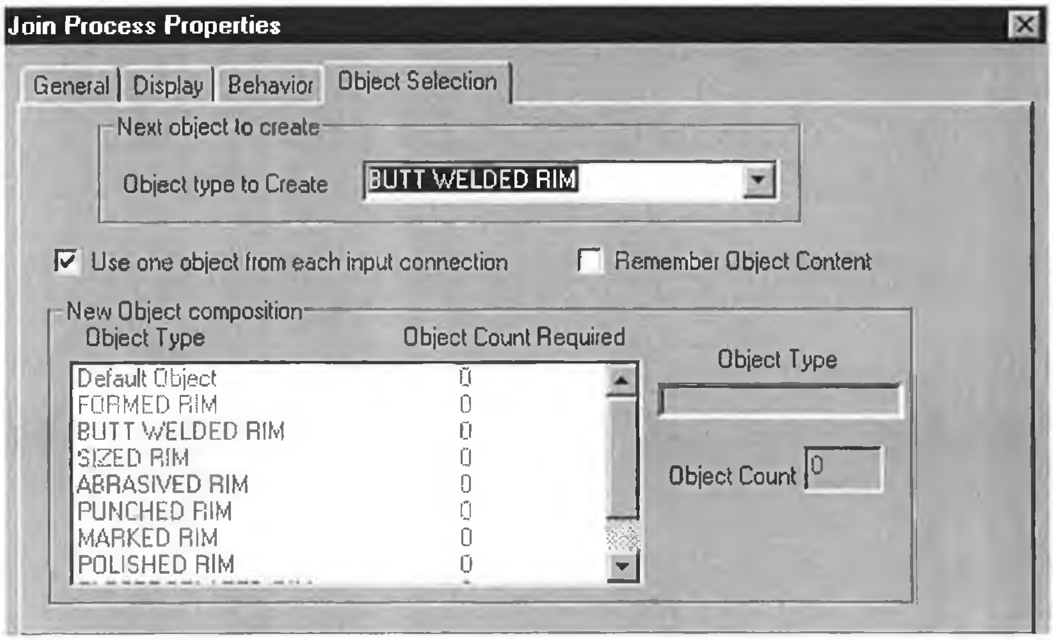


Fig 7.5: Object Selection Icon under Joining Process.

For example: In the case of Butt Welding Process, the joining process properties dialog icon (Fig 7.6) was filled in the following way.

- The value of 'Number of Station' as 1- represents one butt welding' process.
- The value of 'Percentage of Rework' as 0%- represent no percentage of items to be inserted in the process queue after the item processing is completed. This is used to simulate incomplete work to be completed or items not properly completed.
- The value of 'Initial Process Load' as '0'- represents the initial number of objects that the process will have when the simulation starts. Here process load is zero as the butt welding process has to get rim from the forming process which is the first process.

- The value of ' Process Set up Time' as '1'- represents the amount of time (minute) the process requires to initialise itself before it is ready to accept work
- The value of 'Minimum Time Spent' as '2'- represents the amount of time (minute) the process requires to initialise itself before it is ready to accept work.
- The value of 'Maximum Time Spent' as '3'- represents the amount of time (minute) the process requires to initialise itself before it is ready to accept work.
- The value of 'Total Objects in Process (Q+ Station)' as '1'- represents the maximum number of objects the process queue will store in addition to the number of stations. This number should be at least equal to the number of Stationed specified [77].

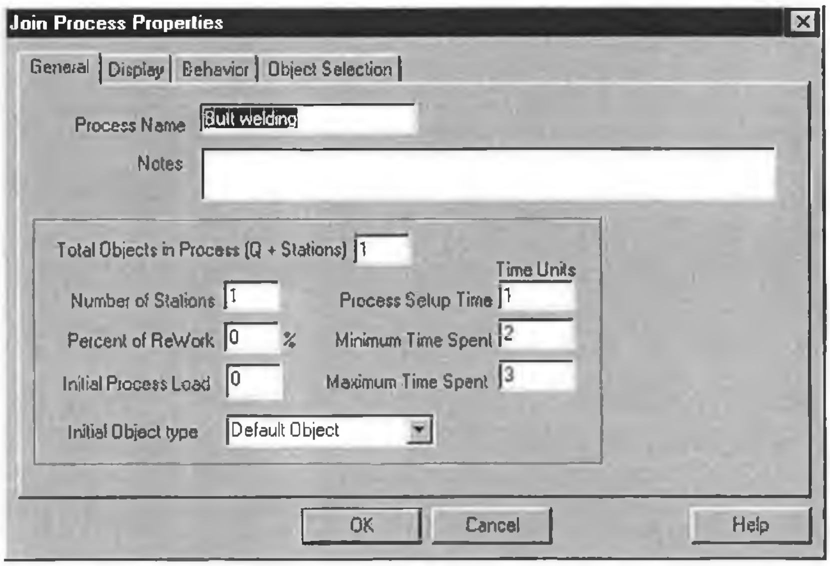


Fig. 7.6: Process General Properties Dialog Icon.

7.2.3 Connection Line Properties

The connection line tool is used to connect two processes and establish their inter- relationships.

The line between Forming and Butt-welding processes is clicked twice to get the line properties. Beside 'Object Transfer Time', the value 10 was typed. This mean that the object/product takes 10 times to be transferred from Forming to Butt-Welding. Also beside "Number of Simulation Objects" is 30 typed. This indicates that 30 objects/products moves simultaneously in that given time.

Table 7.2 shows the number of product transferred in a particular transfer time between Butt Welding and Sizing, Sizing and Abrasive, Abrasive and Punching, Punching and Marking, Marking and Electroplating, Electroplating and Packaging, and Packaging and Storage.

Table 7.2: The number of product transferred in a particular transfer time between processes.

Line connected between processes name	Transfer of number of simultaneous objects	Object transfer time (min)
Forming and Butt welding	30	10
Butt Welding and Sizing	30	10
Sizing and Abrasive	30	10
Abrasive and Punching	30	10
Punching and Marking	30	10
Marking and Polishing	30	10
Polishing and Electroplating	30	10
Electroplating and Packaging	30	10
Packaging and Storage	30	10

The aforesaid data were typed into the connection line properties (Fig.7.7) between the processes shown in Table 7.2.

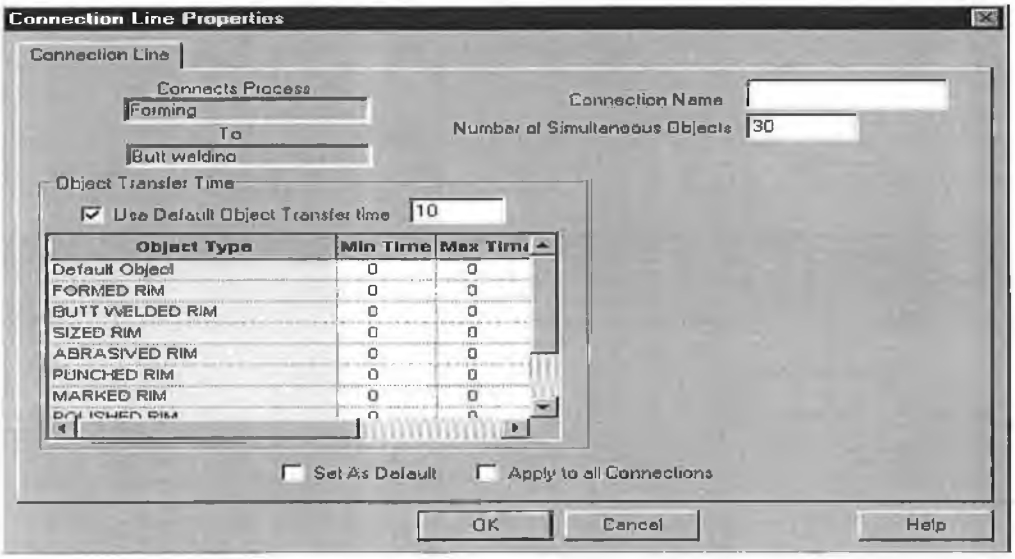


Fig. 7.7: Connection Line Properties Icon.

7.3 Simulation of the Process

This section is divided into two parts. The first part explains the overall simulation status and the selected process status. The second part discusses the simulation result.

Each window in SimCad contains a simulation status section through which simulation details are tracked. The simulation status consists of 2 main sections, The Overall Simulation Status, and the Selected Process Status.

The Simulation Status: The Overall Simulation status section is displayed on the left side of the status window 7.8(a) and contains information related to the overall simulation. The following entries are tracked.

Model Name: This displays the name of the model.

Model Status: This can be 'Stopped', 'Running' or 'Paused'.

Simulation Time: It is the simulation clock. Each time unit is represented by a single increment to the clock.

Number of Objects Created: It tracks all objects created during a simulation run.

Number of objects in Process: This is the total number of objects currently being processed in the simulation. The number includes all objects being transferred, waiting, or are active in processes, at the time status update.

Average Time Per Object: This is the average life time of an object in units. The number is computed by finding the average time an object spends in the simulation by dividing the number of objects completed by the simulation time.

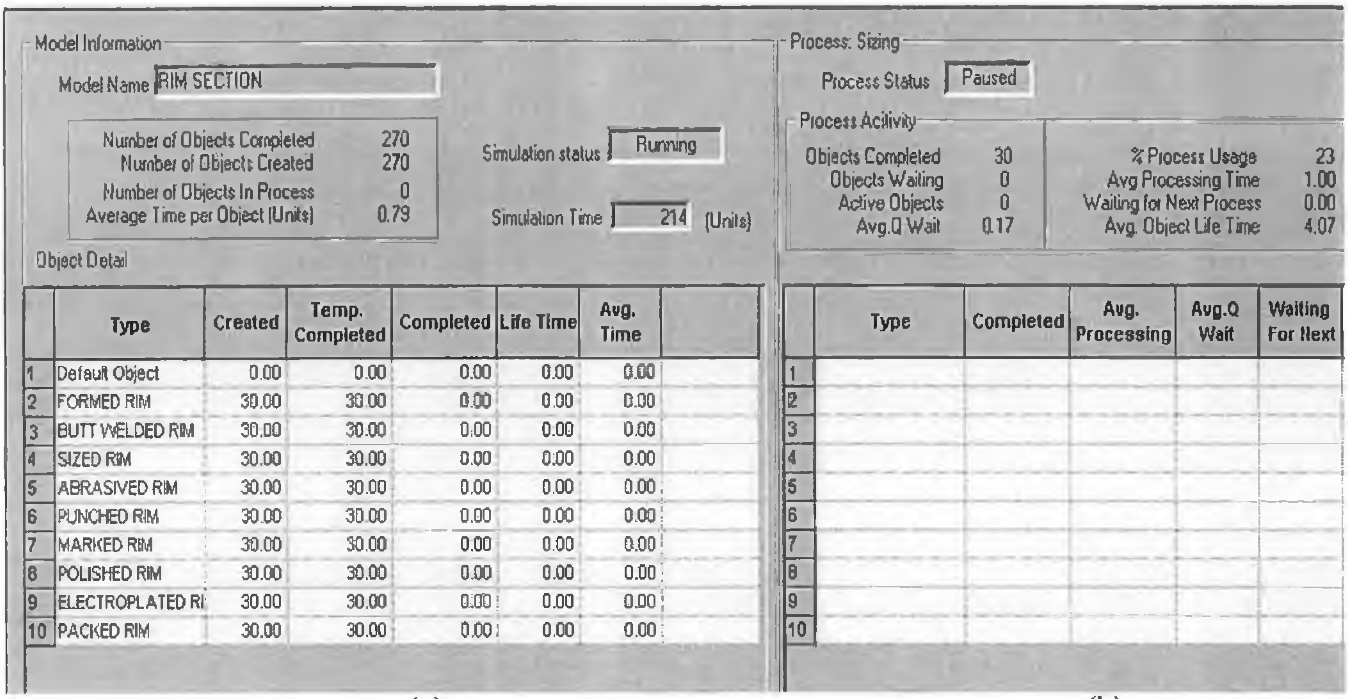
- For each object type in the model, the following information is displayed.
- The 'Object Type' consists of list of processes.
- 'Created' column consists of the number of particular objects created
- 'Temporary Completed' column consist of the number of temporary objects completed. This number consists of all objects that completed the simulation without reaching an End process.

