The Role of Simulation in Design of Material Handling Systems

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Abstract

The paper discusses the role of simulation in material handling design as it applies to different phases of a material handling project. The different phases of a material handling project discussed include the conceptual phase, detailed design phase, launching phase, and fully operational phase. The appendix of the paper contains a list of the issues addressed by simulation in the different phases of a material handling, project for each equipment type.

Keywords: Process system, material handling system, throughput, productivity, conceptual phase, detailed design phase, launching phase, fully operational phase, operational rules, scheduling rules, dispatching rules, buffer banks, continuous improvement.

1. Introduction

In recent years, there has been a tremendous growth of material handling technology and equipment types; robots, automated guided vehicles (AGV), electrified monorail systems (EMS), high-rise storage retrieval systems, computerized picking, systems and computer controlled conveyor systems. Material handling systems, have been accepted as an integral part of today's manufacturing systems and are increasingly playing an important part in the productivity of the plant. Closely correlated to the development of this material handling equipment, we see a corresponding increase in deployment of integrated material handling environments with sophisticated planning and operational rules to achieve Just-In-Time and Agile/Lean manufacturing systems. Material handling projects are often costly ventures with many potential risks. There are many complex design, operational and scheduling, issues that need to be addressed for successful implementation. Simulation technology can be used as a test-bed to better understand the system before its implementation. This understanding helps engineers design the best possible, lowest cost automation solution for their manufacturing, system. Simulation can be used as an affective analysis tool in the conceptual, detailed design, launching, and full operation phases of a project to avoid costly mistakes (Ülgen et.al, 1994).

One can classify the application of simulation according to the four phases of a material handling project. The conceptual phase refers to the initial phase where alternate material handling systems and concepts are tested by the engineers. Discrete-event simulation packages with 3D animation capabilities are the popular simulation tools at this phase. The detailed design phase refers to the phase where detailed material handling layout, path designs, equipment specifications, and operational and scheduling issues are determined and verified for the system. The principal factors considered here include *layout design* (e.g., guide path design, size and location of buffer banks and bias-banks) *equipment design and justification* (e.g., number of AGVs, carriers and speed, accelerations of chains, carriers and movement systems), *cycletime verifications* (e.g., conveyor speeds, line throughput), *movement system operational and scheduling issues* (e.g.. carrier, AGV lane selection rules, dispatching rules, product mix decisions), *integration of material handling with other systems* such as other material handling systems and operators. Discrete-event simulation packages with built-in detailed constructs/templates for the various material handling systems and 3D animation capabilities (e.g., AutoMod) appear to be the most popular ones used at this phase. The launching phase refers to the phase where the plant operates below the designed operational conditions. In some cases, it may take up to six months for the plant to ramp up to maximum capacity conditions. Simulation studies done at this stage are generally used to *test operational policies* (e.g., test different lane selection rules, dispatching rules, vary the number of carriers and of the carriers) and *integration of material handling with other systems* such as other material handling systems and operators. Discrete-event simulation packages used at this stage may require both detailed equipment features and the 3D animation features. The simulators with user-friendly features are the Most Popular packages used at this phase. The fully operational phase refers to the phase where the plant is operating under full capacity conditions. The simulation studies done at this phase consider the impact of factors such as product mix decisions, new product introduction, new operational policies, and line modifications on the throughput of the existing material handling system. Simulation packages used in this phase generally require the same capabilities as those of the packages used during the launching phase.

2. Why Simulate Material Handling Systems ?

2.1. Avoid costly mistakes

Simulation empowers the engineers and managers with a powerful technology to verify and improve the design and operational rules of material handling_systems even before their installation. This clearly reduces the inherent risks and enormous costs involved in any material handling project.

2.2. Choose the right material handling system specific to your system

Each material handling problem may have many solutions. The goal is to find the best solution for a given problem. "Best" may be defined in many ways, but it is usually a combination of the cost of the automation and the benefits of applying automation. The phrase "bang for the buck" summarizes this goal. Sometimes a particular material handling technology does not fit your application. Technology designed for another industry may not meet your needs. The old adage "square peg in a round hole comes to mind. But how do you determine which automation technology if any, fits your system the best. Intuition and experience can help, but the more complex the system is, the harder it becomes to explore all the 'belfries without a decision support tool. A computer model gives you a "virtual factory" to determine which of the proposed automation technologies best fits your system (Van Norman, 1995).

