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SIMULATION MODELING AND OPTIMIZATION OF STOCKYARD LAYOUTS FOR PRECAST CONCRETE PRODUCTS

Ramesh Marasini
Nashwan Dawood

Center for Construction Innovation Research
School of Science and Technology
University of Teesside
Middlesbrough TS1 3BA, U.K.

ABSTRACT

Stockyard is a hob of information that reflects the production, stock and sales of precast concrete products. The stockyard layout plays an important role in storage and retrieval of the products. Stockyard layout planning offers a complex task as large number of products are involved with different handling and storage requirements, and large stock is inevitable due to seasonality of demand. The major issues in planning stockyard layout include the proper design of stockyard space with roads and aisle networks and dynamic allocation of products to storage locations. A prototype "SimStock", an integrated process simulation model, was developed for planning and optimization of stockyard layouts for precast concrete products. The development of the prototype, its capacities and strengths with a case study are discussed.

1 INTRODUCTION

Precast concrete products industry is one of the major contributors of UK national economy and produces 1000-2000 different types of standard precast concrete products. The major clients are the Do-It-Yourself (DIY) stores and the construction industry. The demand for the products is seasonal; the industry adopts "make-to-stock" production philosophy. The products after production are transferred to stockyard where they are cured for two to four weeks. The peak demand being five to ten times higher than average demand (Dawood 1991), the industry builds up huge stock of concrete products for supply in summer. The industry invests huge capital in carrying stock and hence a great risk. In addition to cost and quality, efficient and timely delivery of the products is crucial to the industry for competitive advantage. During the peak sales, the industry is facing space congestion for storage and retrieval of the products, queuing of distribution vehicles, long throughput time and wrong deliveries. Stockyard layout is considered to be a major factor influencing throughput time for loading the concrete products for dispatch to the customers (Marasini, Dawood, and Hobbs 2001).

Stockyards under study store concrete products after production from the presses within the factory or transferred from other factory sites and the products are distributed to the customers from the stockyard. The management of stockyard layout necessitates a holistic approach to identify efficient stockyard layout, as it is a hob of information about production, stock and sales. Previous production planning studies have not considered storage spaces as one of the major variables in developing production schedules. This study has investigated stockyard spaces and layout together with the business processes associated to the storage and retrieval of the precast concrete products. A holistic approach to production, sales and stock management in consideration to storage and retrieval of products was used to model the stockyard layout and loading and dispatch process of concrete products. A prototype simulation model "SimStock" was developed to support dynamic allocation of products to storage locations (and bays), efficient vehicle routing in the stockyard. Arena 4.0 professional edition was used to develop the simulation model, which is customized to perform complicated tasks by linking it with MS Access and Excel using Visual Basics for Applications programming.

2 MODEL OBJECTIVES

The objectives in developing stockyard layout planning model were to:

1. Identify the layout modeling approach for stockyard layouts,
2. Identify the key performance indicators for the stockyard layout planning,
3. Integrate production and sales forecast information to study space requirements,

4. Identify the efficient routing of vehicles in the stockyard, and
5. Enable dynamic allocation of products to storage locations for efficient storage and retrieval of the precast concrete products.

Details about the methodologies used and findings about the layout planning approaches and application of simulation modeling has been presented in Marasini and Dawood (2000). In this paper, we are focussing on the development of integrated simulation model for stockyard layout planning and optimization.

3 INPUTS TO THE MODEL

Databases, spatial information about the stockyard layout (output from graphical layout design), production and dispatch schedules constitute the inputs to the simulation model. In addition, vehicle arrival patterns, loading (order-picking in general) policies, and orders (demand patterns) are also required to develop the simulation model. For a given layout, production and dispatch schedules, the loading and dispatch process is simulated to evaluate the objective parameters such as throughput time, loading time, queuing time, space utilization and loading resource requirements. Detailed description of inputs to the simulation model has been presented in Marasini, Dawood, and Hobbs (2001). In summary, the inputs are:

