SIMULATION FOR FACILITY LAYOUT REDESIGN:
Coventry City Council: Reengineering a multi-activity depot layout

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ABSTRACT

This paper presents an application of simulation modelling within a facility layout reengineering on behalf of a services' organisation; Coventry City Council (CCC). This organisation was burdened with its operational activities that take place at its depot. The available parking places were not adequate to meet the fleet's needs and, in addition, were disproportionally dedicated to the operational activities. Some parts of the depot were bustle with life whereas others were laid idle. Consequently, the poor depot design resulted in inefficiencies in terms of heavy congestion at the entry-exit points, at the resources (fuel station, waste transfersite etc.), Health and Safety issues, lack of control, low space utilisation, high risk of vandalism, and untidy appearance. Therefore, the major objective of this project constitutes the redesign of the depot's layout after evaluating alternative viable plans and deciding on the most valuable. To address this facility layout problem, simulation modelling was employed. Testing various risk-free scenarios, managers could study the performance characteristics of the proposed layouts without affecting the real system. The recommended layout involved the reallocation of resources, the reorganisation of the network of roads, the operational vehicles to be parked at dedicated parking places, and explicit operating rules to be followed by the drivers.

INTRODUCTION

The dynamic character of today's competitive environment forces organisations to an incessant reassessment in an effort to respond. Their facilities, though, should be considered as an integral part of this effort. Hence, organisations must continually revaluate their existing facilities to ensure that they are consistent with both the environment's demands and the management's strategic requirements. For the majority of organisations, though, the first response to any perceived facilities demands is to employ an architect or an industrial engineer. However, the design skills that these specialties tender are only one aspect in creating prudent, cost-effective and long-term facilities restructuring. Amidst this convention, organisations need a clear strategy that incorporates an explicit facilities reengineering plan.

This paper describes an experience where the authors used simulation modelling to redesign a depot's layout after evaluating alternative viable plans and deciding on the most valuable in terms of efficiency. It involves work undertaken for Coventry City Council (CCC). CCC has a depot based in Whitley, Coventry. The depot consists of two distinct parking sites, one for operational vehicles and one for private cars. The depot has a number of diverse operational activities interacting with each other: Street Cleansing; Grounds Maintenance; Waste Services; Special Needs Transport; Highways Works; Street Lighting; Taxi Licensing. It accommodates about 300 operational vehicles that represent these activities. They arrive at the depot to tip; to fuel, to have access to the water supply; to wash out; to be inspected; and to park.

This organisation was burdened with its synchronising operational activities due to disconnected and scattered storage structures and space constraints. The existing network of the logistic activities related to the arrival, loading, and departure processes of the vehicles in the depot showed no clear, underlying plan. Some parts of the depot were bustle with life whereas others were laid idle. The available parking places were not adequate to meet the fleet's needs and, in addition, were disproportionally dedicated to the operational activities. Consequently, the poor depot design resulted in inefficiencies in terms of heavy congestion at the entry-exit points, at the resources (fuel station, waste transfersite etc.), Health and Safety issues, inaccessible resources, lack of control, low space utilisation, overcrowded aisles, high risk of

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vandalism, and untidy appearance. Moreover, the operational vehicles have not got priority over the private ones. In fact, the depot can be viewed as a number of finite operational vehicles arranged on the depot's parking places and a number of resources (i.e. fuel station, waste transfersite, water supply, high pressure washing, and workshops). The spatial rearrangement of these facilities (vehicles, parking places and resources) in an effective manner is what OR people call the *facility layout problem*. Thus, although the facility layout problem may arise in many contexts and can be solved by various approaches, in this case the authors used simulation modelling to evaluate alternative layouts that derived from a strategic facility reengineering framework.

This paper is organised as follows. *Section 2* draws upon literature from the topics of facility layout problem and simulation modelling. Based on the review, a methodology was developed in order to render operational for this application *(Section 3)*. *Section 4* constitutes the main body of the empirical investigation. *Section 5* discusses any implications. Finally, *Section 6* provides the conclusions of the entire depot's reengineering plan and suggests areas and gaps for further work.

LITERATURE REVIEW

Since the whole body of literature in the field of facility layout planning is extensive, this review is, therefore, selective. It deals with literature that provides an overview of different approaches for solving the facility layout problem and reveals the need to incorporate simulation modelling within layout reengineering.

The facility layout problem concerns the spatial and non-overlapping arrangement of numerous interrelated activities to achieve some objectives. There is no single and user-friendly OR methodology that can ensure provably optimal solution and good run times and incorporate the strategic mindset.

In an effort to design and evaluate alternative layouts, many *optimisation* approaches were proposed.