The Selected Process Status: This window deals with a certain process as shown in Fig. 7.8(b). To examine a certain process status during a simulation run, just select the process by clicking on it using the left mouse.

The following is a list of status parameters displayed for the selected process.

- The '**Process Name'** is displayed at the top of the section.
- The **Process Status**, which may be one of the following, 'Started', 'Stopped', and 'Paused'.
- The '**Number of Objects'** completed by the process.

- The **'Number of Objects waiting'** in its Queue. Note that the join process only shows the number of objects, which can be processes by it after the join operation has been successful.
- The '**Number of Active Objects'** in the process, is the number of objects actively being processed. This number will not exceed the number of workstations capable of operating on objects.
- The '**Average Queue Wait Time'** is the average time an object spends in the process queue while waiting to be processed.
- The '**Percent Process Usage'** is the percent of time where the process is busy processing an object. This is equivalent to the process workload during the simulation.
- The '**Waiting for Next Object Lifetime'** is the average time an object, which passes through this process, with respect to the overall simulation.



(a) (b)

Fig 7.8 : The Simulation Status Window part is (a) and the Selected process status Window is (b).

7.4 Simulation Result and Discussion

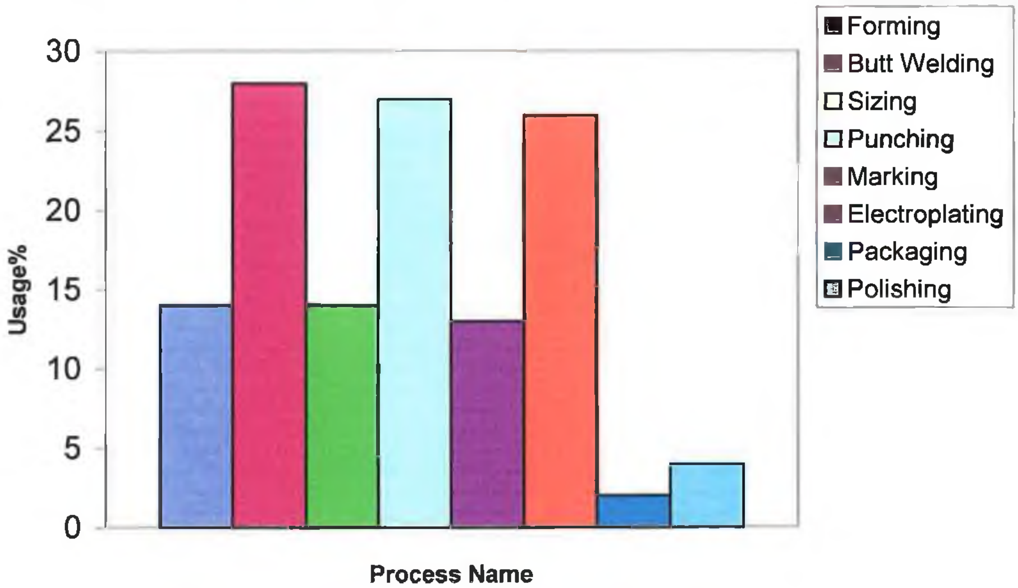


Fig 7.9: Percentage usage of different processes.

Fig. 7.1 shows a snapshot of the model during runtime. Objects arrive along the single headed arrival arrow and travel along routing lines from one activity to another. Fig 7.9 shows in the bar chart form the percentage usage of different processes. The left window, which is known as 'The Simulation Status' window gives the following results,

- Number of object completed is 270
- Number of Object created is 270
- Average Time Per Object (unit) is 0.78
- Simulation Time is 210 (units)

From the 'Selected Process Status' the following data is obtained as given in Table 7.3 for each process on the basis of 30 items of bicycle parts.

Table 7.3: Data for each process.

Process Name	Completed Product	Average Processing	Average Queuing Time	Waiting for Next Process (minute)
Forming	30	1	0.71	0.03
Butt Welding	30	2	0.77	2.83
Sizing	30	1	0.33	0.00
Abrasive	30	2	0.77	0.77
Punching	30	2	0.70	1.90
Marking	30	1	0.39	0
Polishing	30	0	0	0
Electroplating	30	0.63	0.63	2.07

Analysing the data from the Fig. 7.9, the percentage of usage can be arranged in the following manner.

- Butt Welding 28%
- Punching 27%
- Electroplating 26%
- Forming 14%
- Sizing 14%
- Marking 13%
- Polishing 4%
- Packaging 2%

It is seen from Table 7.3 that average queuing time for each process is less than 1. The waiting time for Next process for 'Butt Welding' is 2.83, for 'Electroplating' is 2.07, third is Punching (1.90), fourth is 'Abrasive' (0.77) and fifth is Forming (0.03).

From the 'Selected Process Status' the following data is obtained as given in Table 7.4 for each process on the basis of 60 items of bicycle parts after running the simulation.

Table 7.4: Data for each process on the basis of 60 items of bicycle parts.

Process Name	Completed	Average Processing	Average Q. Time	Waiting for Next Process	%Percentage Usage
Forming	60	1	0.782	0.00	44
Butt Welding	60	2	0.82	2.93	58
Sizing	60	1	0.32	0.00	29
Abrasive	60	2	0.53	0.70	47
Punching	60	2	0.80	1.95	42
Marking	60	1	0.45	0.00	20
Polishing	60	2.17	0.03	0.00	6
Electroplating	60	2.05	0.75	2.32	34

Analysing the data from the Fig. 7.9 and Table 7.4 for the percentage of usage can be arranged in the following manner.

Process Name	For 30 items	For 60 items
• Butt Welding	28%	58%
• Punching	27%	42%
• Electroplating	26%	34%
• Forming	14%	44%
• Sizing	14%	29%
• Marking	13%	20%
• Polishing	4%	6%
• Packaging	2%	5%

From the above chart it is seen that percentage usage of different processes differs for 30 and 60 items. For example for Butt welding process, the percentage usage of this process is 28% for 30 items and 58% for 60 items.

7.4 Conclusion

In this chapter step by step development of rim section, 2D simulation of the rim section has been described. Performance utilisation of different process stations for batch sizes of Simulation of 30 items and 60 items has been compared. Different data can be used for the simulation of the section in the same manner described in this chapter.

Chapter 8

CONCLUSION AND RECOMMENDATION FOR FUTURE WORKS

8.1 General Conclusion

Virtual factory modelling, layout analysis, simulation of virtual factory was carried out in this work. Two different types of factories were modelled in the virtual environment. Layout analysis technique was implemented in the virtual bi-cycle parts manufacturing factory. One Pentium PC with 64-MB memory was used in this project. 3D Studio MAX and Superscape VRT 5.5 packages were used for modelling, animation and simulation works in the project. Lastly, Process Modelling and Simulation Software SimCad was used to simulate the processes of bi-cycle parts manufacturing factory in 2D environment.

Summary findings from the research are presented as follows:

(i) The results were satisfactory, when the applicability of the 3D Studio MAX system was assessed for its user friendliness for the user to perform specific operations. The designer can build up a virtual factory just like constructing a miniature model of the real factory. A 3D model of a real bi-cycle parts manufacturing factory has been modelled using 3D Studio Max Software. Participants can navigate through the virtual factory and examine the virtual factory from different viewing points.

After visualising different sections of the factory using viewing points, it is considered that both the factory walkthrough and visualisation facilities are useful for 3D design and planning activities in virtual environment. The problem faced in using the 3D Studio MAX is that the user cannot control objects in the virtual environment. The user cannot move around, and interact with the simulated process. Simulation is done using animation time frame, which is preset. Walkthrough can be achieved by moving the Free Camera created from the icons only. This Free Camera can be operated smoothly in one direction using the predefined path. 3D solid modelling and animation based simulation can aid engineers in analysing the virtual factory layout with a view (i) to identify bottlenecks in the existing factory (ii) proper utilisation of space and other facilities by applying plant layout problem solving techniques.

Thus 3D solid modelling and animation based software technique provides a fast, effective method of visualising and experiencing new design which can be easily modified. The Designer can design and see different types of layout before making final decision to choose the best from them.

(ii) Secondly a simple toy factory, which makes a toy sports has been modelled using Desktop Virtual Reality System (Superscape VRT 5.5). The model factory model has been designed to visualise shop floor virtually and to test both the factory walkthrough and visualisation facilities.

It was found that the factory walkthrough and viewing point facilities of Superscape VRT 5.5 is better than that of 3D Studio MAX. Participants can navigate freely through the virtual factory using Superscape VRT 5.5 mouse whereas for the case of 3D Studio MAX, participants can not navigate freely through the virtual factory using the mouse. In Superscape VRT 5.5, grouping objects was very important for effective sorting and rendering purpose. In the

World Editor, object size was modified from their actual size in order to be assembly correctly.

The developed virtual factory has a number of benefits for the first time user.

- It offers a unique learning experience, which helps retain the participants attention better than seeing 2D views of a factory.
- The plant engineers can have a 3D view of the factory and can interact with different sections of the factory (i.e. virtual walkthrough).
- Similarly, a customer can have a 3D view of the product and can interact with the product (i.e. look around the product to have an overall idea of the product).
- Space allocation, working area and safety can be assessed before any change is made in the real factory.

There were some limitations when creating shapes in virtual environment using Superscape VRT 5.5 which are listed as the following:

- To create an object from scratch requires one to define points first. Then points are joined and they must be of the correct order to form facets. Therefore, it is quite time consuming to create a complex product presentation.