- *Dispatch patterns*
- *Production patterns*
- *Storage locations, their position and sizes*
- *Roads and their position*
- *Distances* between the locations and the travel routes, and velocity of vehicles are required to calculate the travel time and travel cost.
- *Knowledge of stacking requirements of products*: Bill of Materials (BOM) for each products with unit weight of storage unit, size of storage unit and recommended height of stock-shell based on safety considerations;
- *Handling weight*: Unit weight of products in terms of number of storage units of products) handled by the forklifts for loading and stacking.
- *Loading equipment details*: Number of forklifts and clamps available for loading and transportation, their unit loads.
- *Lorries arrival pattern*: Lorries arrive at different rates during the service hours and their hourly arrival rates or inter arrival times are considered to develop the model.
- *Loading (order picking) policies*: In general, applied to warehouse operations, order picking is the process of retrieval of number of items from their warehouse storage locations to satisfy one or more customer orders. In this study, it refers to the process of loading products into a customer lorry to satisfy one or more orders by a customer. The policy followed in order picking (products loading) also affects the resource allocation and throughput time on the yard. The policies considered are: Area and Zone System
- *Cost information:* The costs for use of forks to transport the products from the plants to the stockyard, to retrieve and load the products have been considered.
- *Mode of storage*: the concrete products are kept either in pallets or in a pack. Thus, the mode of storage in terms of packaging is fixed. Using the size of the storage units, the area required for a given amount of stock is calculated.

4 DEVELOPMENT OF THE SIMULATION MODEL

The simulation model represents loading and dispatch process of precast concrete products in the stockyard and consists of stock-initialization (product arrival), order processing, lorry arrival in the stockyard, vehicles routing and loading processes (Figure 1). The loading and dispatch process is as following. A distribution lorry arrives in the stockyard to serve an order placed by the customer. In the entry gate, a pick-slip is given to the lorry and the loaders with forklifts, clamps or cranes pick up the products from different locations. The lorry travels through the main path whereas forklift trucks move to different aisles find the product and load into lorry. When the loading for the products stored in one location is finished, the lorry and loaders forward to next location along the main route and the process is repeated to load all the products ordered. In the simulation model, travel routes were modeled as a network of graphs. The sequence of visiting different storage locations to pickup the products to serve an order are calculated using the Fencl's heuristic algorithm (Fencl 1973). Dijkshtra's shortest path algorithm has been used to find shortest route to travel to different locations in the stockyard. The customization and integration of information for Access and Excel, and integration of different algorithms was achieved using VBA programming. A loading process template (Marasini 2002) was also developed to model the loading and dispatch operation in the stockyard. This template in Arena enables rapid modeling of loading and dispatch process for precast concrete products. The information about production and forecast of sales information are stored in MS excel and used for the initialization of stock in the stockyard. MS Access database is used to store the product attributes and spatial attributes of the stockyard. The network of roads and aisles are designed using AutoCAD using knowledge rules through a semi-automated procedure. VBA macros have been developed and used to