- *Mathematical modelling* demonstrates an optimal solution but only in case of small or greatly restricted problems (Foulds and Robinson, 1978; Montreuil and Ratliff, 1989; Boswell, 1992).
- *Heuristics* can usually give a sufficient (but not optimal) solution quickly in case of large-scale problems (Jaydeep et al., 2003). These algorithms are available as layout software packages.
- Finally, literature provides also some *hybrid algorithms* that represent a combination of approaches. For instance, Dunker et al. (2005) presented an algorithm that combines dynamic programming and genetic search for solving a facility layout problem.

Despite their effectiveness, these approaches imply difficult-to-use mathematical formulations and in addition, require accurately defined design objectives and constraints. *Approaches based on graphical representation* were developed in order to offer more comprehensible procedures, the possibility of adding multidimensional factors and not having accurately defined elements.

- *Systematic Layout Planning (SLP)* represents this category (Muther, 1973). However, this approach focuses on a functional way of thinking.
- Thus, in order to "get away from the functional mindset and meet today's rapidly changing strategic operations needs", the *Strategic Facility Planning (SFP)* was built on the earlier approach of SLP (Wrennall and Lee, 1994).

However, none of the above methods looked at the facility layout problem as a large-scale reengineering project. Thus, *integrated facilities reengineering approaches* were developed.

- The most effective one seems to be that of the *FacPlan method* proposed by Lee (1996).

A step forward is that of *simulation modelling*. While it is *certainly not a scientific measure*, simulation models can be an extremely valuable, timely and cost-effective means to study the performance characteristics of a proposed layout. By providing system-wide views of the impact of changes to the existing system without physically building, amending or interrupting the system, simulation offers a platform to validate the effectiveness of an altered design (Senko and Suskind, 1990). There are many contributions focused on *simulation modelling in general* (Law and Kelton, 2000; Banks et al., 2001, Robinson, 2004). What is worth mentioning, though, is that there are several contributions *dedicated solely to the application of simulation to facility layout design*. However, these applications are mainly dedicated to *manufacturing systems design* such as material handling system design, manufacturing cell design, warehouse or factory layout design

(Law et al., 1993; Heavey and Browne, 1996). Nevertheless, literature provides only a few applications to the facility layout problem for *services' organisations*. An example is that given by Lo et al. (2002). Running large-scale emergency exercises constitute a time- and cost- consuming process. Thus, in order to examine the existing layout and assist in planning the spatial arrangement during emergency situations, Lo et al. used simulation modelling.

METHODOLOGY

The authors implemented a compound methodology that can be considered as an innovative way to structure such a problem as no similar case has been presented in the literature*:*

1. a FacPlan method that consists of an in-depth analysis of all the depot's elements and the design of alternative layouts (SFP approach). The phases of this approach are described thoroughly by Karagiannaki (2005).
2. simulation modelling in order to evaluate the proposed layouts and attain a more efficient allocation of the resources.

SIMULATION MODELLING

Two alternative layouts were agreed to be evaluated using simulation modelling.

Conceptual Modelling

Modelling objectives

- Determine which proposed layout offers the most efficient allocation of the operational vehicles and which operating rules it must incorporate so that with 95% confidence:

1. the maximum queue size in each facility (exit gate, fuel station, waste transfersite, weigh bridge, water supply, high pressure washing) is less that 6 vehicles
2. the average queuing time in fuel station, waste transfersite, weigh bridge and exit gate is less than 5 minutes and the average queuing time in water supply and high pressure washing is less than 20 minutes
3. the maximum queuing time in fuel station, waste transfersite, weigh bridge and exit gate is less than 10 minutes for 80% of vehicles and the maximum queuing time in water supply and high pressure washing is less than 30 minutes for 80% of vehicles

- Determine whether the agreed layout with its operating rules allows for a potential 10% increase in the fleet of each operational activity without affecting the above objectives.

Model content

Table 1: Model scope

Component	Include/ exclude	Justification
Aggregation of vehicles of each operational activity	Include	Flow through the depot system during the day. The individual vehicles are represented by their density (meaning the type of operational activity) and not directly as individual entities
Operatives	Include	Flow through the depot system at the start and end of shift Depart from and arrive to a building-base
Queues for each resource	Include	All resources need to be modeled to give full statistics on queues and resource utilisation
Allocation of the fleet of each operational activity	Include	Experimental factor
Allocation of each resource	Include	Experimental factor
Operating rules	Include	Experimental factor Include agent-based behaviours; meaning the use of a set of rules that individual drivers follow (e.g. drivers usually choose the shortest queue, or they will not join a queue if there are more than five vehicles in it)
Traveling times	Include	Fixed, based on the speed limit in the depot
Scale	Include	Design of the layout based on a 1:500 scale
Visitors	Include	Visitors are represented as vehicles (not pedestrians)
Priorities (islands-crosswalks)	Include	The priority is given to the driver inside the island. The priority is given to pedestrians in the crosswalks
Inspection time	Include	The drivers inspect their vehicles before departing
Interrelation between the two parking areas (operational and private)	Exclude	Only pedestrians can walk through the two parking areas. Moreover, not all the operatives park at the private area. The exact number of operatives coming into the depot from the private parking is not known
Processes outside depot	Exclude	Beyond the purpose at hand

Simplification

- Worst case scenario. The number of vehicles of each operational activity was the maximum available. Thus, absence of operatives -because of illnesses or vacations- and in addition, fleet deficiencies -because of vehicles inspected in the workshops- was not modelled.
- Only model the operational parking area.