2.3. Test-bed to improve design and operational rules and implement new systems

Simulation can serve as an "experimental test-bed" to try out new policies and decision rules for operating a system, before running the risk of experimenting on the real system. When new machines or product lines are introduced into a system, a computer model can be used to point out bottlenecks and other problems that may arise during system operation. Similarly, with new systems about which we may have little or no information, simulation can be used to answer "what if' questions in concept and design phases of the project.

2.4. Integration with other systems

New automation is being added to existing equipment or manual operations. No matter what the integration issues are, all automation components must work well together in order for a project to be Successful. A detailed computer model helps determine how well the system components integrate. A model also shows which of the components fall short of performance goals. Getting this information early in the design stage eliminates problems once Your system is installed (Van Norman , 1995).

2.5. Valuable insight

The experience of designing a computer simulation model may be more valuable than the actual Simulation itself. The knowledge obtained in designing a simulation study frequently suggests changes in the system being simulated. Simulation of complex systems can yield valuable insights into which components are more important than others in the system and how these components interact. This knowledge may result in a possible new approach or simplified redesign of the system.

2.6. Estimate crucial parameters

Simulation modeling of a material handling system helps estimate crucial parameters such as throughput of the proposed system, number of pallets, carriers or AGVs required, specification of the material handling equipment needed, etc. These parameters help engineers make the right decisions regarding the need for and type of material handling systems required from both an economic and operational point of view.

2.7 Experiment on model rather than actual system

Through simulation, one can study the effects of certain informational, organizational, and environmental changes on the operations of a manufacturing system by making alterations in the simulation model rather than experimenting directly on the system itself. This enables the analyst to observe the effects of these alterations on the systems behavior before making costly changes on the real system.

2.8 Visualization and communication

The animation provided by 2D and 3D simulation packages make an excellent case for the motto “a picture is worth a thousand words." Visual aids go far in helping to comprehend solutions. Animation helps the engineer visualize and explain the working of a proposed or existing material handling system. The clients, in turn, find it an excellent tool to present their solutions to decision makers and upper management. Animation also helps the simulation model builders verify and validate a complex model visually. Simulation packages such as Quest and AutoMod have excellent 3D animation capabilities for many material handling systems, and users, aside from designing accurate systems, can also develop quality presentations and managers in design decisions.

3. Application of Simulation to Material Handling Systems in the Four Different Phases of a Project

One can classify the application of simulation to material handling systems according to the four phases of a material handling project, namely; conceptual phase, detailed design phase, launching phase and fully-operational phase. See Figure 1. In what follows, we discuss possible simulation applications at each of these phases.

3.1 Conceptual phase

Years ago when designers were in the early stages of manufacturing design, sample sketches of the manufacturing process and material handling system were made based on common industry rules of thumb. These designs were discussed in detail by the experts and finally accepted and put into operation. As time passed, these rules of thumb fell short of manufacturing needs in terms of quality, reliability and increased complexity and diversified customer demand. It was at this point that the manufacturing community began to look closely at discrete event simulation as a tool to help them design new manufacturing systems.

The *conceptual design phase* itself is that phase in which no current manufacturing process currently exists. The entire process is "on the drawing board" and there are no physical systems put into place that will actually transfer or manufacture the product. Designers and engineers start with a rough idea of what they want to accomplish. In the process of developing a new material handling system, they incorporate into their design the past experience of systems that did not work well and their expectation of what the new system must accomplish. The goal of a new material handling system is often to try a concept that has never been used before in manufacturing that will allow them to be more cost effective in producing high quality products, which would eventually give the company the competitive advantage.

The principal objectives of applying simulation to the conceptual phase are to

3.1.1. Evaluate/justify the need for automation.
3.1.2. Estimate the type and level of automation required.
3.1.3. Visualize the proposed system.
3.1.4. Communicate ideas to the management and engineers.