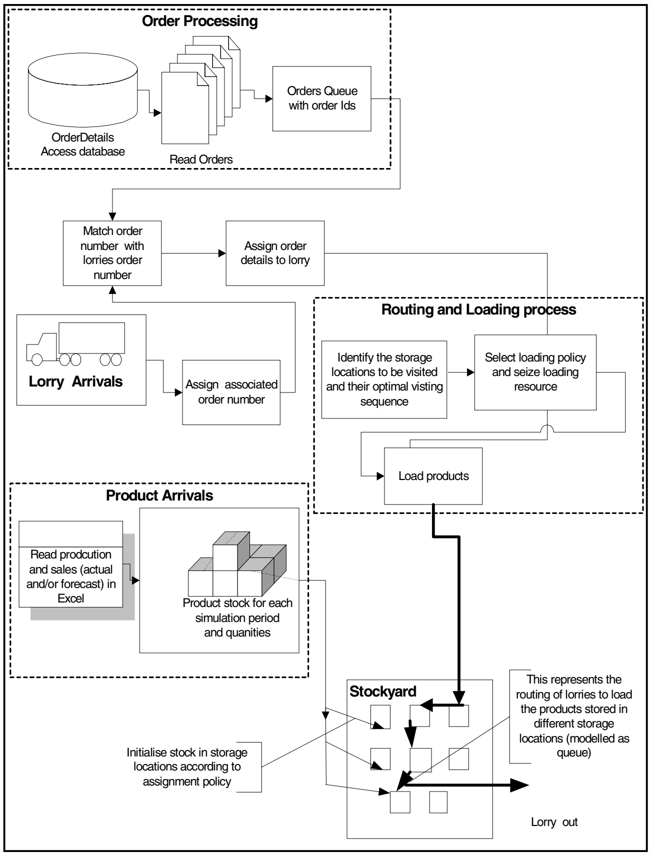

Figure 1: Loading and Associated Stockyard Processes

store the spatial information in MS Access relational database, which is used to calculate distances between different storage locations and aisles.

5 INTEGRATION WITH OTHER WINDOWS APPLICATIONS

Using Visual Basics for Applications, the simulation model inputs are derived from MS Access databases, production schedule and sales forecast information from MS Excel. Some examples of using Arena and VBA to develop customized complex simulation models can be found in Kelton, Sadowski, and Sadowski (1998) and Seppanen (2000). The spatial layout of storage areas, main roads and aisles information within the factory premises are designed in AutoCAD and stored in the databases using VBA and AutoCAD dbConnect feature. The database structure used to derive inputs to the simulation model has been presented in Dawood and Marasini (2001). The graphical layout is imported in Arena environment as DXF file for the purpose of animation. Figure 2 shows an integration of Arena simulation model with other applications from which inputs to the model derived. The inputs can be changed easily to generate and study several "what-if" scenarios; space requirement for different production and sales scenarios can be calculated and dynamic allocation of products to storage spaces is possible.

6 SIMULATION RUN

Figure 3 presents an animation of loading and dispatch process of concrete products in Arena 4.0 environment.

