The building products manufacturing industry supplies a wide range (2,000 to 4,000) of pre-cast concrete building products to the construction industry. Sales in the industry are highly seasonal; demand is high in summer and very low in winter. For the industry to cope with such fluctuations and maintain a fairly constant production rate, stock is built up in winter and dispatched in summer. The products stay on the yard for four to five months. Due to improper stocking of products on the yard, the industry experiences space congestion for both the storage and dispatch of products. During dispatch process, it becomes difficult to track the products for loading into lorries, long queues of lorries are formed and desired level of service cannot be maintained. To address this problem, it is seen essential to devise an appropriate stockyard layout planning system that advise management on physically stocking products in the yard by providing fluency of stock, minimizing loading time of dispatches and maximizing efficiency of stock rotation. This paper presents a review of stockyard operations, analysis of parameters affecting loading and dispatch process on the yard and strategies to optimize the stockyard layout. It is expected that a proper layout will reduce the cost of delivery of products by 5–10%.

Keywords: artificial intelligence, pre-cast building products, simulation, stockyard layout.

INTRODUCTION

The building products industry supplies a wide range of pre-cast building products to the construction industry. The demand is high in summer and low in the winter as the major construction works are carried in summer. To account for the seasonality of demand, large stock is built in winter and dispatched in summer (Dawood 1995). The pre-cast concrete products after preliminary curing are transported to the stockyard using forklifts and clamps. The products need 3 to 4 weeks for curing and then they are ready for sale. The products produced during winter stay on the yard for four to five months. From an industry point of view, the products produced first should be dispatched first and the products need sufficient curing time for gaining adequate strength. This needs rotation of products stock within the yard.

The dispatch of pre-cast building products from the yard is unique to the industry. The products are supplied to the customers using lorries whereas forklifts and clamps are used to load the products into the lorries. Upon arrival to the yard, usually the lorry takes main routes along the stockyard and forklifts move across the yard to pickup the products. During the period of high sales, massive stock is present on the yard occupying almost all the space available. The lack of appropriate techniques that
advises suitable location of the products on the yard and help tracing them for dispatch, products are stocked on the yard intuitively. This makes the dispatch of products from the yard very complex and inefficient. A long queue of lorries is formed; desired level of service cannot be maintained. To cope with the situation and upkeep the level of sales, it is essential to devise a system that suggests about the suitable locations of the products on the yard, guides loaders about the route to be followed during loading and considers ease of handling products.

The production planning aspect in pre-cast products industry has been dealt with in Warszawski (1984) and in Dawood (1994, 1995). However, the stockyard management and its implications in production planning need to be considered. It is indispensable to treat stockyard space as a resource, and its proper management is very crucial to increase of throughput over the entire products transport chain. The appropriate planning of stockyard layout is required to ensure the optimal choice of storage space (locations), effective utilization of storage areas, minimization of products movement, ease of loading products for dispatch to the customer and hence timely supply of products. This created an impetus to study about the stockyard layout planning aspects in pre-cast building products industry.

The following sections describe the nature of stockyard layout, literature review to identify appropriate techniques to model stockyard layout and then introduce a case study of current practices. Finally, a proposed intelligent system is presented.

CHARACTERISTICS OF STOCKYARD LAYOUT

Prior to reviewing the appropriate techniques to solve stockyard layout problems, it is worthwhile to familiarize with the problem and hence its characteristics are enumerated as following.

1. The layout is dynamic in nature. Different products are produced from a plant over a period of time; new products occupy the resulting vacant space after dispatch of products from the stockyard.

2. Large number of products (in the range of 2000 to 4000) are stored in the yard so that determining the location of individual product offers a complex problem which consumes time and resources; manually ensuring efficient layout becomes almost impossible.

3. Multiple criteria should be considered while determining the appropriate layout. They are: least product handling cost, reduction of inventory holding cost, ease of loading and dispatching products, ease of product rotation and safety considerations.

4. Due to heavy weight of products, power operated vehicles i.e. fork lifts and clamps are used for transporting and loading the products. Lorries are used for supplying products to the customers. The efficient routing of vehicles in the yard is vital to optimize the loading and dispatch process.

5. The production schedule and dispatch schedule must be integrated to study the dynamic behaviour of stockyard. Production planning policies and marketing strategies has direct impact on the inventory so a holistic approach is required to solve stockyard layout problem.
REVIEW OF PREVIOUS LAYOUT PLANNING TECHNIQUES

The state-of-the-art techniques used to solve facility layout problems (manufacturing industry) and the temporary facilities layout on construction sites (construction industry) were reviewed as no relevant study was found in stockyard layout planning. These industries were chosen, as some of their characteristics are common to the stockyard layout problem in pre-cast building products industry.