- The system does not have Boolean operation (i.e add, subtract etc.) like 3D Studio MAX. Some shapes were created in 3D Studio MAX and then were transferred to AutoCAD file as DXF and again transferred to Superscape VRT 5.5 through converter. Converting DXF files to VRT involved a great deal of calculation and processing, as the DXF file did not contain much of the specific information required by VRT. The missing information must be generated by the converter and only be obtained by calculated guesswork. Therefore, it is recommended for use on single objects, which then are assembled using the VRT editors.

- Overlapping of bounding cubes also creates rendering problems in Object Model.
- Producing a visually complex and detailed virtual world requires more computing power than that needed to create simple cubes.
- Several complex objects in the virtual world would slowdown the walkthrough. It is advisable to have simple objects and fewer objects. The faster the screen updates (typically 5 to 25 times per second), the smoother and more compelling the viewers experience. The factors that contribute to this are PC processor type and speed, screen resolution, window size, and the complexity of the 3D world. Computer processor power is increasing everyday and it is envisaged that desktop Virtual Reality will benefit from this processor power which will be available in the near future. Today's computer technology is evolving fast. A $6,000 desktop computer will now outperform a $300,00 minicomputer from the late 1980s [29].

- Therefore, the problems which will have to be overcome in the future in order to model product or factory in virtual environment are:
- More computer power is necessary i.e. higher rate of renderings per second.
- The simulation process must appear to be seamless in its movement and not 'jumpy'.

The opinion of the author is that the advantages conferred in utilising such a system far outweigh the disadvantages. This application showed that the design of an industrial product system for viewing and assembling in a virtual world can shorten the product system development time. Superscape VRT is one of the most popular VR software packages available in the marketplace today. The developed application can be viewed on most computers with an additional software package named Viscape. This application is inexpensive, making the end product viewable to many organisation, whatever their budget.

(iii) Lastly the Process Modelling and Simulation software SimCad has been used by applying CIM (Computer Intregated Manufacture) concept to the bi-cycle manufacturing factory and the processes were simulated. The simulated results been analysed for comparison of percentage utilisation of process stations for 30 and 60 items.SimCad can be very helpful to those new to simulation. Different data can be used to see the percentage usage of different process.

8.2 Thesis Contribution

In this research, using Virtual Reality software and Process simulation sofware SimCad, the followings have been developed.

- It has been possible to simulate a real factory using general facilities of 3D Studio MAX.
- After implementation of the aisle and the CRAFT (Computerised Reallocation of Facilities Techniques) concept, optimum layout has been achieved which has increased total productivity of the factory in terms of (i) by shortening material handling distance(ii) allocation of more space for setting up new production machineries.

- Visualisation effect of Virtual Reality has been applied in Plant layout analysis to give better feel to the change of layout.
- Using Superscape VRT 5.5 it has been possible to test the real time interaction by free movement through the factory model which was not possible for the participant to move freely through the model factory using 3D Studio MAX.

  This has been possible due to control programme developed by using Superscape Control Language (SCL).
- Using SimCad a section of the bi-cycle parts manufacturing factory has been simulated to evaluate the performance utilisation of different process stations for batch sizes of 30 and 60.

8.3 Recommendation for Future Work

Virtual Reality has great potential in the industrial sector.

The following enhancements should also be carried out:

- The participants could use data gloves for picking and placing purpose in the virtual factory.

- Adding sound to the virtual world could further enhance its realism, the users could generate the deep sense of feeling of immersion in the virtual environment, hence in believing that were actually in the real world.

- A Head Mounted Device(HMD) can be added with the existing desktop system for finding out the effect of different users in Cyberspace.

- Development of Internet based virtual factories for online distance learning and training.

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Appendix A

Basic Construction of Virtual Reality

This appendix describes the basic construction of Virtual Reality IN Superscape VRT 5.5.

Basic Construction of VR

The Editors: VRT contains seven editors, which could be used to create a virtual world and control it the way the end-user is interested. The Shape Editor and the World Editor are the most important editors, in which the shape and objects are created to make up the world. The Image Editor and the Sound Editor are used to import and create pictures, textures and sounds to enhance the appearance of the world. The keyboard Editor is to provide additional information and interaction for the user.

Visualiser: The Visualiser is an application that enables the user to display and interact with the virtual world that is created using the VRT editors. All basic movements and interactions with the world could be made from the desk mouse, space mouse or keyboard.

Superscape Control Language (SCL): It is similar to C based programming language that allows the user to attach a vast range of conditional attributes to an object. These include a high level of 'Intelligence' so that they react and inter-react with the end-user and other objects in the world.

Data Converter: The Data converter included in VRT is for importing and exporting data files from many other applications. VRT includes a module for importing data in popular DXF format, as used in many CAD packages.

Objects in Superscape's

VRT can be given a range of dynamic features that mimic the dynamics of objects in the real world. They include gravity, fuel, climbing, falling, friction, restitution, driving velocity, maximum velocity, angular velocity and whether an object can be pushed or not. Time can be defined in terms of absolute time, or based upon the scene update[64].

Gravity: Gravity is entered as units which alter an object's Y velocity at a rate of g per frame^2 downwards (where g is the acceleration due to gravity), thus accelerating the object towards the ground.

Fuel: Fuel is an attribute that can control an object's behaviour. For example, using Superscape's control language SCL, an object's fuel attribute can be used to determine the intensity of a light source, or the velocity of an object.

Climbing: The Climbing attribute specifies how an obstacle is allowed to be before a Collision occurs and restitution is applied. An object, for example, may be moving in a straight line on a horizontal surface. If it has a climbing value of 20 and meets an obstacle on the same surface which is only 10 units high, then the moving object will rise 10 units over the obstacle and continue with none of its velocity values changed. If the object hits any obstacle that rises more than 20 units above the surface, then this is interpreted as a collision.

Falling: The falling attribute specifies the maximum distance that an object can fall without it being 'damaged'. If an object falls by a distance greater than that specified by the falling value, then it is stopped and flagged as having fallen 'too far'. This can be accessed with the control language SCL.

Friction: In VR, friction is an attribute of a moving object rather than of the virtual surfaces, it moves over, and it is expressed as the percentage reduction in the object's external velocity per frame on the horizontal plane.

Restitution: Restitution is associated with collisions between objects. Basically, when objects collide, their velocity is changed. When hitting a wall, for example, a car will come to a halt, but a ball will bounce off. The amount of 'bounce' in a collision is measured by the restitution attribute. Superscape's VRT permit an object to be given in horizontal and vertical restitution attributes. When an object hits a surface, the object's current velocity is multiplied by the restitution, and the direction of the velocity is reserved.

Driving Velocity: The driving velocity is a constant assigned to objects as they move about the VE. It is unaltered by friction, and is associated with one or a combination of the X-, Y- or -Z directions.

External Velocity: An object's external velocity is acquired through the external events such as collisions with other objects.

Maximum Velocity: The maximum velocity parameter restricts the velocity of an object to some upper limit.

Angular Velocity: The angular velocity updates an object's rotation attribute and turns the object through a given angle in every frame.

Pushable: The Pushable attribute allows an object to respond to collisions with other objects. Thus, walls, floors and ceiling would have this attribute switched off.

Apart from the above physical attributes, Superscape's VRT includes facilities for animations, bending, viewpoints and paths.

Animation: Preparing a sequence of states that show the object in different states animates an object. At run time, these are activated at a specified rate, resulting in a smooth animation. Sequence can consist of a linear pass, a cycle repeat, a bounce (the animation runs forwards and then backwards), include pauses and combinations of all the modes.

Bending: Bending, like animation, alters the position of vertices in an object, which in turn changes the position of facets. The bend is made about an existing point, and is effected by selecting a collection of points in the object and specifying a bend angle.

This is shown in figure A1 part (a) shows the initial position of a shape; (b) shows how a group of vertices are rotated; and part (c) shows how a second bend is introduced.

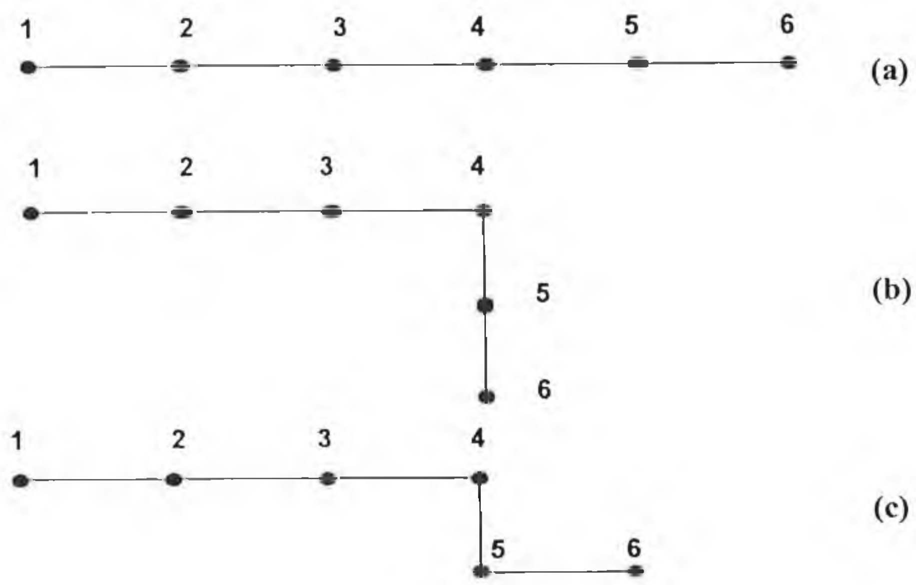


Fig. A1:An object can be bent about one of its vertices to create new shapes. (a) The original object.(b)Bending part of the object about vertex 4. (c) Bending part of the object about vertex 5.

Viewpoints: As the Virtual Reality observer is treated as an object in the virtual Environment and controls the viewpoint, it is a simple process to attach the viewpoint to any object. For example, a Virtual Environment might have one viewpoint attached to a car to control the movement of the car. This can be steered using a spaceball, while the viewpoint provides a view as seen from the driver's seat. Other viewpoints can be established external to the car that are either moving with the car or stationery.

Viewpoint path: A viewpoint can be moved through a Virtual Environment along predefined path. The path is a closed loop, defined by a few set positions of key frames. The viewpoint moves between the key frames at a speed set by the number of frames between them. At the end of the sequence, control returns to the beginning. Each key frame can define the position of the viewpoint, its rotation, or both. There are several different options for each of these. Positions may move along a straight line between key frames or they may follow a smooth curve through them. Rotation may be set relative to the rotation of the object, to which the viewpoint is attached, targeted to look at another object, or looking forward along a defined path.

In order to create a realistic virtual world, VRT offers the following suite of editors:

Word Editor: Virtual Worlds are built using the World Editor from simple objects (Cubes) whose profile is defined by the shapes that are created in the shape editor or imported using Virtual Clip Art (VCA) objects. A library of VCA objects are available in VRT. Many of these objects have SCL attributes. Objected created could be placed, grouped together, re-sized and coloured within the virtual world. Details are given in the Superscape VRT 5.5 guide book.