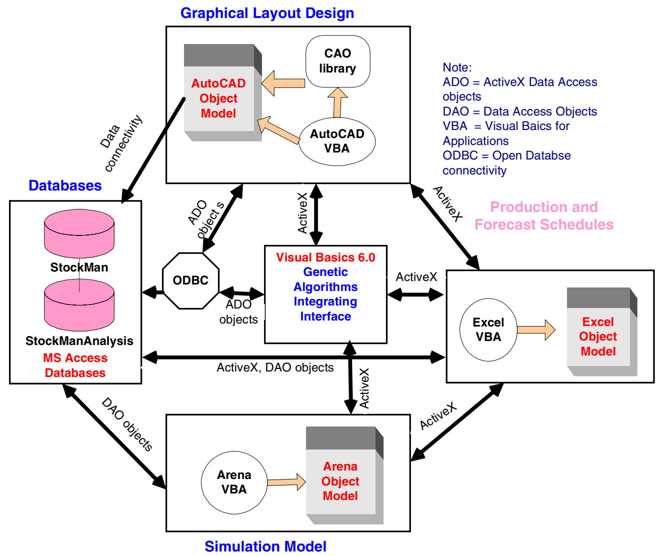

Figure 2: SimStock Development Architecture and Integration

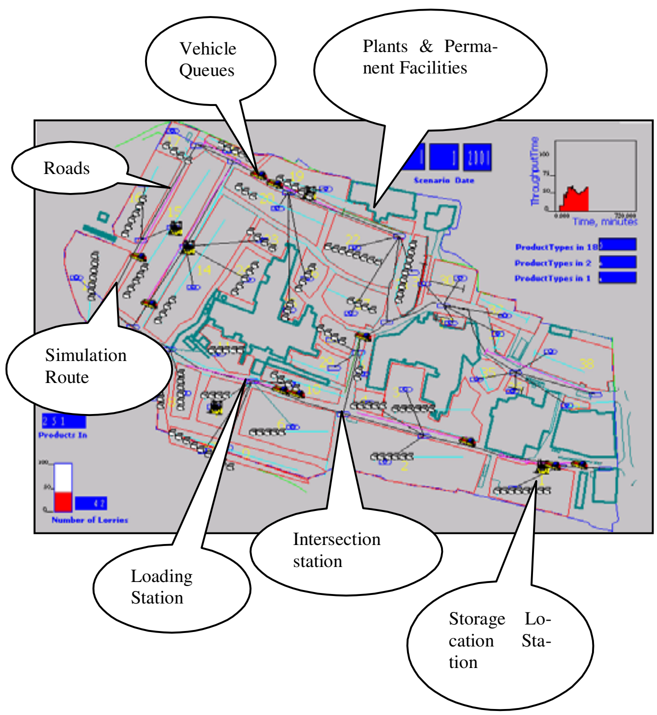

Figure 3: Running and Animation of the Loading and Dispatch Process

The stockyard layout simulation belongs to terminating type of simulation models (refer Kelton, Sadowski, and Sadowski (1998) for detail descriptions). The simulation will start and terminate according to some specified rule or condition. For instance, the loading and dispatch process starts at 6 AM and finishes at 6 PM (until lorries being served are finished). The model runs 1-day scenario, which could represent a day for daily scenarios or an average day for the week based on weekly scenarios or average day for each month of the year for monthly scenarios being simulated. Due to unavailability of daily or weekly schedules, this study has used monthly scenarios and hence the model runs an average day for each of the month of a year. Therefore, the model runs to simulate one-day scenario for each month to evaluate stockyard layout design by measuring the key performance indicators (KPI). For each replications, the run length was set to 720 minutes (6 AM to 6 PM, i.e. 12 hours *60 = 720 minutes). Statistics are collected about the entities, resources, variables, queues and cost of loading of the products.

7 MODEL OUTPUT

The animation of the model provides visual scenario of the stockyard for the simulated scenario. Outputs are saved as text files and stored in MS Access database. The parameters evaluated include :

- Storage Space Utilization (SSU) ratio = storage space occupied / total available storage space, SSU < = 1.0
- Total Cost of storage and dispatch.
- Total cost = Cost of Transport from Plant to storage + Cost of retrieval
- Throughput time on stockyard for a lorry loading for the purpose of dispatch
- Vehicle waiting times and queue length in the stockyard.

8 OPTIMIZATION USING GENETIC ALGORITHMS

Simulation models support measure and analyze process performance and develop future process design (Aguilar, Rautert, and Pater 1999) as is the case with the stockyard layout planning simulation model developed in this study. Paul and Chanev (1998) highlight that mostly simulation models are developed to measure the output or model performance with given input parameters and structure of the model but finding the parameters and /or the structure of the model that will produce the desired output is rarely used. The latter is more complicated to solve and difficult for classical optimization problems. Paul and Chanev (1998) demonstrate a real-coded GA for steelworks simulation model. We have used simple GA with integer representation to find out the optimum allocation of the concrete products to storage locations that will ensure minimum throughput time required in loading and dispatching the products from the stockyard. Simple genetic algorithms were developed in VBA and integrated with the stockyard layout simulation model to identify the best allocation of clusters of products to the storage locations. The clusters represent a group of products that tend to be shipped together, which are obtained by the analysis of sales historical data. Genetic algorithms were utilized for the optimization due to their capability to deal with the large problem domain. The optimization process has been presented in Marasini and Dawood, 2001.

9 SIMSTOCK AS STRATEGIC / ANALYSIS TOOL: A CASE STUDY

A case study was used to test and validate the simulation model in one of the major UK precast concrete products manufacturing company. Lorry arrival patterns, service times and generation of simulated orders for the purpose of simulation have been described in Marasini, Dawood, and Hobbs 2001. Analyzing three peak months sales history data, it was found that 24% (251 out of 1056 products) were ordered 87% of times with average frequency of one per day. These products were referred as A-class products. The production and sales information about A-class products was used to run the simulation model. The model was run by varying spatial configuration, production and sales schedules, resources, vehicle routing policies and order picking policies. Some of the examples are described as follows.