The early efforts to solve manufacturing facility layout problems used operations research (OR) techniques. The objective of OR techniques is to minimize of the distance travelled by personnel or material handling carriers between each pair of the facilities. The aim of these methods was to determine acceptable alternatives rather than optimal using heuristics. Early computerized systems such as Computerized Relative Allocation of Facilities- CRAFT (Armour and Buffa 1963, Buffa et al. 1964), Computerized Relationship Layout Planning- CORELAP (Lee and Moore 1967) and Automated Layout Design Program- ALDEP (Seehof and Evans 1967) were based on operation research techniques. These methods used quadratic assignment formulation, which divides the site into a rectangular grid with each cell or a set of cells in the grid assigned to a facility. These systems including their improvements in later years (several references are available in Jacobs 1987) use single objective as an optimization criterion to solve facility layout problems.

Muther (1973) uses closeness ratings (high rating indicates that is absolutely necessary for the two departments (facilities) to be together and vice versa) as a qualitative technique to solve the facility layout problems.

Rosenblatt (1979), Fortenberry and Cox (1985), Jacobs (1987) treated the facility layout problem as having multiple objectives on the layout solutions. Fortenberry and Cox (1985) combined qualitative and quantitative approaches by weighting workflow by closeness ratings. Jacobs (1987) used multiple factors to evaluate the layout such as the weighted distance between interacting layout elements, the structure of the final layout design, the use of circulation space in the layout and satisfaction of special adjacency requirements.

The shortcomings of quadratic assignment problems to deal with different geometric shapes as well as to solve problems consisting of large number of facilities, Tam and Li (1991) presented a hierarchical procedure. They utilized continual plane approach in layout design and hence grid was eliminated. In this approach, the facilities can be placed in any location within the designated area. The process involved three phases: cluster analysis, initial placement and layout refinement. Cluster analysis was used to combine facilities into clusters; the layout of each cluster was determined; each cluster was treated as a large facility to generate the overall layout.

Since the mid-1980s artificial intelligence (AI) techniques were used as an aid to OR techniques. AI emphasizes more qualitative aspects of the problems, and rely on expert knowledge and heuristics to solve the problems and use inferential approaches. Kumara et al. (IFLAPS- Intelligent Facilities Layout Planning System 1988), Malakuti and Tsurushima (1989) developed expert systems to system to solve multi-criteria facility layout problems. Welgama and Gibson (1993,1996) developed an integrated methodology for automating the process of determination of layout and material handling system. They developed knowledge-based /optimization algorithm to solve such problems.
With the advancement of artificial intelligence techniques, several studies are being conducted to utilize them to solve facility layout problems. Tam (1992a) and (1992 b) used simulated annealing algorithm and genetic algorithm respectively in designing facility layout. Ishlier (1998) demonstrated that genetic algorithms (GA) could be utilized to solve multiple criteria facility layout problems. Shayan and Al-hakim (1999) described the potential of GA to solve unequal area facility layout problems.

Unlike facility layout problems, the layout of temporary facilities in construction industry is dynamic in nature. The typical factors influencing the layout of the temporary facilities are: frequency of travel between facilities, access to roads/ utilities, nature of usage, space requirements of the facility, type of terrain, duration of facility requirement, project schedule and human factors (Philip et al. 1996). Due to ill defined, fragmented nature of construction industry, AI techniques are popularly used in planning temporary facility layouts on construction sites. Mainly expert systems and knowledge base systems have been developed to solve temporary facilities layout problems. The OR techniques are embedded within the AI systems wherever required.

Tommelein et al. (1991) explored the possibilities of using artificial intelligence modelling to site layout problems and developed a knowledge-base system called SightPlan. SightPlan uses diverse domain knowledge sources, functioning independently, to solve co-operatively by recording and exchanging solution elements on a global data structure. It uses procedural constraint processing to reach to the solution. Tommelein and Zouein (1993: MovePlan) addressed the dynamic nature of temporary facilities on construction site and integrated layout planning with scheduling and used resources required to perform activities. A dynamic layout of a construction site, for a selected time interval, was achieved by positioning temporary facilities and tracking the movement of materials and the equipment in relation with the schedule. Zouein (1995) alleviated space conflicts (limitations of MovePlan) by changing activity duration and resource use, and propagated these changes through the schedule. She developed a prototype system called MoveSchedule, and modelled how space gets freed up when resources are consumed, so that it is available to accommodate others. MoveSchedule solves a constrained dynamic layout problem with the objective of minimizing resource transportation and relocation costs.