Shape Editor: The shape editor permits the designer to create three-dimensional shapes using points and facets, which are used to give a profile of the object to be used in the virtual world.

An object is called 'Shape' in the Shape Editor. A shape consists of combined facet, and point information is contained inside the bounding cube. Defining points in three-dimensional space within bounding cubes are first created. These points are connected together to form facets, which then are grouped together to create shapes.

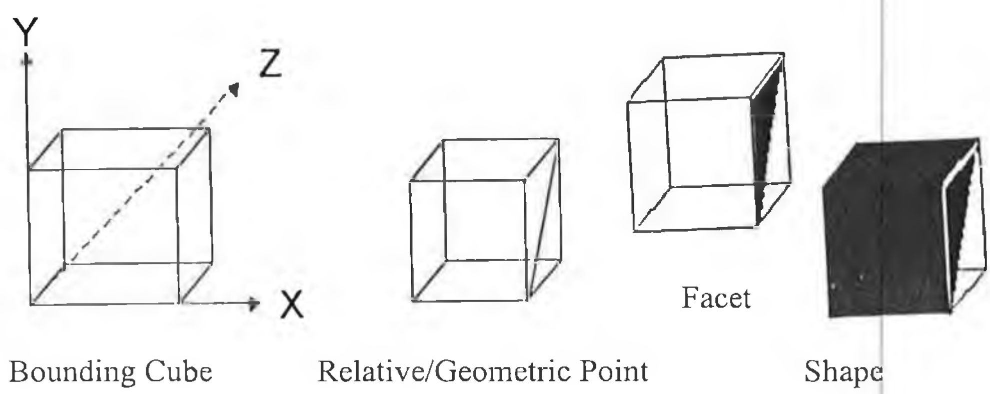
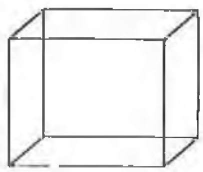


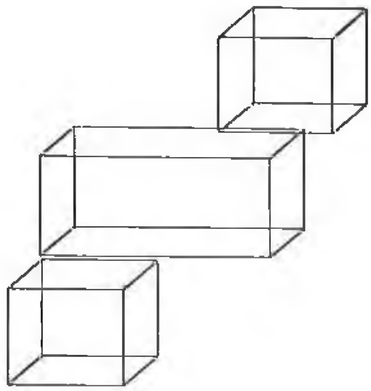
Fig.A2: Points and Facets Grouped together.

The bounding cube is an invisible cube, outlined with x, y and z-axis in the Shape Editor, used by VRT to sort objects within the world. In the virtual world, VRT orders objects, created from shapes, by position of their bounding cubes. Therefore, to create convincing contacts between objects it is important that a shape's bounding cube x, y and z proportions should match the outer edges of a shape whenever possible and that all points and facets are within this cube.

Generally the shape Editor is used mainly to create complex shapes. All points and facets created are within the bounding cube regardless of the complexity of the shapes. Simple shapes, which have an appearance of cubes, are not normally created with this method. Instead, they are created in World Editor by selecting the default shape-cube, then are re-set to the required attributes.



Default Shape cube



Duplicate, Resize, Rotate,&Reposition

Fig.A3: Duplicate, Resize, Rotate, and Reposition Shapes.

Facets are surfaces created by connecting points together. However, facets containing concave areas is not legal facets and should be avoided as they create rendering difficulties. T-shape facet say, with concavity should be built up from several facets, i.e to make a 'T' from a single vertical facet and a single horizontal facet.

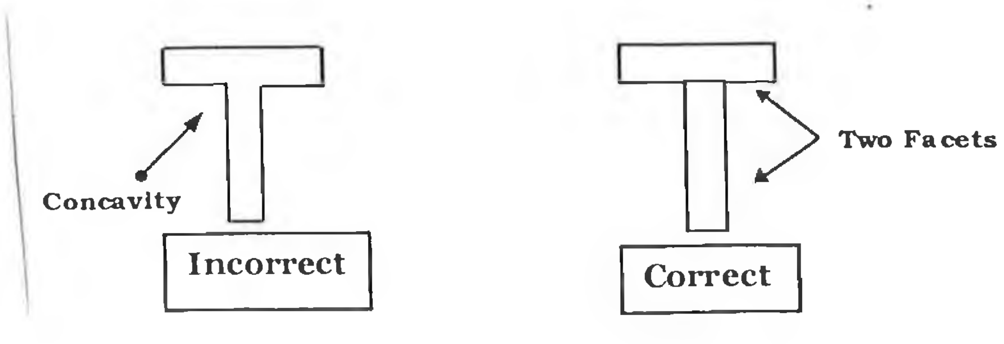


Fig. A4: Correct and Incorrect Facets.

The order of facets within a shape is important in producing a convincing shape. Facets at the back of shape must be rendered first so that they do not obscure facets at the front of the shape. Sometimes it is unavailable to produce shapes that could not be rendered correctly from all angles. Therefore, reordering these facets is necessary which could be done through the facet editor. For instance in Fig. A5, if facet 'A' obscures facet 'B' it is moved on the top of the facet 'B' and so on. Sometimes trial and error is the only possible way.

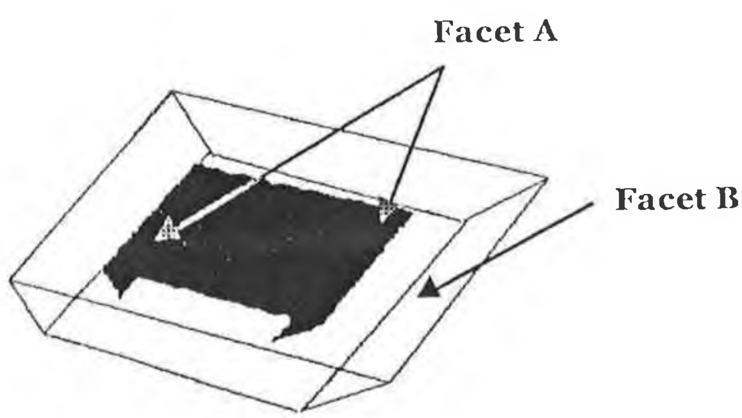


Fig. A5: Two facets obscure each other.

Image Editor: The image editor permits the word editor to design and edit.

images, which may be applied as textures to the objects. With the image editor,

I can draw, rescale, crop and edit each image pixel by pixel.

Layout Editor: The Layout Editor permits the designer to customise the Visualiser screen. Multiple windows can be added to let the end user have an array of viewpoints of the world.

Sound Editor: The sound Editor, in conjunction with the end users sound card (option), allows the designer to record, play, import and modify sounds. The sounds are represented as sound waves.

Keyboard Editor: All the keys on the keyboard have been assigned default settings, which may suit the end user.

Resource Editor: This Editor is used for creating dialog boxes and menus. This lets the designer tell the end user specific details, which may be difficult to translate using the standard interface. VRT stores all information relating to objects in the world in a mathematical description rather than as a picture, thus enabling the complete world to be stored, as a small amount of computer data. Invisible bounding cubes are used in VRT in much the same as blocked in AutoCAD. These enable objects to be ordered correctly in the world, and henceforth simply moving the bounding cubes can move a series of objects. Facets are used which gives the effect of a surface between points. Facets are one dimensional or two-dimensional surface created by connecting two or more points together. These points are first created in a virtual space and the facets are then created using the points. The invisible bounding cube will then be created around the complete set of facets.

Table A1 shows the differences between Auto CAD and Superscape VRT 5.5.

AutoCAD	Superscape VRT 5.5
A Shape consists of lines not Facets or bounding Cubes.	A shape consists of Facets, which can be created from points. Shapes can be created within its bounding Cube.
In AutoCAD, object created could be positioned directly within the viewing area.	In Superscape VRT 5.5, shape created must be stored in shape file and used in W.E to create objects.
In Auto CAD, only one colour is applicable to the boundary of one object.	Different colour could be applied to the facets of the same shape.
Only static parts could be created.	Static and Dynamic parts could be created.
Object of any shape could be mirrored or rotated to any angle required and directly positioned within viewing area.	Shape must be duplicated, transformed or rotated, then merged with previous shape to form a complete shape. Only quarter and half shape could be done in this way.
An object could be positioned on the other object accurately by using the assist command such as Intersect, or mid point etc.	In Superscape VRT 5.5, position must be calculated before an object can be placed to another object.
In AutoCAD overlapping objects have no effect on performance.	Object overlapped could cause sorting and rendering problems.
Object dimension could be very accurate	All fractional unit values need to be rounded up.
No grouping of objects.	Objects must be grouped for effective sorting.

Appendix B

Manual of 3D Studio MAX

This appendix shows the application of 3D Studio MAX object creating tool for generating and operating virtual objects.

Object Creating Tools

Creating and Modelling Tools: Creation and modelling tools (Fig.B1) were used to create factory walls, machines and furniture and then were positioned in 3D space. Under the creation and modelling tools, there are two ways to create objects as follows: 2 dimensional and 3 dimensional. Under 3D shape box, cylinder and tubes and under 2D shape line, circle, arc, rectangle were used to generate different objects in the virtual factory. Also Boolean tool bars (Fig.B1) was used for subtracting or adding the geometry of two or more objects.

Example: Creating a Cylinder

To create a cylinder:

1. Start a new session of 3D Studio MAX. If the program is running , reset it with File/Reset and go to the Create Command panel. The create command panel appears with the Geometric button highlighted.
2. In the drop list below the Geometric button, make sure that Standard Primitives is chosen. While Standard Primitive is chosen, several buttons appear in the Object Type rollout, including Cylinder, Box, and Sphere. All these buttons create geometric primitive objects in much the same way.
3. Click Cylinder.
4. In the perspective viewpoint, press and hold down on the mouse button. The point which is pressed defines the centre of the cylinder's base.
5. Drag the mouse.

6. This defines the radius of the cylinder.
7. Release the mouse button and move the mouse upward. This defines the length of the cylinder.
8. Click once to set the length.

This completes the cylinder. Similarly the length and the radius of the aforesaid cylinder can be adjusted using the cylinder parameter menu.

Select and Move Buttons: Select and Move buttons are used to make and move links between objects. For example, walls are generated using 3D box buttons by putting the dimension values.

Creating Architectural Walkthrough

Having a camera to follow a path is a common way to create architectural walkthrough, roller coaster rides, and so on.

Moving a camera along a path: If the camera must bank or tilt close to the vertical (as on a roller coaster), use a free camera. Assign the path controller directly to the camera object. The camera follows the path and one can adjust its point of view by adding Pans or rotate transforms. This is comparable to filming with a hand-held camera.

The 3D Studio MAX software has two types of cameras as follows:

(i) Free Camera.

(ii) Target Camera.

Both the cameras are under a camera icon (Fig. B1). If the camera icon is pressed those two camera icons appears hiding the former.