To study the variation in average throughput time in different months of the year, the results of 25 replications made for each month for the existing, random and GA allocations were analysed. Figure 4 shows the simulated average throughput time values for each months of year 2001 with a comparison of average values for existing, random and GA allocation. From the experimentation, it is concluded that:

1. The allocation of products to storage location in the stockyards has significant impact on throughput time for loading and dispatch of concrete products. The queuing of lorries in the stockyard is also reduced.
2. The GA allocation of products has reduced average throughput time by 3.13 and 6.68 minutes as compared to existing and random allocation of products for the analyzed scenarios. The average throughput time for GA allocation being 30.5 minutes. This has proved the potential of GA to solve the allocation of products to storage locations.

Figure 5 shows the average number of lorries being serviced in the stockyard for different months. The existing

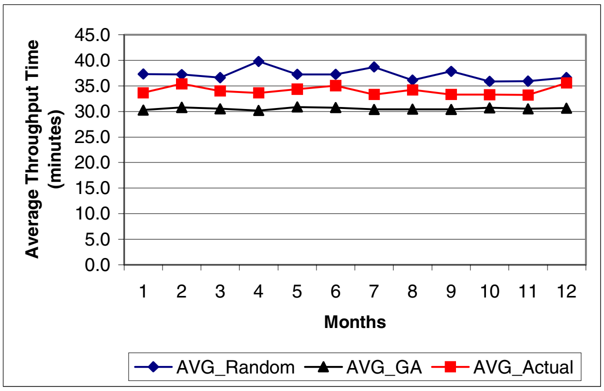

Figure 4: Variation on Average Throughput Time with Different Assignment of Products to Storage Locations

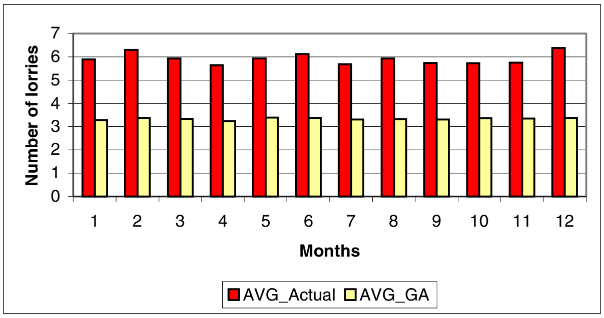

Figure 5: Number of Lorries on the Stockyard on Progress

(referred as actual) scenario has shown higher number of lorries. It is inferred that the GA based allocation has reduced number of lorries in service in the stockyard and therefore, queues will be smaller. It should be borne in mind that the figures are indicative due to the use of A-class product's production and forecast of sales data. However, it justifies the objective of the study.

The prototype enables study of the space utilization under different production schedules hence provides tools to production planners to investigate storage spaces while developing production plans. The resource requirements can also be analyzed. Due to the unavailability of the different schedules, the variation in space utilization under different production schedules could not be studied. For the production plan studied (for 251 products), the space utilization was studied by varying sales by +/- 10% (Figure 6) and by varying sales by +/- 10% production (Figure 7). The figures show the space utilization by A class products in different months for different production and sales scenario.

The animation of the simulated processes is a simple and effective method of communicating the system functioning. The simulation model logic, in SimStock, was verified by observing the animation of queue build-up process, lorries and forklifts visiting different loading stations and storage locations. The animation revealed that the model is replicating the "as-is" situation of queuing of vehicles. The model was presented to the managers of three