CAD based approaches are also utilized in construction industry. Williams (1996), McKinney and Fisher (1997) described about the use about 4D models (3D-CAD +time) to visualize the construction process. Through the simulation, integrating 3D CAD models with the schedule, the construction process is visualized. The situation of construction site at any time is traced, the positioning of temporary facilities and what if analysis is carried out to decide with the efficient locations of the facilities.

**Conclusions from literature review**

The review of literature on construction site layout and manufacturing facility layout problems suggested that artificial intelligence techniques are potential techniques to solve problems having multiple objective criteria and having ill defined nature. Further, the domain specific constraints can be accounted through AI techniques. As the layout problems are treated as NP-complete, the objective of solving such problem is always to determine suitable and nearly optimal solution that satisfies the desired criteria. The hybrid approach that uses artificial intelligence techniques and embeds OR techniques wherever required is seen as a suitable approach to deal with the multiple criteria stockyard layout problems.
INDUSTRIAL CASE STUDY

One of the stockyard sites of a major pre-cast building products company in UK (not named for confidentiality) was used as a case study. The company is one of the major suppliers of thousands of different pre-cast concrete building products to the construction industry mainly in UK and some in other countries. The major products include paving, walling, and garden products. The products are produced from a number of flexible, automated presses that are capable of producing different products. The products are produced in different sizes and colours.

The company adopts make-to-stock principle to produce concrete products to meet the seasonal demand. Thousands of different products produced during winter are stocked on the yard. As an order is received, the products are shipped to customers for delivery using lorries. A study conducted on the site reveals that the products are delivered countrywide utilizing a fleet of between 65 and 205 vehicles per day.

Products loading and dispatch process

The products are dispatched from the stockyard using lorries. The process consists of picking slips from sales department, getting loading resources (loaders and forklifts) to load the products and loading of products into the lorries. The lorry takes a main route while forklifts move to the different locations to pick the listed products and the products for loading. Once all products listed in slip(s) are loaded, the sales department checks them finally and the invoice is issued.

Throughput time

The time required for loading to serve a particular order and probable queuing time on site depends on the efficiency of stockyard. The stockyard layout has direct impact to the throughput time that is defined as the time spent by a lorry in the stockyard for loading. Quantitatively, throughput time is the difference in time of arrival of a lorry to the yard and the time when it leaves the yard after loading.

To assess the parameters that have potential impact on throughput time on the stockyard for loading and dispatch of products, work-study was conducted on the site during August and September 1998. This period was chosen for study as it represents an average situation of sales. Using random sampling method, 228 observations were made in 8 days. The time for loading each product on a particular load, number of loaders used, the number of packs and the number of product locations visited were recorded. The actual loading and queuing times were calculated. The study revealed that the average loading time is 30.75 minutes and queuing time is 49.56 minutes, thus queuing time is 61% more time than the time required for loading. The throughput time, the sum of loading and queuing time, is hence high (average 80.31 minutes) because of time wasted in queuing on the yard.

Correlation Analysis

In order to identify the factors causing long turnaround time, a correlation analysis was carried out between the following parameters.

1. Number of products: Each lorry loading consists of one or more products.
2. Number of packs: Pre-cast concrete products are packed in a pack having certain standard number and stacked. Each lorry loading consists of different number of packs.
3. Number of loaders: Each lorry loading requires at least a loader. Depending upon the requirements and availability, the number of loaders assigned for each delivery will be different.

4. Number of areas visited: As products are located at different areas, the loading process requires visiting different areas to load the products. With the increased number of areas to be visited, the complexity of loading process increases.

5. Loading time: This represents actual time required to load the products into the lorries without any disturbances.

6. Queue time: This is defined as a time waited by a lorry for loading in the stockyard. As the time to travel from one location to other is short and neglecting it, this is calculated as the difference between total time used on site and the exact loading time.

The result of correlation analysis of these parameters is presented in Table 1. There is a positive correlation between the number of products to be loaded with the number of loaders (r = 0.69), number of areas visited (r = 0.63), loading time (r = 0.43). The positive correlation between the number of products in a load with the queuing time (r = 0.43) suggests that with the increase in number of products in a load, the queuing time also increases, as it is likely that the lorry has to wait at different locations. Also, the positive correlation queue time with number of loaders (r = 0.5), number of areas visited (r = 0.26) and loading time (r = 0.27) indicates that complex loading pattern also contributes to queuing.

The correlation coefficient between number of packs in a load is not significant with the number of products, number of loaders or number of areas visited. A slight negative correlation between queuing time with number of packs (r = -0.14) is observed which is difficult to explain. However, it can be stated that the number of packs is not a representative parameter in the analysis of loading and dispatch process. The reasoning behind this is that the products are handled in different ways and more than one pack is picked up in one time.

