A Multidisciplinary Knowledge Transfer Partnership in Development of Lift Simulator

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Abstract. Lerch Bates Limited are consulting engineers specialising in short range transportation systems for moving people and materials. Projects include the Taipei 101 Financial Centre and the new Burj Dubai Tower, which is the world's tallest tower, completed in 2008. As the building are becoming more and more complicated, so are the transportation systems in them. Lerch Bates decided to join forces with Kingston University to develop a computer simulation system for lift design. This system is strategic to the company, not only in terms of its reputation as the world-leading consultant in people transport systems, but also in terms of cost efficiencies realisable both to internal staff and the architect / developer of a given project.

This paper addresses the work done within the Knowledge Transfer Partnership for designing building passenger vertical transportation systems. This was a multidisciplinary project, requiring knowledge transfer in the areas of dynamics, control systems, development of dynamic simulation systems and computer graphics/visualization. The design and specification of lift systems for large buildings is a very complicated process, with a wide range of variables that need to be evaluated in order to design a system that will deliver acceptable performance. Such evaluation is performed with the help of computer simulation software. The limited functionality of the currently existing programs for lift simulation however prompted the project to pursue the development of a new system, suitable for the demands posed by modern building designs and improved control algorithms. The project provided the calculation and simulation modules together with the generation of the visual simulation and building information model.

Keywords: dynamic simulation, control of elevators, software systems, visualisation software.

1 Introduction

Lerch Bates (LB) Limited are consulting engineers specialising in short range transportation systems for moving people and materials. These services include

R.J. Howlett (Ed.): Innovation through Knowledge Transfer, SIST 5, pp. 115–123.
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vertical and horizontal transportation (e.g. lifts, shuttles and escalators), façade access, facilities management, non-clinical support services, materials handling and management and disabled access. The majority of the company's projects involve consultancy for installations in new or refurbished buildings provide, with maintenance supervision (facilities management) accounting for the rest of their work. LB's customers include property owners, developers, and architects; projects include the Taipei 101 Financial Centre and the new Burj Dubai Tower, located in Dubai, which is the world's tallest tower, completed in 2008.

Due to the success of their first Teaching Company Scheme programme which focused on Facilities Management, the company wished to further exploit their developed relationship with Kingston University as key R&D support for this strategic development need. The Knowledge Transfer Partnership undertook to develop an expert system for designing building passenger vertical transportation systems. The design and specification of lift systems for large buildings is a very complicated process, with a wide range of variables that need to be evaluated in order to design a system that will deliver acceptable performance. Such evaluation is performed with the help of computer simulation software. The limited functionality of the currently existing programs for lift simulation however prompted the partners to pursue the development of a new system, suitable for the demands posed by modern building designs and improved control algorithms. The partners have completed the calculation and simulation modules together with the generation of the visual simulation and building information model.

The development of such a system is strategic to the company, not only in terms of its reputation as the world-leading consultant in this area, but also in terms of cost efficiencies realisable both to internal staff and the architect / developer of a given project. From this, developers will be able to view key outputs; the space take, performance and capital cost of a solution, allowing them to make commercial decisions about the optimal system to meet their need.

The project involved collaboration between Lerch, Bates and two Faculties from Kingston University, namely Faculty of Engineering and Faculty of Computing, Information Systems and Mathematics. The Faculty of Engineering contributed expertise in the dynamics and in control design whereas Faculty of Computing, Information Systems and Mathematics contributed expertise in the software implementation, 3D visualisation, and software integration. The project employed two Research Associates: one in the area of dynamic simulation and control of lifts and one to cover the software development aspect. The project has been completed successfully with a "beta version" of the system operational and ready for use.

2 Background to the Project

The design and specification of lift systems for large buildings is a complex process. This complexity is demonstrated by the fact that many systems already adopted in high rise buildings are considered sub-optimal. Large modern buildings often incorporate shuttle lifts that take people to a sky lobby, from which local lifts take people on to their final destination and, to date, it has not been possible to model this whole system.