Using discrete event simulation in this matter allows designers and engineers to have a "crystal ball" to evaluate their proposed design before the following phases of the design concept are attempted. The goal is to achieve a reasonable, if not optimal, system to produce the product(s) needed in the manner they wish to have them built.

3.2. Detailed design phase

Once the management and engineers mutually agree to proceed with the project, the *detailed design phase* begins. In this phase, the engineers build on the details developed in the conceptual phase. Extensive design plans are developed for all the issues that have to be addressed, including the *layout design, equipment design and justification cycletime* *verifications, operational, scheduling and dispatching issues* and *integration of material handling system with other systems.* The simulation engineer develops a base model for the entire system which includes the process system logic (e.g., machines, part routings, operator logic) and the material handling system logic (e.g., carriers, conveyors, routing and scheduling of the movement system logic). The model developed can be viewed as an equation consisting of variables, the objective of which is to determine the best values of the variables to attain a cost effective and productive system which meets the demands of the customers. The simulation model developed captures the stochastic nature of the system and the dynamic interactions among the various subsystems present, thereby making it a very powerful tool to make real fife decisions. The base model undergoes numerous iterations of chancre before the desired system specifications are attained.

The principal objectives of applying simulation to the detailed design phaseare for
3.2.1. Layout design.
3.2.2. Material handling design and Justification
3.2.3. Cycletime verifications.
3.2.4. Movement system operational and scheduling issues.
3.2.5. Integration of material handling system with other systems.

The principal factors considered here include *layout design* (e.g., guide path design. size and location of buffer banks and bias-banks), *material handling design and justification* (e.g., number of AGVs, carriers and speed, accelerations of chains, carriers and movement systems), *cycletime verifications* (e.g., conveyor speeds, line throughput), *movement system operational and scheduling issues* carrier. AGV lane selection rules, dispatching rules, product mix decisions), and *integration of material handling with other systems* such as other material handling systems and operators. The layout design for the material handling system should try to minimize the cost and traffic of material flow between different stations. To address this issue, as a precursor to simulation of the material handling system, it is advisable to optimize the layout and material flow between stations using a layout optimization package (e.g., LayOPT). Discrete-event simulation packages with built-in detailed constructs/templates for the various material handling systems and with 3D animation capabilities (e.g., AutoMod appear to be the Most Popular ones used at this phase.

3.3. Launching phase

After the engineers develop detailed designs for both the process system and the material handling system, the designs are validated using Simulation and other mechanical design software (Note that simulation also assists the engineers in developing robust designs as discussed in the detailed design phase). Once the engineers are completely satisfied with the final design, the *launching phase* of the project begins.

The *launching phase* refers to the phase during which the plant actually installs the automation and equipment and begins production. It is common to find that the plant operates below the designed operational conditions at this phase. This state commonly referred to as the ramp up phase, need not reflect any kind of shortcomings in the designs developed but reflect the inability to comprehend all the interactions and micro-level details specific to the real systems in the detailed design phase. In some cases, it may take up to six months for the plant to ramp up to maximum capacity conditions. The changes to the system usually are of a minor nature, such as changing the velocities of the conveyor segments, location of stop points, etc.

The principal objectives of applying simulation to the launching phase are to

3.3.1. Ramp up the productivity of the plant to the desired throughput.

3.3.2. Vary operational policies.

3.3.3. Integrate material handling with other systems.

Simulation studies done at this stage are generally used to vary operational *policies* (e.g., test different lane selection rules, dispatching rules) and fine tune the movement systems (e.g.. indexing times, conveyor velocity) and integration of material handling with other systems such as other material handling systems and operators. Discrete-event simulation packages used at this stage may require detailed equipment features and the 3D animation features if detailed equipment features are to be tested before they are implemented. The simulators with user-friendly features are the Most Popular packages used at this phase.