Free Camera: This camera views the area in the direction the camera is aimed . Free camera button was clicked using the mouse and dragged into top view for positioning. Free cameras are easier to use when the camera's position is animated along the path. Free camera has been used to animate along the path to visualise factory.

Target Camera: This camera views the area around a target object one creates when the camera is created. Target camera s are easier to use when the camera does not move along a path while rendering the scene or animation. These cameras have been used on static objects like machines and tables and so on. Target camera button was clicked using the mouse and dragged into the top view for positioning.

Viewpoints: The four large windows that take up most of the screen are the viewpoint (Fig. B1). One use viewpoints to look at one's scene from different angles, using various display methods and arrangements. At the lower right, is the perspective view that shows the scene from any angle. The remaining viewpoints are currently set to orthographic views, which means that you see the scene directly along one of the X,Y and Z world axes, from the front ,top, left, and so on. These viewpoints have been used to generate objects.

Viewpoints Navigation Controls: Viewpoints are navigated by the controls in the lower right of the 3D Studio MAX screen (Fig. B1) to navigate the viewpoints. These controls alter the view of the scene, but not the objects in the scene. Viewpoints navigation controls have been used to generate objects.

Animation Tool: 3D Studio MAX is a time-based animation program. 3D Studio MAX measures time, and store animation values, at 1/4800 of a second. Fig. B1 shows animation button tool.

To begin animating an object:

a. Turn on the animation button.

b. Drag the time slider to a time other than 0.

c. To animate a cylinder.

To animate a cylinder, the steps are given as follows:

The animation button has to be turned on frame 20 and the cylinder is rotated 90 degrees about its Y axis. Then rotate keys are created at frame 0 and 20. The key at frame 0 stores the original orientation of the cylinder, while the key at frame 20 stores the animated rotation of 90 degrees. Now play the animation, the cylinder rotates 90 degrees about its Y axis over 20 frames.

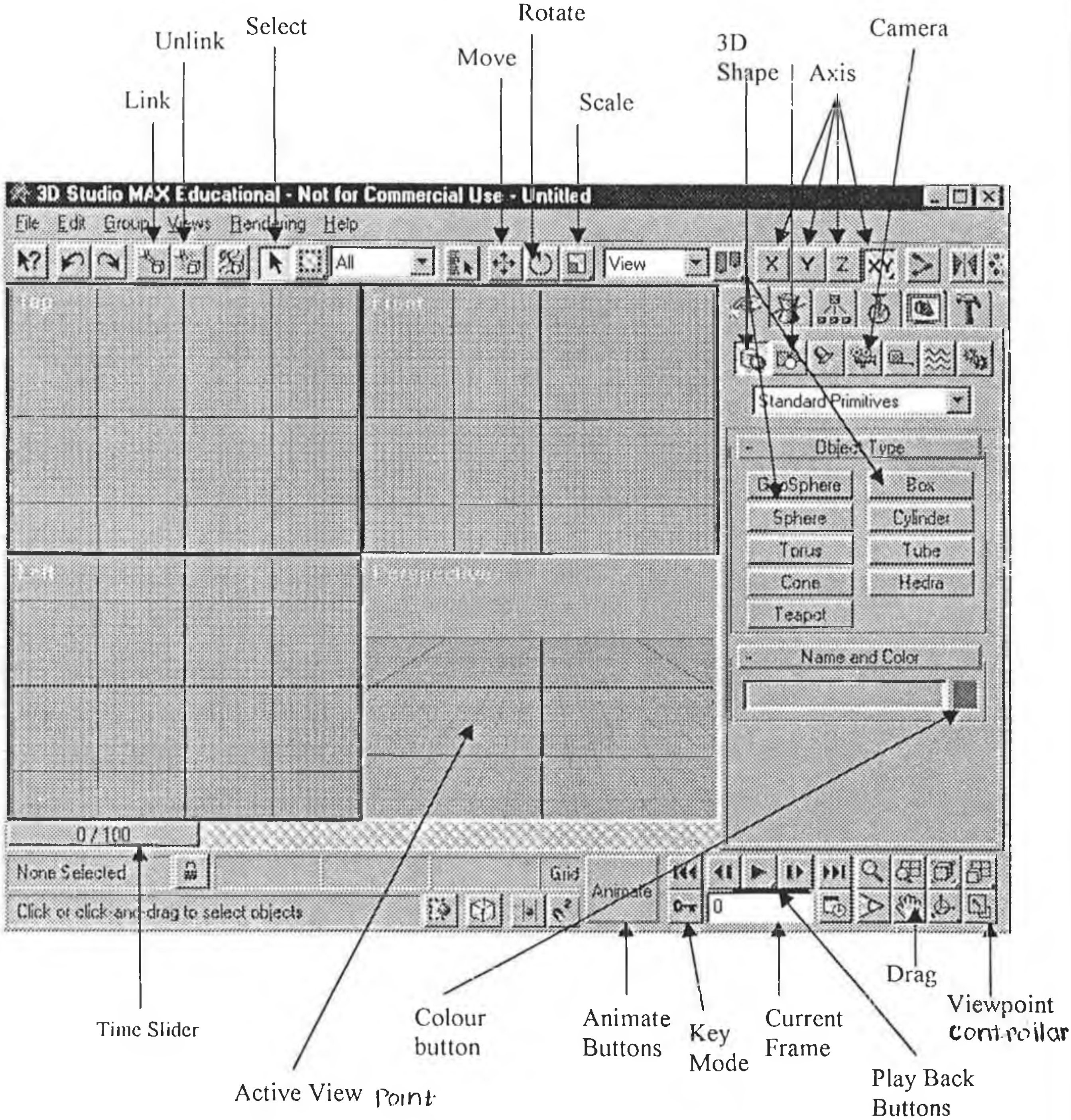


Fig. : Different Tool Buttons of 3D Studio MAX.

Appendix C

Manual of Superscape Vrt 5.5

This appendix shows the steps and commands used to create shapes in the World Editor and in the Shape Editor for this project. Shapes, which have the appearance of a cube, would be created in World Editor (Fig.C1). The srtructure of the factory building was built using the World Editor. Also Position and Size icons were used for building the walls and cube objects (Fig. C2).

Position and Size dialog box : The Position and Size dialog box lest re-position and re-size an object in realtime. One can see the changes as they are made. Once the dialog box (Fig. C2) is displayed, one can move around the world using the keyboard and select any object and apply the functionto it. One needs need to exit the dialog box when another functuion is to be used. Fig.C3 shows the creation of a four legged table from cubes and the procedure using the World Editor.

To set up a simple viewpoints: To create and edit viewpoints in the World Editor using Views>Viewpoints, and Visualiser or Viscape using Setting>Viewpoints.

There are 10 viewpoints in the World Editor. The steps are given below to set up a simple viewpoint.

1. Move to the position to be used as the viewpoint.
2 Choose View>Viewpoints. The values for the last selected viewpoint are displayed (Fig. C4).
3. Click Next or Ptrevious to go to an unused viewpoint number(Fig.C4).
4. Click the Attached To Select button, and select the object to which you want to attach the viewpoint (Fig. C4).
5. -1 is displayed in the Controlled box by default, indicating that the viewpoint is not attached to a controllable object (Fig. C4).
6. Click on the Number Select button, and select a proportional control type from the displayed (Fig.C4).

SUPERSCAPE VRT - QUICK REFERENCE CARD - WORLD EDITOR

Repeat	Function	Shortcut	Icon	Shortcut	Function	Repeat
	Look at Object				Select Object	
	Select Child	CTRL+DN ARROW		CTRL+UP ARROW	Select Parent	
	Select Next Sibling	CTRL+RT ARROW		CTRL+LFT ARROW	Select Previous Sibling	
R S	Create Object	CTRL+N		CTRL+D	Duplicate Object	R S
R	Delete Object	DEL		CTRL+R	Rename Object	R
	Clone Object				Load VCA Object	
R S	Select and Drag			CTRL+P	Position and Size	
R	Initial Position	SHIFT+P		CTRL+ENTER	Standard Attributes	R
R	Dynamics			SHIFT+R	Rotate Object	R
R	Flags	CTRL+F		SHIFT+S	Edit SCL	R
R	Set Shape Type			SHIFT+F	Color Facets	
	Grid Settings				Grid Snap On/Off	
	Plan View	CTRL+2		CTRL+1	Perspective View	
	Play			SHIFT+G	Show Group Objects	
	Object Dragging Mode On/Off				Manipulate Texture	
	Context Help	SHIFT+F1			Reference Books	

Fig.C1: Shows the main icons available in World Editor.

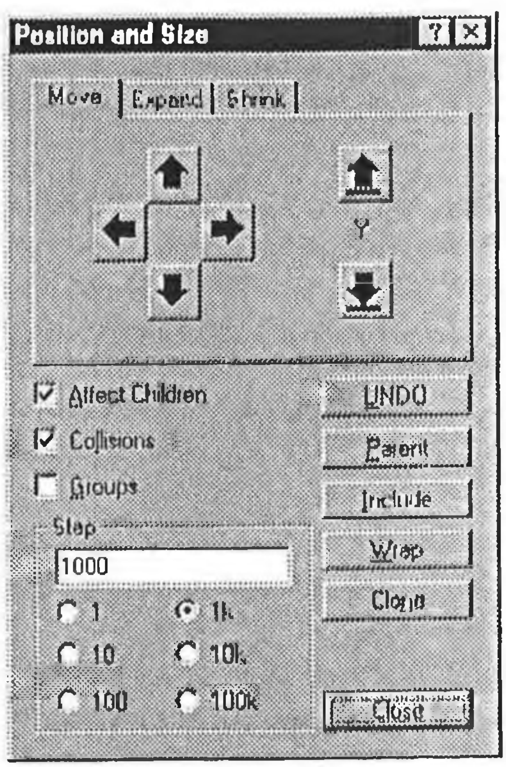
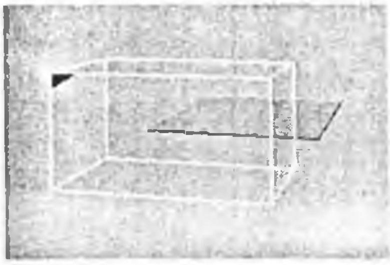


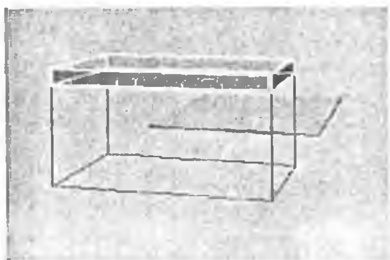
Fig.C2: Shows the Position and Size Dialog.