In the late 1970's the use of computer simulation to evaluate lifts systems was introduced by Barney and Dos Santos (Barney and Dos Santos, 1977). Around 1998 a PC-based simulation program was developed for general use by Peters (Peters, 1998).

This program, called ELEVATE, enabled users to model most types of buildings with associated lift control systems and types of traffic. It could not look at multiple groups of lifts in operation in parallel nor did it account for designs involving sky lobbies, double deck lifts with new so-called "destination" hall call control or address the various other important parameters of design including building space taken, capital cost estimates or the generation of a 3-D Building Information Model of the proposed lift services.

Currently the "state of the art" from the viewpoint of independent lift system simulation resources is the availability of either "PC-LSD", a program developed by Barney or "Elevate" a program developed by Peters.

The limited functionality of the current programs means that the designer must have considerable experience and tacit knowledge of how to address all the variables involved. The current systems are also not compatible with the planning requirements of modern lifts which now increasingly incorporate destination hall-call control systems where users "book" their calls even before they enter the lift lobby.

Recent advances in software development have provided the opportunity to develop an Expert System based upon a Building Traffic Simulator. Such a system would allow consultant's expertise in the form of rules that could be captured together with their in-depth knowledge of lift system design, to meet a wide range of needs.

Moreover, around year 2000 it became feasible to start and portray lift systems visually to give clients and architects a more direct understanding of the likely performance of the lift services. Telling the developer that 11% 5-minute handling capacity would represent "poor" lift service was nothing compared to seeing people queuing outside the building to get into it! Such visual simulations were "job specific" and very expensive, often costing over £20,000. In 2007 Lerch Bates approached Kingston University with an ambitious project. In summary we wanted an all-in-one system to deliver calculation, simulation, 3-D visualisation and an architectural building information model all to be delivered as output files, including:

- Calculation engine to perform basic calculations of lift design parameters, such as speed, capacity, average waiting time, depending on the traffic patterns in the building.
- Dynamic simulation of the operation of lift systems, with passengers generated randomly over a given time period.
- Advanced control algorithms incorporated as "plug and play", so that new algorithms could be potentially added to the simulation.
- 3D calculation of the space taken, i.e. physical dimensions of a system that can be transferred as a Building Information Model into architectural CAD packages. This enables the building efficiency to be calculated i.e. the net to gross rentable space figure.
- Graphical performance output demonstrating the system's performance under differing traffic situations, efficiency curves and information in graphical format.

- Visual demonstration of performance to interested parties e.g. architects and developers enabling any long wait passengers or substantial queuing to be seen in a visual simulation of the operation of the lift services.

3 Simulation Structure

Computer simulation is especially valuable for large buildings when the traffic patterns are more complicated. Primarily simulation allows the relative capacity of different elevator configurations to be analysed, especially for peak traffic, in terms of "quality" and "quantity" of lift service.

The traffic simulation solution developed uses the concept of a so-called 'simulation platform' which performs all the underlying functions and processes of car movements and passenger activities. As seen in Fig. 1, the simulation platform consists of four parts; passenger generation, car jump model, individual car controller and the group controller. The group controller implements the passenger allocation to individual lift cars and is responsible for overall performance optimization. It will be described in more detail in the next section. The three main elements in the simulation platform are passenger simulation, car jump and individual car controller.