3.4. Fully operational phase

The fully operational phase refers to the phase where the plant is operating under full capacity conditions. With changes in the demand, the plant should have the capability to change rapidly and still stay productive. This particular phase may take five or more years for the major manufacturing lines in the plant and during this time the plant strives to continuously improve its operations and adapt to new technology and concepts to maintain or even better its productivity. Adhering to the *continuous improvement* philosophy usually involves not just a change in the operating policies but also involves shifting to the state-of-art equipment and material handling system. Simulation proves to be a valuable tool in this phase as it allows the engineers to verify the effects of the changes to the current system and also gives them valuable insight as to the specifications of the new system needed.

The principal objectives of applying simulation to the fully operational phase are for

3.4.1. Achieving continuous improvement.

3.4.2. Testing alternate operating policies to accommodate new concepts.

3.4.3. Adding new material handling systems.

The simulation studies done at this phase consider factors such as product mix decisions, new product introduction, new operational policies, line modifications and the impact of all the above changes on the existing material handling systems throughput. Simulation packages used in this phase generally require the same capabilities as those used during the launching phase. The appendix of the paper includes a list of the issues addressed by simulation in the different phases of a material handling project for each equipment type.

4. Conclusion

Simulation has become an indispensable tool in the design of material handling systems. In the paper we developed a classification of the problems that are encountered in each phase of a material handling project and how simulation plays an important role in each one of these phases. Through the use of systems simulation techniques, it is possible to identify and solve problems associated with material handling systems, in the conceptual, design, launching, and operational phases of material handling systems.