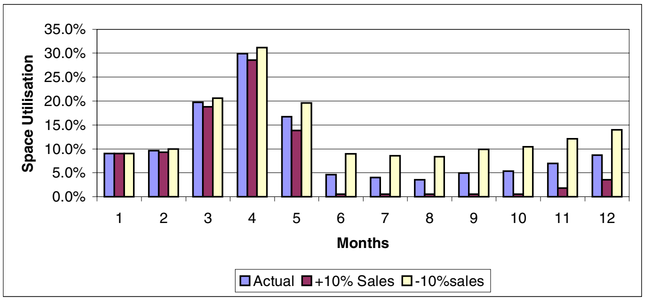

Figure 6: Comparison of Variation in Storage Space Utilization for A- class Products using Actual and +/- 10% Sales (No Production Variation)

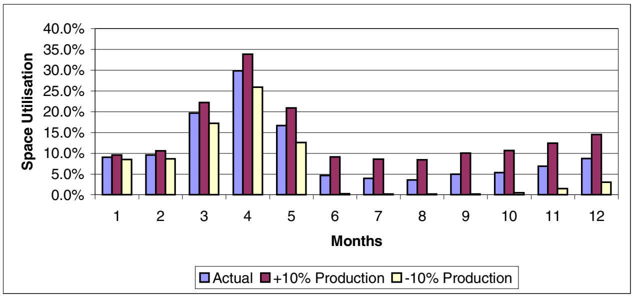

Figure 7: Comparison of Variation in Storage Space Utilization for A- class Products using Actual and +/- 10% Production (No Sales Variation)

different companies and helped them to understand the implications of different stockyard layouts. The simulation model has shown potential to be used as strategic decision making tools for efficient storage and handling of precast concrete products in the stockyard. It is envisaged that the implementation of SimStock could save 5 to 10% of the cost of delivery of products to the customers in one factory site.

10 CONCLUSIONS

This study has investigated in-depth the stockyard layouts, the allocation of products to storage spaces and stockyard space utilization for different production plans. A process simulation model was developed that demonstrates a methodology to model stockyard layouts. Genetic algorithms were developed and used to identify the clusters of products that are frequently ordered together and to assign the developed clusters to storage locations. The integration of genetic algorithms with the simulation model has demonstrated an approach to optimize simulation model inputs to obtain desired outputs; an example is the identification of allocation of products to storage locations to reduce throughput time to service orders in the stockyard. Genetic algorithms, integrated with the simulation model, have proved to be potential techniques to identify the allocation of products to storage locations. This was justified by the significant improvement in average throughput time to service orders using GA-based allocation of products to storage locations as compared to the random and existing allocation of products in the case study site. It was established that process simulation model could be efficiently used for stockyard layout planning and their evaluation.

The integration of different windows-based software applications for stockyard layout planning was achieved using Microsoft's Component Object Model (COM) technology mainly using Active-X automation, Data Access Objects (DAO) and ActiveX Data access Objects (ADO). The strength of VBA has enabled the development of customized integrated simulation model. This approach could be used for other industries, where the model inputs are presented in spreadsheets and databases.

The model aids decision making process by providing a means to evaluating different "what-if" scenarios with different production schedules, storage policies, loading (order picking) policy and different spatial layout of stockyards. The model is a tool to provide more effective product allocation strategies. This will help to disseminate the advantages of simulation models for layout planning. The prototype also acts as a tool for the visualization stock data in terms of location, quantity and storage space utilization and acts as a decision making tool.

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AUTHOR BIOGRAPHIES

RAMESH MARASINI is a Research Fellow in Center for Construction Innovation Research, School of Science and Technology, University of Teesside, UK. He received his Ph.D. from Teesside University in 2002. His research interests are in simulation modeling, artificial intelligence and construction information technology. His email and web addresses are <R.Marasini@tees.ac.uk> and <sst.tees.ac.uk/external/u0018615>.

NASHWAN DAWOOD is a Professor of Construction Management Information Technology at Center for Construction Innovation Research, School of Science and Technology, University of Teesside, UK. He received his Ph.D. from Loughborough University in 1991. His research interests are mainly construction information technology, virtual reality, simulation modeling and decision support systems. His email and web addresses are <N.N.Dawood@tees.ac.uk> and <sst.tees.ac.uk/external/u0000923>