Creating a four legged table from cubes

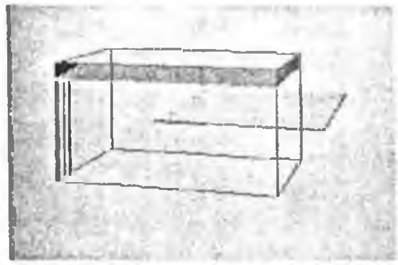
Create a group object that is the correct length, width and height. This will be the holding object. Its bounding cube defines the space that the table occupies in the world.



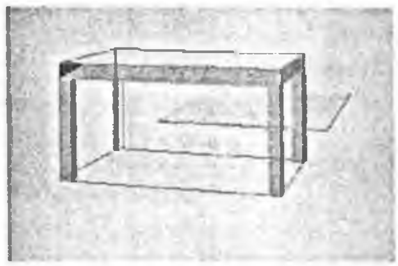
Create an identical object in the same position using Object>Clone, change its shape to a cube, and then shrink it to make the table top.



Clone the table top and change its size to form a table leg, which you can easily position in the corner of the holding group using the grips or collision detection option in Position>Size.



Clone the table leg object three times to create the other legs and position them in each corner. Then select the holding group (the first object you created) and use Object>Grouping>Group All Enclosed Objects to make the table top and legs the children of the group—moving the holding object moves all its children.



You now have the elementary definition of a table, that consists of a holding group which has five children which are siblings of each other. Moving the parent object will move all its children, so you can now reposition it as necessary.

Fig.C3 : Shows the creation of a four legged table from cubes with the procedure

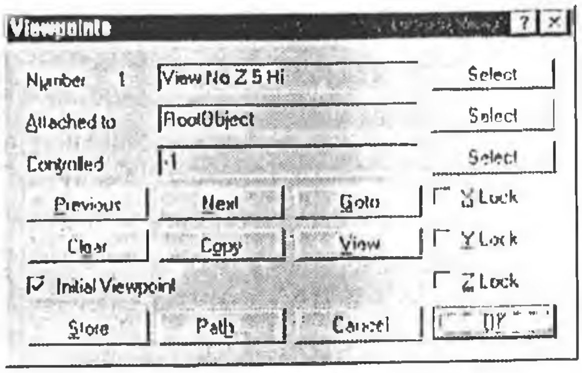


Fig.C4: Shows the Viewpoint Dialog Box:

Appendix D

SCL of Machine And Buttons

```
resume (1, 1);
if (first)
  invis ('Sports hold');
if (activate (me, 0))
{
  alert ("Starting machine process.", 0);

  /*** Check to see if conveyors are moving. ***/
  if (animode ('CONVEYOR:Belt ', 1)==0 && animode
      ('CONVEYOR:Belt [12]', 1)==0)
  {
    animode ('CONVEYOR:Belt ', 1)=1;
    animode ('CONVEYOR:Belt [12]', 1)=1;

  /*** Turn the robot arm to fill. ***/
  }
  repeat (18)
  {
    yrot ('TopGroup')-=5;
    waitf;
  }
  waitfs (5);

  /*** Fill up the moulding box with fluid. ***/
  do
  {
    ysize ('MouldingFluid')+=250;
    waitfs (4);
  }
  until (ysize ('MouldingFluid')==6291);
  waitfs (20);

  /*** Turn the robot arm back to start position. ***/
  repeat (18)
  {
    yrot ('TopGroup')+=5;
    waitf;
  }
  waitfs (5);


  /*** Now empty it. ***/
  do
  {
    ysize ('MouldingFluid')-=250;
    waitfs (4);
  }
  until (ysize ('MouldingFluid')==291);
  waitfs (10);

  /*** Open the flap to let the object out. ***/
  repeat (18)
  {
    xrot ('Door')-=5;
    waitf;
  }
  vis ('Sports hold');
  waitfs (10);

  /*** Move the created object onto the conveyor belt. ***/
  repeat (10)
  {
    zpos ('Sports hold')-=600;
    waitf;
  }
  waitfs (10);
```

```
    /*** Close the flap for completness. ***/
    repeat (18)
    {
      xrot ('Door')+=5;
      waitf;
    }
    waitfs (50);

    /*** Open the corner flap. ***/
    repeat (18)
    {
      zrot ('CornerFlap')+=5;
      waitf;
    }
    waitfs (60);

    /*** Close the flap for completeness. ***/
    repeat (18)
    {
      zrot ('CornerFlap')-=5;
      waitf;
    }
}
```

```
resume (1, 1);
if (first)
  invis ('Sports hold');
if (activate (me, 0))
{
  alert ("Starting machine process.", 0);

  /*** Check to see if conveyors are moving. ***/
  if (animode ('CONVEYOR:Belt ', 1)==0 && animode
      ('CONVEYOR:Belt [12]', 1)==0)
  {
    animode ('CONVEYOR:Belt ', 1)=1;
    animode ('CONVEYOR:Belt [12]', 1)=1;

  /*** Turn the robot arm to fill. ***/
  }
  repeat (18)
  {
    yrot ('TopGroup')-=5;
    waitf;
  }
  waitfs (5);

  /*** Fill up the moulding box with fluid. ***/
  do
  {
    ysize ('MouldingFluid')+=250;
    waitfs (4);
  }
  until (ysize ('MouldingFluid')==6291);
  waitfs (20);

  /*** Turn the robot arm back to start position. ***/
  repeat (18)
  {
    yrot ('TopGroup')+=5;
    waitf;
  }
  waitfs (5);


  /*** Now empty it. ***/
  do
  {
    ysize ('MouldingFluid')-=250;
    waitfs (4);
  }
  until (ysize ('MouldingFluid')==291);
  waitfs (10);

  /*** Open the flap to let the object out. ***/
  repeat (18)
  {
    xrot ('Door')-=5;
    waitf;
  }
  vis ('Sports hold');
  waitfs (10);

  /*** Move the created object onto the conveyor belt. ***/
  repeat (10)
  {
    zpos ('Sports hold')-=600;
    waitf;
  }
  waitfs (10);
```

```
  /*** Close the flap for completness. ***/
  repeat (18)
  {
    xrot ('Door')+=5;
    waitf;
  }
  waitfs (50);

  /*** Open the corner flap. ***/
  repeat (18)
  {
    zrot ('CornerFlap')+=5;
    waitf;
  }
  waitfs (60);

  /*** Close the flap for completeness. ***/
  repeat (18)
  {
    zrot ('CornerFlap')-=5;
    waitf;
  }
}
```

Appendix E
Operating Manual

Operating Instruction For Beginners To Operate Virtual Factory

1. Start the computer.
2. Logging into Netware icon will appear.
3. Type iqbalM beside "Name" and type BBBBB beside password.
4. Click OK.
5. Many icons will appear on the computer screen.
6. Click on **myvirtual world icon** marked with **yellow colour.**
7. A few icons will appear again.
8. Click on Machine January 2000.svr or machine 4.1. vrt
9. World Editor Screen will appear.
10. Click on Editor icon (on top middle of the screen) and click on Visualiser.
11. Click on Number 8 to see the entrance of the factory.
12. Press the **Forward Arrow icon** (which is at the lower middle of the screen) by pressing the left button of the mouse to move toward the blue door (See fig.1).
13. Reception area is seen after entering through the blue door.
14. Repeat step 9 to go through the second blue door to the factory floor.
15. Move forward and turn left before the conveyor.
16. Press the green button to start the machine.
17. Now press 1,2,3 and 4 to see the machine from different angle.
18. Again using the mouse and forward button the storage area can be entered (which is at the right side of the conveyor). Follow step 9.
19. In the storage area drag the mouse toward the green sliding door and press the light green door with the left button of the mouse the door will open. Similarly the dark green door can be opened.

20. Click on Number 6. This shows the back portion of the factory with trucks parked. Follow step 9 to move toward the Red door.
21. The red colour sliding door can be opened by following step16.
22. Different views are set at 1,2,3,4,5,6,7,8,9 and 10 for quick look. Click on them one by one.

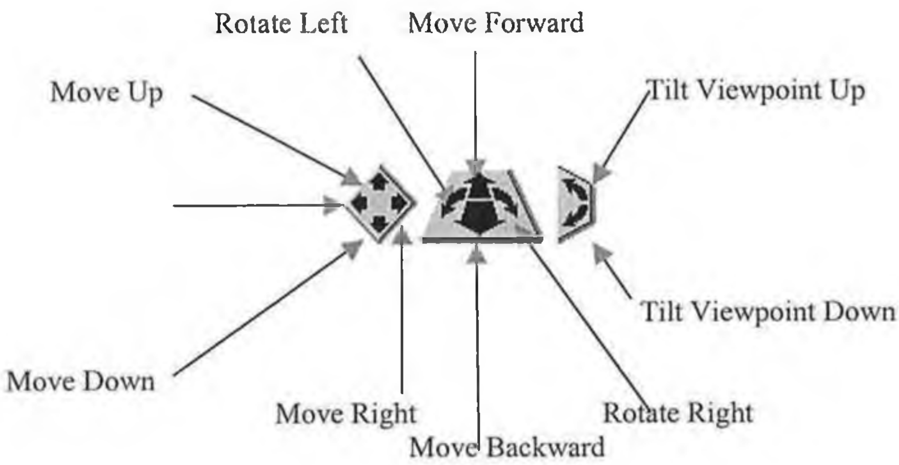


Fig.1: Icons

Appendix F

Manual of SimCad Software

This Appendix explains capabilities and menus of SimCad software.

Introduction to Simcad 3.0 : SimCad is a visual process simulation and modelling software for Windows 95, Windows 98 and Windows NT. Through a user-friendly graphical interface, SimCad provides the tools to model the most complex environments. SimCad uses animation techniques to simulate the model flow and to graphically detect bottlenecks and process usage. Multiple object types are tracked and created at different stages of the simulation.

SimCad is a modelling tool for all environments that are process based. As "Objects are created, or entered into the model, each process modifies the object properties, or transforms into one or many new objects. Manufacturing, assembly, process based office environment, and workflow-based environment are a good fit for SimCad modelling capabilities. Other environments that can also benefit from the simulation capability of SimCad include networked systems, process improvements, company restructuring and reengineering. In summery, SimCad is a general-purpose simulation tool that can model most process-based environments with ease.

Simcad 3.0 Capabilities And Menus

Simcad 3.0 Capabilities

- Graphical, Simple, and effective user interface
- No simulation languages to learn-model building is done through the graphical interface with predefined process templates.

- Support continuous and Batch processing.
- Full animation of objects through the model.
- Support for unlimited levels of nested departments.
- Import objects and processes images to customise the model.
- Customise the model to be either process or object based or Both.
- Process Copy/Paste and merge capabilities.
- Online help, printing, logging, and export capabilities including simulation and detailed model reports.
- Assign and monitor resources as the simulation develops.
- Assign and dynamically modify object priorities as it traverses through the model.
- Assign individual process setup time, object splitting, and assembly per processing item.
- Use selective distribution to assign objects to multiple destination processes.
- Use different time distribution curves for a more accurate representation of the simulated environment.
- Assign different times and properties for the "Interprocess connections".
- Monitor individual process progress in real time.
- View and print real time charts for different processes and the overall model.
- Access to thousands of ClipArts from www.arttoday.com.