- Fridays and weekends were not modelled due to the different shift patterns and the different number of vehicles that operate these days.

Model Coding

The computer modelling was implemented using the standard version of SIMUL8 simulation software. The model layout was designed based on a 1:500 scale (Figure 1). Each run of the simulation model starts with all the vehicles parked at different blocks. The blocks are based on the shift patterns in order to permit the vehicles that are parked in the back rows to depart. Thirty nine of these vehicles are grounds maintenance' vehicles (yellow vehicles), sixty two are mini buses (orange), forty are skips (green) and twenty six are street cleansing vehicles (blue).

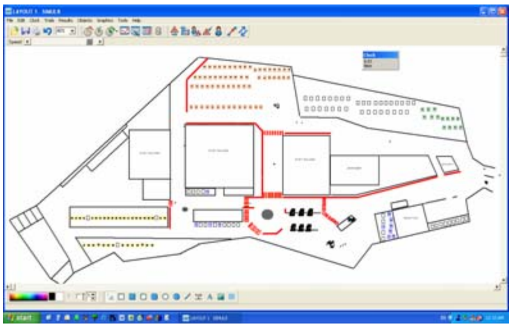

Figure 1: Print Screen of the depot's model

Based on shift patterns, the operatives depart from a building-base, follow the pedestrians' clear path (red line) in order to reach the vehicles and spend some time in order to inspect and prepare the vehicles before leaving. Then, they leave the depot (the image of the parking place changes to an empty space). The vehicles follow the network of roads inside the depot and deal faithfully with the driving regulations. This signifies that they give priority to the pedestrians before any crosswalk and the driver inside the island has priority, as well. Vehicles return to the depot throughout the day to tip, to have access to the water supply, to fuel and for lunch breaks. There is no set times to these. Thus, the times used in the simulation model were based on an attempt to fit proper distributions to the data gathered. For the fuel station, especially, a specific set of rules was introduced in order to include the behaviour of the individual drivers and thus, to model the process of fuel as close to reality as possible (agent-based behaviours). For example, drivers usually choose the shortest queue, or they will not join a queue if there are more than five vehicles in it. Finally, the vehicles return to the depot approximately half hour before the end of shift to tip, fuel (if they did not manage to do so during the day), wash down and complete vehicle checks. When the operatives park their vehicles, they follow again the pedestrians' path and return to the buildings.

Verification and Validation

To illustrate the concept of verification and validation, several forms of testing had to be employed. However, because of the complexity of the depot's system and the time available, the authors found it inefficient to use some formal techniques for validating the model. Therefore, they were forced to validate the model through discussion with the managers who have a detailed knowledge of the system and feedback sought on whether the model is appropriate.

FURTHER ANALYSIS

None of the output statistics (maximum queue size, average queuing time and percentage of vehicles within the time limit) in itself can be considered as sufficient and necessary to lead to valid results. Each output serves different purposes and questions. Only by *combining them* will they offer an overall understanding of the system and thus convincing inference. In addition, it is imperative not to forget that the simulation models were based on the *worst case scenario*. Therefore, based on the models' outputs, although some significant lengthy queues may appear, this is not the case. Their size can not be considered as strictly precise. However, it can be concluded that they definitely indicate problematic areas.

Regarding the first agreed layout and its first experiment (that incorporates a change in the operating rules), the outcomes of the analysis are:

- It appears that the fuel station and the waste transfersite satisfy the responses that determine the achievement of the objectives.
- The water supply and the high pressure washing seem to operate properly as well. The fact that there is a significant maximum queue size for the water supply is based on the worst case scenario effects. Moreover, this occurs due to the rules that determine when to use this facility; meaning that all the sweepers have to use the water supply in the morning (before departing from the depot) and after the lunch time. Therefore, it is reasonable to observe a lengthy queue.
- The outcomes regarding the exit gate indicate a problematic area. The maximum queue size is 13 vehicles. However, the average queuing time (1.5 minute) and the percentage within the time limit (100%) reveal that this lengthy queue occurs only at peak times; in this case

in the morning (between 7:00 and 7:30am). Also, taking into consideration that in the current system such a queue size can be observed, the situation is not aggravating in this proposed layout, but it does not give an improvement, as well.