Role of simulation in the 4 phases of a Material Handling project

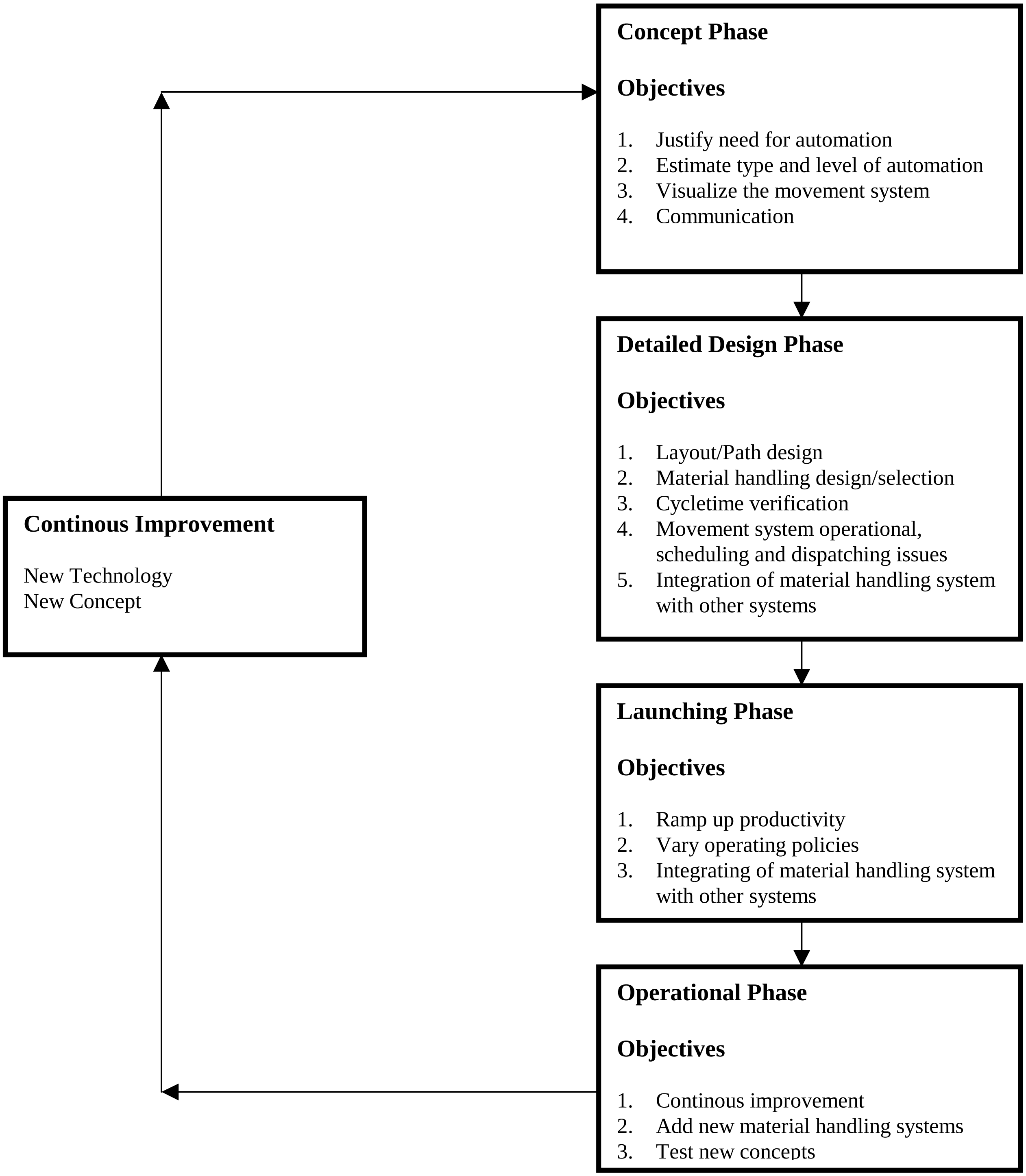

Figure 1: Application of Simulation to the four phases of a Material Handling project

Acknowledgment

Edward J. Williams, Principal Computer Applications Engineer, Ford Motor Company, made valuable contributions toward improving the clarity and presentation of this paper.

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Biographies

Onur M. Ulgen is the president of Production Modeling Corporation and also a Professor of Industrial and Manufacturing Systems Engineering at the University of Michigan-Dearborn. He received his Ph.D. degree in Industrial Engineering from Texas Tech University in 1979. His present consulting and research interests include the applications of discrete-event and robotics (kinematics) Simulation to manufacturing problems, Object-oriented simulation program generators, scheduling, and project management.

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Appendix: Trademarks

AutoMod is a registered trademark of AutoSimulations Incorporated.
QUEST is a registered trademark of Deneb Robotics Incorporated.
LayOPT is a registered trademark of Production Modeling Corporation.

Appendix

Tables 1-5 in the appendix of the paper include a list of the issues addressed by simulation in the different phases of a material handling project for different equipment types. The material handling systems in this paper are broadly classified as *convectors, guided vehicles, cranes,* and *automated storage and retrieval systems*

Table 1 : Issues addressed by simulation in the four phases of design of a Conveyor System				
	Phases of Material Handling project			
Material Handling systems	**Concept**	**Design**	**Implementation**	**Operational**
Conveyors				
Belt Conveyor Power and Free Conveyor Electrified Monorail system Skuck system Chain-on-edge Skid systems	1. Requirement analysis 2. Communication 3. Visualization 4. Justification	1. Layout 2. Buffer type, sizes arid location 3. Specifications speed, indexing distance, dog spacing, etc. 4. Dimensions 5. Type of conveyor 6. Estimate carrier, pallet requirements 7. Repair loop location and effects 8. Alternate analysis 9. Design verification 10. Visualization 11. Throughput verification	1. Layout & path 2. Control Riles 3. Integration arid interaction with other systems 4. Verify safety rules 5. Visualization	1. Identify bottlenecks Traffic management 2. Control rules 3. Clear-switch logic 4. Verify sortation algorithms 5. Effects of downtime 6. Cycletimes of carriers, pallets anid stations 7. Integration and interactions with other systems 8. Operator requirements 9. Effect of mass and tag relief' 10. Throughput verification 11. Visualization