Menu Commands

The File menu offers the following commands:

New :Creates a new document.

Open :Opens an existing document.

Close :Closes an opened document.

Save :Saves an opened document using the same file name.

Save As : Saves an opened document to a specified file name.

Print Graphical model: Prints a graphical represenation of the model.

Print: If the report window is open, this menu item prints the active report.

Simulation report: Starts the reporting and analysis tool of SimCad

Print Preview: Displays the document on the screen, as it would appear printed.

Print Setup: Selects a printer and printer connection.

Send: Sends the active document through electronic mail.

Exit: Exits SimCad 2.0.

Edit Menu Commands

The Edit menu offers the following commands:

Cut: Deletes data from the document and moves it to SimCad internal clipboard.

Copy: Copies data from the document to SimCad internal clipboard.

Paste: Pastes data from SimCad internal clipboard into the document.

Paste Link: Pastes from the SimCad internal clipboard a link to data in another application.

Insert New Object: Inserts and embeds an object, such as a chart or an equation in a document.

Links: List and edit links to embedded documents.

View Menu Commands

The View menu offers the following commands:

Toolbar: Shows or hides the toolbar.

Status Bar: Shows or hides the status bar.

Process toolbar: Shows or Hides the Process Tool bar

Large Icons: Switches the display mode to show normal or large icons for process images. If large icons are checked, all process icon will be displayed at twice their normal size. Specific process bitmaps are stretched to fill the new area.

Hide Processes: Shows or hides the process icons in the simulation window. Note: Defined process bitmaps are always displayed regardless of this selection.

Hide Connection Line: Hides or Shows the connection lines connecting the processes. This selection is provided to enhance the animation of the simulation.

Conventions and Definitions

Conventions

The following list of conventions is used in SimCad.

Using the Mouse

- Left Mouse Button

Use the left mouse button to select a process or a connection line by clicking on the desired item. Dragging the mouse while holding the left mouse button is used to move a process, and to create connection lines.

- Right Mouse Button

Use the right mouse to select and display the floating menu.

- Double Clicking with the Left Mouse Button

Double clicking on a process or a connection line opens up the item properties dialog.

Definition

The Object: The object is a named entity that is created during a simulation and is tracked by SimCad in order to detect process characteristics. The object has a determined lifetime that is based on the process definition.

The Process: The process consists of a set of actions and constraints used to define a procedure to be performed on an object. The process constraints differ based on the process definition.

The Item: An item is used to represent either a process or an object. It is used in sections where an action applies to both a process and an object.

The Process Toolbar

The Process toolbar provides an interface that allows for the creation and selection of different types of processes. When a toolbar button is selected, the button appears to be

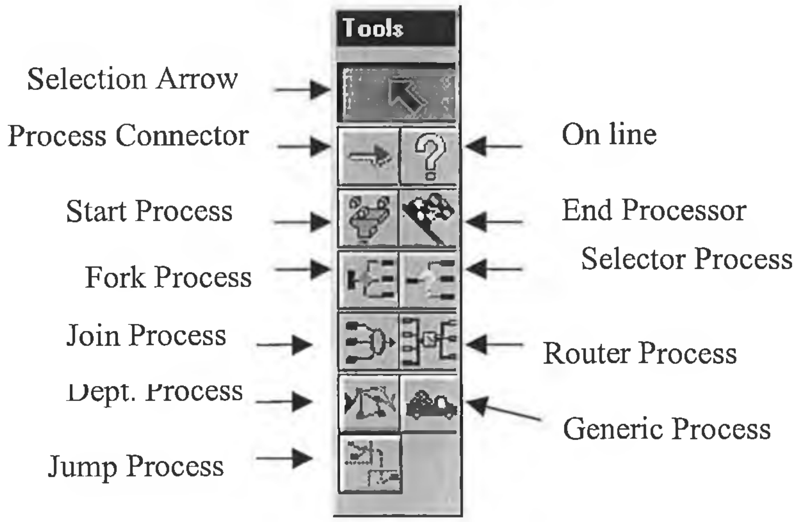


Fig F 1: Tool Bar.

Process toolbar buttons

The Selection Arrow

The Selection arrow is used to select processes and connection lines. After a process is selected, it can be moved, copied, deleted or modified. A Connection line may only be deleted or modified. By default, the selection arrow is always selected when SimCad starts. To select a process, select the "Selection Arrow" from the process toolbar, then click the left mouse button on the process or connection line to be selected. When a process is selected, a rectangular line is drawn around it. When a Connection line is selected, the line is drawn as a dashed blue line.

Note: Only one process or connection line may be selected at a time except in the case of a department process. When a department process is selected, actions performed on the department process affects all processes and connection lines enclosed in the department.

The Connection Line

The connection line is used to connect 2 processes together. The direction of the connection is decided during the line creation process.

The Start Process

The Start process creates new objects in the simulation model and initiates activities on the created objects. Each Start Process is capable of creating objects of a predefined type. If no type is defined, the default object is created.

There should be at least one Start Process in each simulation model. If a Start Process does not exist in the model, other processes in the model must have an initial process load specified.

The End Process

The End process signals the end of an object life span in the simulation model. When an object completes an End Process the average object completion time is updated.

The Selector Process

The Selector process selects one next process to start from a list of processes. The selection criteria is defined in the process properties which can be one of the following,

Random Selection

- Even Distribution
- Selection of the least busy destination process
- Percentage based selection

The Distribution Process

The Distribution Process sends its objects to all processes connected to it. It is viewed as the distribution process where a copy of the active object is created and passed to every connected process.

The Join Process

The Join process is considered to be the assembly process in SimCad. The Join process waits until it receives a defined set of objects and combines them into one object of a predefined type. It also has the capability of remembering the object composition to allow for splitting the object to its original composition.

The Router Process

The Router process routes objects to different destination based on their types or their originator process. The router process acts as the traffic co-ordinator in the simulation model.

The Generic Process

The generic process consists of a simple process that can have only one destination. This is considered a One_to_One connection in the model.

The Department Process

The Department Process provides the functionality of the department in the simulated environment. Processes included in the department are viewed as one entity from the higher level. SimCad allows the creation of a multi_layered department hierarchy limited only by the amount of memory available.

The Jump Process

To simplify model creation, the Jump process allows objects to Jump through the simulation without the presence of connection lines. The Jump process is also capable of sending objects between department boundaries.

The Connection Line

The Connection Line tool is used to connect two processes and establish their enterprise relationships. The Originator process starts the connection line, and the destination process ends it. After selecting the connection line icon from the Process Toolbar, use the left mouse button to select the Originator process. While holding the mouse button down, drag the connection line and drop it on the Destination process. The connection line is then drawn between the two processes. Either double clicking on the line, or selecting the line and opening its item properties may modify the line properties.

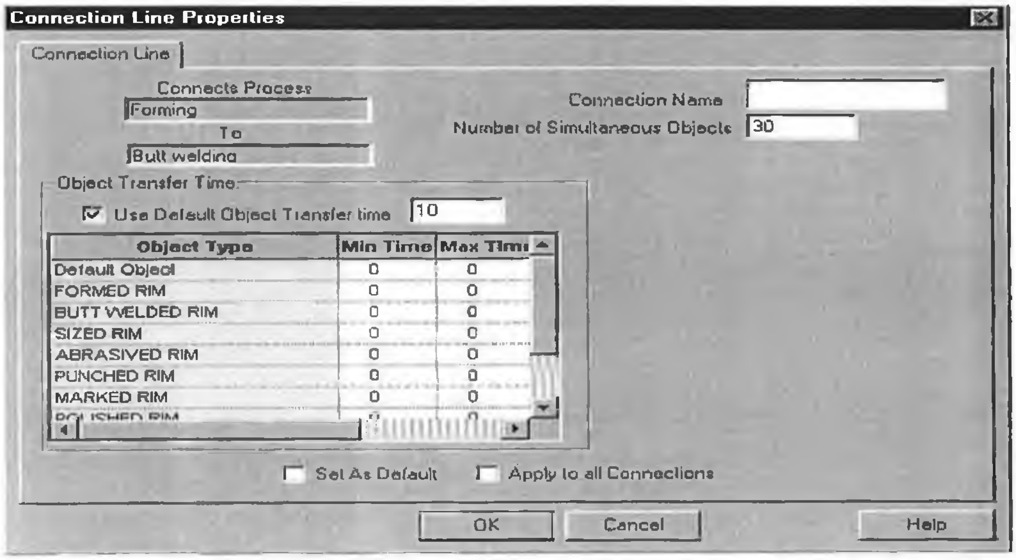


Fig.F2: Connection Line.

The following conditions apply to adding Connection Lines:

- If the Originator process is not capable of acting as an originator process (The End Process, and the Jump Process for example), the connection line addition will not be initiated.

- If the Destination process is not capable of accepting incoming connection lines (The Start process for example) the connection line will not be added.

- If no destination process is selected, SimCad will create a connector point, which is displayed as a black dot. Connector Points may be used to route connection lines around processes, or to increase the number of connection lines connecting two processes. Note that the insertion of the Connector Points will affect the final result of the simulation.

When the simulation is running, the direction of the connection line defines the direction of the object flow in the model.

Simulation Control

Start Simulation: Starts the simulation of the active model. After the simulation starts, the Simulation status window is displayed along with individual process properties. If the Animation flag is selected (By Default), the object animation will start.

Pause Simulation: Pause the Simulation for the active model. After pausing the simulation, all properties, states of processes and objects are not modified The simulation may be resumed at a later time without affecting the final outcome of the simulation. Use the Resume simulation selection to resume the simulation.

Resume Simulation: Resumes a paused simulation. After the simulation is resumed, all processes in the model resume their operations simultaneously. Also, All process states are maintained accordingly.

Stop Simulation

Stop a simulation: All open windows related to the simulation are closed. If logging was enabled, the log file is closed.

Pause Process

Pause the activities of the selected process: When a process is paused, it will not accept any new objects into its processing module, and will not complete the processing of any object already in the processing module. Note, however, that the process queue remains active, and will receive additional objects until the queue is full. When a department process is paused, all internal processes are paused simultaneously.

Resume Process: Resume the activities in a Paused process. To resume activities of a process, first select the process then use this selection to resume process activities. Before the process is resumed, the Process State is reset based on its state before it was paused.

When a department process is resumed, all internal processes are resumed simultaneously.

Load Process Queue: Loads the process queue of the selected process. This operation creates enough objects to fill the queue.

Clear Process Queue: *Delete all objects from the current process queue. When the operation completes the selected process queue will be empty.*

Adding a new process: From the Process Toolbar, select the process type to be added. After the selection is made, the process template button will appear to be pressed down. Move the mouse cursor to the location where the new process is to be added, then click the left mouse button. The process property dialog is displayed to set the process properties.