- Regarding the weigh bridge, the outputs definitely indicate a bottleneck. However, the average queuing time (4.17 minutes) and the percentage within the time limit (82.35%) reveal that this lengthy queue occurs only at peak times (between 4:10 and 4:30). Figure 2 depicts the time-series of the queue size. In an attempt to solve this bottleneck, the authors changed the operating rules (experiment 1). Indeed, the outcomes of experiment 1 proved that the queue size has been decreased. Figure 3 depicts the time-series of the queue size for the experiment. Comparing the two graphs, it is obvious that the new rules resulted in smoothing the peak time, which leads to the decrease in the queue size. Of course, while solving the traffic in the weigh bridge, the remainder system was also affected; especially the fuel station and the waste transfersite as the change in the rules incorporated these resources. However, the results are still consistent with the objectives and no other problematic areas occur.

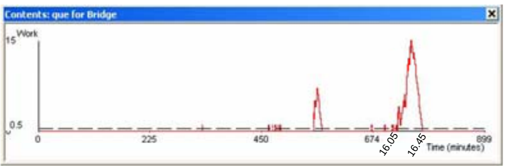

Figure 2: Time-series of the bridge queue size (Layout 1)

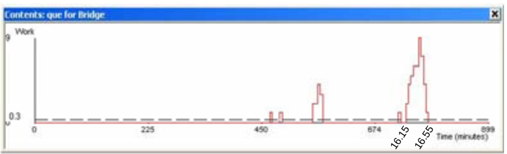

Figure 3: Time-series of the bridge queue size (Layout 1: Experiment 1)

The first alternative layout and its improvement -that the experiment 1 represents- solved the bottleneck regarding the weigh bridge. Respectively, the second alternative layout and its improvement -that its experiment represents- solved the bottleneck regarding the exit gate. Based also on the fact there are no significant changes regarding the remaining outputs, it can be assumed that the two layouts are supplementary. Therefore, it can be concluded that the simulation model infers the combination of their experiments as the most efficient layout. This solution implies a wide range of tangible and intangible benefits. The tangible outcomes can be summarised as the decrease of any bottlenecks and the reduction in the queuing and processing times. The intangible ones can be considered as the aggregation of each operational activity’s vehicles, more control, tidier appearance, health and safety issues.

In addition, it should be mentioned that although the above solution reduced the lengthy queues, some points of congestion still appear but only at peak times. If CCC feels that the queues that still occur at peak times are not satisfactory, the authors identify three experimental factors that can assist in giving an even more efficient layout: the *operating rules* that the individual drivers follow; the *routes* that the vehicles follow inside the depot; and the *shift patterns* of each activity. By combining these factors, a wide range of alternative solutions emerge.

Furthermore, considering an experiment that incorporated a 10% increase in the fleet, it should be highlighted that there are space limitations (break-down point) that may not allow a further increase. In such a case, it is recommended that CCC repeat the entire reengineering project; meaning to redesign and propose new layouts and implement new simulation models. Here, it is worth mentioning that the outcomes of the existing simulation project can be used as *benchmarks* for evaluating the efficiency of the new layouts.

CONCLUSIONS

Regarding the simulation modelling implications of this paper, this approach can be viewed as a powerful *facility evaluation tool* as it can be employed within a facility layout problem and thus, assist in evaluating alternatives. The major outcomes that the CCC’s managers may experience, but also any managers that deal with a facility redesign problem can be summarised as follows:

- ✓ The factors that effect the evaluation of the alternative layouts can be easily identified. In this instance, these experimental factors were: the reallocation of the parking places and the resources; the operating rules; the routes; and the shift patterns.
- ✓ The use of simulation within layouts should be an iteration process and not be used once and thrown away. Rather, it should be retrieved by managers on an occasional basis. Thus, the outcomes of any simulation model can be used as benchmarks for evaluating the efficiency of the new layouts.

- ✓ Simulation can incorporate agent-based behaviours, which play a vital role for a successful model development; meaning that it includes individual behaviours.

The literature review revealed that there is no single and widely accepted technique to provide optimal solution to a facility layout problem. Thus, the authors suggest the combination of different approaches and techniques. In this case, they implemented a compound methodology (FacPlan method and the SFP framework it incorporates with simulation modelling) that can be considered as an innovative way to structure such a problem. Therefore, concerning any further work that can be employed, this paper can be seen as the launch for further examination of the use of simulation modelling with facility layout problems. Moreover, in order to capture the financial aspect of the proposed layouts, a financial analysis could be integrated with the alternatives. Thus, after performing the different simulation experiments, financial analysis could provide a significant tool to poise the various benefits that each alternative promises.

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