The correlation coefficient between number of loaders and number of areas visited is 0.57 indicating that if the numbers of areas (locations) visited are more, then number of loaders required for that loading will be more. But the increase in number of loaders does not reveal decrease in loading time (r = 0.32). Further, the queuing time has positive correlation with number of loaders (r = 0.5) indicating that greater number of loaders are required for a complex loading and hence a longer queue is formed on yard. It is, however, contradicting to the assumption that the queuing time should decrease with the increase in number of loaders. Analysing the results of

<table>
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<th>No of products</th>
<th>No of packs</th>
<th>No of loaders</th>
<th>No of Areas Visited</th>
<th>Loading Time</th>
<th>Queue Time</th>
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<td>No of Areas Visited</td>
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<td>0.575</td>
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<td>Loading Time</td>
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<td>0.317</td>
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<td>Queue Time</td>
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<td>-0.137</td>
<td>0.501</td>
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</table>
correlation analysis, it can be said that the behaviour of loading of dispatch process constitutes a complex process.

**Conclusions from Correlation Analysis**

1. With the increased number of products in a particular loading, the number of loaders required is higher and the loading time and queuing time is higher.
2. There is no significant impact of number of packs on loading. The time required for loading resource depends on the magnitude of the handling weight and quantity of each product. The data is not representative in terms of number of packs in a loading.
3. As the number of areas to be visited for loading increases, queuing time also increases.
4. Queuing time is 1.61 times the loading time; the queuing problem exists on the yard. The current layout of yard is contributing to high queuing time. An improved layout of stockyard is imperative.

**Strategies to reduce throughput time on yard**

A preliminary study of stockyard site suggests that throughput time is dependent on:

- Number of products in an order
- Number of locations to be visited for loading
- Number of loaders assigned
- Total quantity (tonnage) of products

The throughput time for loading a lorry can be increased by following ways.

1. Developing and implementing appropriate stockyard layout
   - Defining product locations
   - Fixing travel routes for material-in and products transport from production facilities to yard
   - Minimizing travel routes for loading vehicles- forklifts and lorries
   - Ensuring adequate space for manoeuvre of vehicles, ease of rotation of products inter-bay or intra-bays, safety in stacking and destacking of products

2. Implementing management strategies
   - Minimizing diversity of products
   - Reducing inventory of products implementing just-in-time production strategy
   - Considering stockyard space availability as one of the criteria in deciding the production plans
   - Fixing minimum service load in an order
   - Defining arrival time for lorries
   - Increasing the number of loaders
   - Implementing appropriate communication system

Among these two, the determination of suitable yard layout is a first step and the latter should be implemented to achieve increased efficiency. It is essential to emphasize that these options should not be seen in isolation but in integration. However, the implementation should be practised in steps.
The proposed system architecture (Figure 1) to optimize the stockyard layout consists of knowledge based layout generation and testing the appropriateness of the generated layout in terms of its efficiency in loading and dispatching process through simulation. The system consists of user-interface; databases and schedules as data inputs; knowledge base components: knowledge rules and inference engine as processors; and final graphical layout of the stockyard as output. The integration of production and dispatch schedules help model the dynamic behaviour of the stockyard whereas the simulation integrated on this model acts as a tool for testing different strategies.

Software viz. ILOG (ILOG, Inc.) and ARENA (Systems Modelling Corporation) are being evaluated as potential software for the implementation of the system.

INFORMATION AND KNOWLEDGE NEEDED FOR DEVELOPING THE SYSTEM

The following information is needed for developing an understanding of this problem.

1. Dispatch patterns: this includes information about sales patterns of products i.e. frequency of product demand and product mix patterns of demand.

2. Production patterns: this includes weekly and daily schedules of production lines and plant.

3. Access of stockyard, width of roads and turning radius for the movement of lorries, aisle spaces required by the forklifts, and the routes for raw material delivering vehicles.
4. Knowledge of stacking requirements of products: weight considerations, height and width and geometry of a single stock shell; handling weight (or number of products) by the forklifts for loading and stacking.

5. Travelling time of product handling vehicles (forklift trucks) from loading points to any location in the stockyard and unit cost of handling products.


8. Knowledge of different layout patterns of products to ease the rotation of products so those products produced first will be dispatched first retaining the ease of loading.

9. Constraints in stockyard operations, production and dispatch schedules.

CONCLUSIONS

This paper identified the need of a suitable stockyard layout planning system for a pre-cast building products industry. AI techniques, preferably knowledge base systems, are considered potential techniques to solve stockyard layout problem. The parameters affecting throughput time on the yard are defined and the information required developing a stockyard layout planning model using AI techniques are enumerated and necessary foundation for suitable software selection and for the future research has been established.

REFERENCES