Table 2 : Issues addressed by Simulation in the four phases of design of a Guided Vehicles System				
	Phases of Material Handling project			
Material Handling systems	**Concept**	**Design**	**Implementation**	**Operational**
Guided Vehicles				
Automated Guided Vehicles (AGV)	1. Requirement analysis 2. Communication 3. Visualization 4. Justification	1. Layout 2. Control points requirement and location AGV specifications ahead, rotational, spur and crab velocities, acceleration, deceleration 3. Dimensions 4. Type of AGV 5. Estimation of number of AGVs 6. Type of guidance system required 7. Battery charging stations Design 8. Alternate analysis 9. Design verification 10. Visualization 11. Throughput verification	1. Layout & path 2. Control rules 3. Integration and Interaction with other Systems 4. Verify safety Rules 5. Visualization	1. Identify bottlenecks 2. Traffic management 3. Dispatching rules 4. Scheduling and Routing rules 5. Control rules 6. Logic at Intersections 7. Lane selection rules Operator and machine interaction 8. Effects of downtime 9. Indexing Times between stations 10. Integration and interactions with Other systems 11. Operator requirements 12. Battery charging stations schedule 13. Throughput verification 14. Visualization

Table 3 : Issues addressed by Simulation in the four phases of design of a Guided Vehicles System				
	Phases of Material Handling project			
Material Handling systems	**Concept**	**Design**	**Implementation**	**Operational**
Guided Vehicles				
Railcars Dollies Forklift	1. Requirement analysis 2. Communication 3. Visualization 4. Justification	1. Layout 2. Vehicle specifications velocities, acceleration and deceleration 3. Dimensions 4. Number of railcarts, dollies required 5. Forklift fleet schedules 6. Operator requirements. 7. Alternate analysis 8. Design verification 9. Visualization 10. Throughput verification	1. Layout & Path 2. Control rules 3. Integration and Interaction With other systems 4. Verify safety Rules 5. Visualization	1. Identify bottlenecks 2. Traffic management 3. Scheduling and routing rules 4. Operating Rules 5. Maintenance schedules 6. Logic at Intersections 7. Operator Interaction and requirements 8. Effects of downtime 9. Integration and interactions with other systems 10. Throughput verification 11. Visualization

Table 4 : Issues addressed by Simulation in the four phases of design of a Cranes System				
	Phases of Material Handling project			
Material Handling systems	**Concept**	**Design**	**Implementation**	**Operational**
Cranes				
Bridge cranes Gantry cranes	1. Requirement analysis 2. Communication 3.Visualization 4. Justification	1. Layout 2. Crane specifications velocities, acceleration and deceleration 3. Dimensions 4. Number of cranes required 5. Develop crane order Execution rules 6. Interaction between cranes 7. Crane assignments and Zoning issues 8. Operator interaction and Requirements 9. Determine location and Number of drop-off and pick-Up Stations 10. Determine buffer requirements between stations. 11. Alternate analysis 12. Design verification 13. Visualization 14. Throughput verification	1. Layout & path 2. Control rules 3. Integration and Interaction With other systems 4. Verify safety rules 5. Visualization	1. Identify bottlenecks 2. Crane order Execution rules 3. Operating rules 4. Maintenance Schedules 5. Operator Interaction with cranes 6. Effects of downtime 7. Integration and interactions with other systems 8. Throughput Verification 9. Visualization

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Table 5 : Issues addressed by Simulation in the four phases of design of a Automated Storage/Retrieval System

	Phases of Material Handling project			
Material Handling Systems	**Concept**	**Design**	**Implementation**	**Operational**
Automated Storage/Retrieval Systems				
AS/RS Storage carousels	1. Requirement analysis 2. Communication 3. Visualization 4. Justification	1. Layout 2. Determine number of aisles, hays, bins of Stacker 3. Retrieval system specifications velocities, acceleration and Deceleration 4. Dimensions 5. Develop crane order execution rules 6. Order retrieval algorithms. 7. Zoning of storage and retrieval of parts 9. Integration of AS/RS with other material handling systems such as, conveyors and AGVs 9. Operator interaction and Requirements 10. Alternate analysis 11. Design verification 12. Visualization	1. Layout & Path 2. Control Riles 3. Integration And Interaction With other Systems 4. Verify safety Rules 5. Visualization	1. Identify bottlenecks 2. Retrieval system control rules 3. Operating rules 4. Maintenance Schedules 5. Effects of downtime 6. Integration and interactions with other systems 7. Throughput Verification 8. Visualization