Copying a process: Another method of creating processes in SimCad is to make a copy of an existing process and paste it at the desired location. Multiple processes may be copied if they are contained in a department. The copy operation is available between departments and across simulation models.

To copy a process, simply the select it using the selection arrow, then either select the Edit menu then Copy, or use the right mouse button to open up the floating menu, then select copy. Select the window where the process is to be copied, then select paste from the floating menu or the edit menu. All properties are transferred to the newly created process.

Note: When adding departments, make sure the internal processes in the department are connected. If the internal processes are not connected, the simulation will not run properly.

Simulation Details

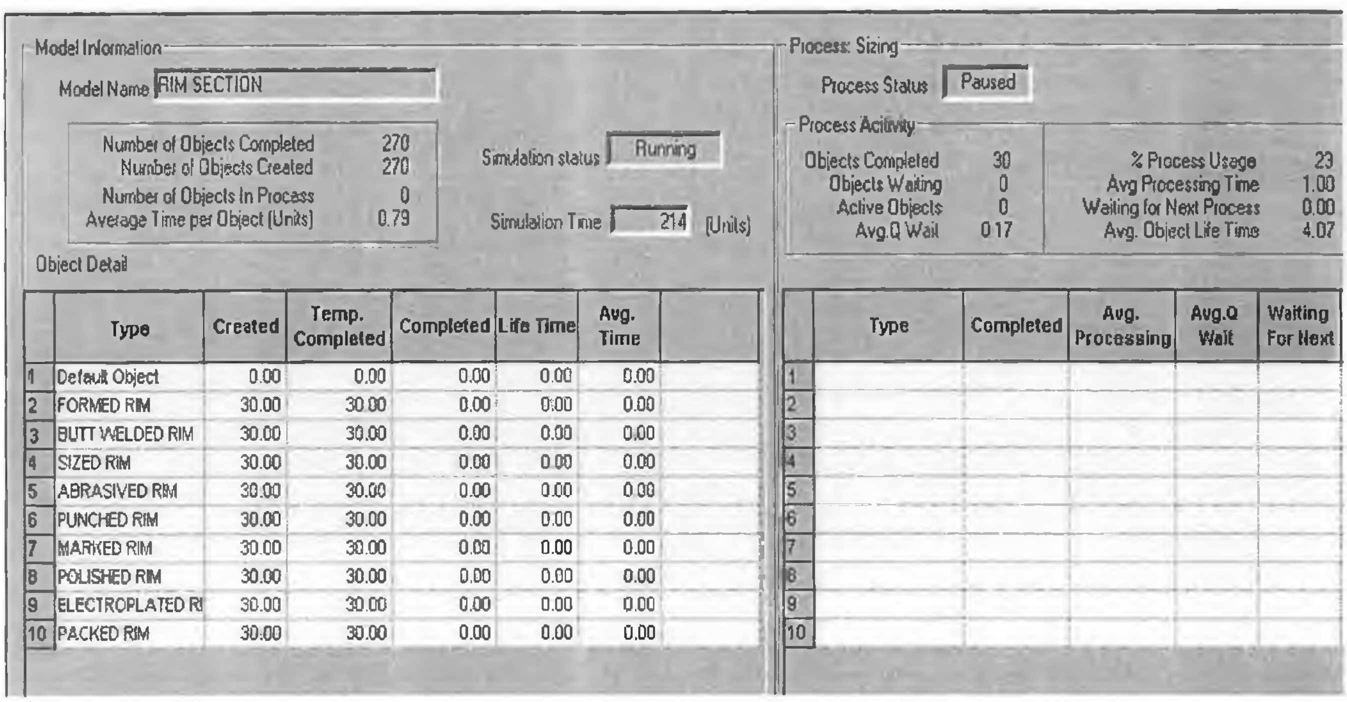


Fig.F3. Simulation Details Window.

Each window in SimCad contains a simulation status section through which simulation details are tracked. The Simulation status consists of 2 main sections, The Overall Simulation Status, and the Selected Process Status.

The Overall Simulation status

The Overall Simulation status section is displayed on the left side of the status window and contains information related to the overall simulation. The following entries are tracked

Model Name

Model Name is displays the name of the model. Model Status, which can be either Stopped, Running or Paused. The Simulation time is the simulation clock. Each time unit is represented by a One increment to the clock.

The Number of Objects Completed, which displays the overall number of objects completed through the simulation. The object completion is determined when a process does not send the object to a destination process as in the case of the End Process. The Number of Objects created tracks all objects created during a simulation run.

The Number of objects in Process, is the total number of objects currently being processed in the simulation. The number includes all objects being transferred, waiting, or are active in processes, at the time of status update.

The Averaged Time Per Object is the average life time of an object in units. The number is computed by finding the average time an object spends in the simulation by dividing the number of objects completed by the simulation time.

For each object type in the model, the following information is displayed

The Object Type

The Number of objects created of this type. This number will include all objects created in the Distribution Processes, and as defined in the Object Definition behaviour of each process.
The number of temporary objects completed of each type. This number consists of all objects that completed the simulation without reaching an End process. This number is not used in computing the average processing time of the objects.

The number of objects completed through an End process of the specified type. This number is used to determine the Average Processing time of the object type.

The Selected Process Status

To examine a certain process status during a simulation run, just select the process by clicking on it using the left mouse button.

The following is a list of status parameters displayed for the selected process.

The Process Name is displayed at the top of the section.

The Process Status, which may be one of the following, Started, Stopped, and Paused.

- The Number of Objects completed by the process.
- The Number of Objects waiting in its Queue.

The Join process only shows the number of objects, which can be processed by it after the Join operation has been successful. The Number of Active objects in the process, is the number of objects actively being processed. This number will not exceed the number of workstations capable of operating on objects.

The Average Queue Wait time, is the average time an object spends in the process queue while waiting to be processed.

The Percent Process Usage, is the percent of time where the process is busy processing an object. This is equivalent to the process workload during the simulation.

The Average Processing Time is the average time a process spends processing objects. This number does not include the time required to wait for the next Queue to be available.

The Waiting for Next Process time, is the average time an object waits before it is accepted by the next process.

The Average Object Lifetime is the average time an object, which passes through this process, with respect to the overall simulation.

For each object that is processed by the process, the following properties are displayed

The Object Type.

- The number of objects completed of this type.
- The Average processing time of all objects of this type.
- The Average Q Wait time for all objects of this type.
- The Average Wait time for the next process for all objects of this type.

Report and Analysis

SimCad provide an extensive report and analysis tool which can be accessed from the File menu / Simulation Report option. When selected, the following option dialog is displayed.

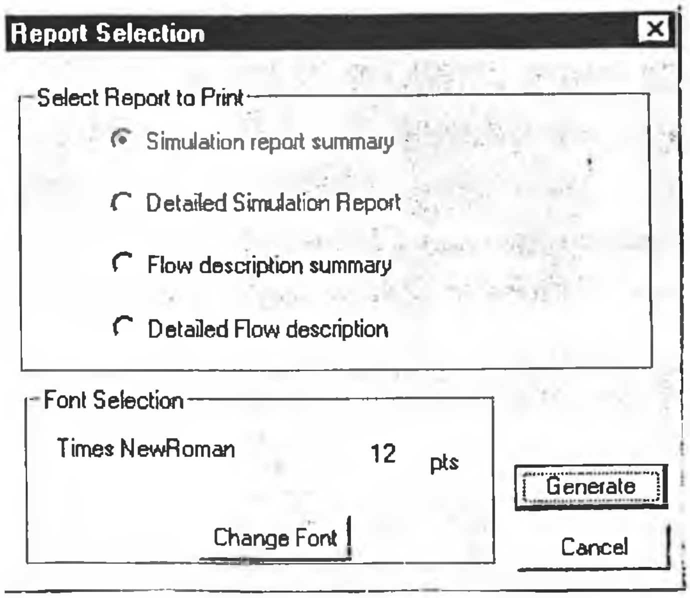


Fig. F4: Report and Analysis Tool Bar.

Reports

Simulation Report Summary

The Simulation Report Summary prints information related to the current simulation run or to the last run if the simulation is stopped. The report contains summary information for all processes and their objects based on the outcome of the simulation.

Detailed Simulation Report

The Detailed Simulation Report is generated from the same data as the "Simulation Report Summary" except that it prints all saved information about the run. The generated report includes the report summary in addition to a detailed description of each object on a process by process basis.

Flow Description Summary

The Flow description Summary generates a brief description of the active flow. This is a concise report aimed at providing a quick view of some of the simulation settings.

Detailed Flow Description

The Detailed flow description prints all flow, process, and connection settings in the model. The report is intended to be used for export and archival purposes in order to provide a detailed setting for simulation.

Changing Report Fonts

SimCad can print the report in any font supported by the system. To change the report font, click on the "Change Font" then select the font from the font dialog. Note that it may be necessary to select a small font size for detailed reports, as the report size may be too large.

To generate the report, select the "Generate" button. Only one report may be open per simulation model. If other reports need to be created, the original report window must be closed.

SimCad Graphical User Interface

The SimCad user interface is Windows compliant. The primary interface to the software is either pulldown menus or the button tool bar. The operation of the simulation model is controlled at the top of the screen, from a toolbar, which starts, stops, and resets the model. The Majority of the activity however, takes place in the Simulation Window. It is here that items are placed in drag-and-drop fashion. The Designer Elements are commonly used to quickly drag-and drop pre-defined items on to the simulation screen. After the required elements are on the screen, visual Push and pull rules are added, via the mouse. Once a basic model has been assembled on the screen, the next step is to add more detail to elements in the model.

Standard SimCad reports can be viewed on the screen either in tabular or graphic format. In addition, several graphical elements are available for summarising statistics from a model. Pie charts and histograms provide a meaningful, easily read format for data from a simulation model run.

Publications Arising From the Present Work

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3. Bakker, I. Khalid , Iqbal, M., Hashmi, M.S.J., "An Overview of Virtual Reality in Mechanical Design Engineering", Proceedings of the International Conference on Advances in Materials and Processing Technologies (AMPT 98), University Putra Malaysia, Kuala Lampur, Malaysia, August, 1998, eds. Hamouda A.M.S., Sulaiman S. and Ahmadun M., Vol.II.pp.1147-1155, 1998.

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7. Iqbal, M. Hashmi, M.S.J., "Application of Virtual Reality for the Training of Engineering Personnels", Proceedings of the International Conferences on Advances in Materials and Processing Technologies (AMPT 99) & 16th Annual Conference of the Irish Manufacturing Committee, IMC-16, Dublin City University, Dublin, Ireland, August 1999, eds. Hashmi, M.S.J., and Looney, L., Vol. III. pp. 1957-1966, 1999.

8. Iqbal, M. Hashmi, M.S.J., "Review of Virtual Reality Software and Comparison Between 3D Studio MAX and Superscape VRT 5.5", Proceedings of the International Conference on Manufacturing (ICM2000), Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh, February 24-26, 2000.