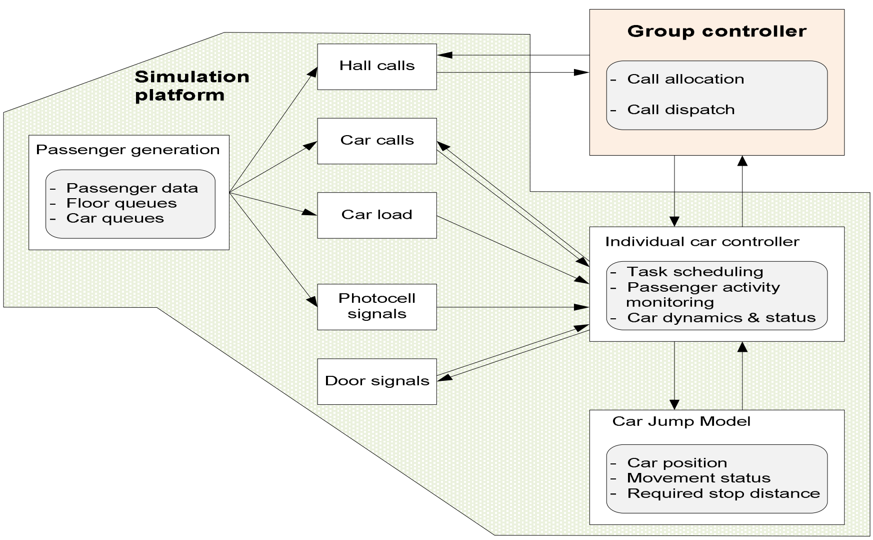

Fig. 1 Elevator traffic processes (adapted from Siikonen 1997)

Passenger generation is the starting point for traffic simulation. The arrival and destination floors of individual passengers are random but they statistically follow a given or measured population distribution in the building. The Poisson arrival process takes account of passenger arrival time. Passengers are externally generated and are introduced to the model one by one at their arrival time. Every passenger is listed in the queue information and given a unique identity number.

The car jump model describes the movement of the elevator car within the shaft. There are basically three jump scenarios in typical floor to floor car movements:

1. The lift reaches full speed and full acceleration. This is typical for a low speed lift moving from floor to floor or a high speed lift making a multiple floor run.
2. The lift reaches full acceleration, but not full speed. It is typical for a short distance run for a high speed lift, where the distance travelled is not enough to accelerate up to and decelerate down from full speed.
3. The lift does not reach full speed or acceleration. This scenario corresponds to very short trips, e.g. single floor.

The **individual car controller** coordinates the operations of each individual car such as loading and unloading passengers selectively upon the car stopping and control of next destination stop for car movement. It takes account of functions inside the car, e.g., registering and cancelling of car calls, opening and closing of the door, passengers loading and unloading and measurement of the car load. It has two major functions, one for jump task scheduling, which means taking the hall call allocated from the group controller and car calls registered by in-car passengers to issue a destination signal for the car jump model; the other is monitoring passenger activity, which includes selective passenger loading and unloading upon car stops, appropriate passenger identifying methods compatible with passenger tracking and logging their every movement in the activity log.

The **Group Controller** algorithm represents the software installed in the group controller, which decides when, how and what to communicate to the car controller. The group controller selects one of the algorithms to be used to allocate passenger (hall) calls to an appropriate lift (car) which can service that call.

For each lift in the group, the Algorithm uses the current state of the lift and all its registered calls to create a journey plan for the lift as it follows a Simplex Collective algorithm (*answering all its registered calls at floors encountered in its current committed direction of travel to one end of the shaft, then reversing and answering all its registered calls in the opposite direction, then finally answering all its registered calls for its current committed direction of travel that are at floors currently behind the lift*). The journey plans include relative timings of arrival at each planned floor stop, which represent the estimated time to cancel the registered calls at the floor for the current committed direction of travel.

Two types of hall call are considered: **Conventional** (Directional) calls and **Destination** calls.

Calls are *Conventional* when only the Origin Floor and the requested Direction of Travel is known. In general, only one conventional call can be registered per floor per direction at any one time.

Calls are *Destination* calls when both the Origin and the Destination Floors are known and the requested Direction of Travel may be computed by comparing them.

4 Software Development Structure

The application is developed as four distinct sub-systems (Fig. 2): *Calculation*, *Simulation*, *Visualisation* and *Reports*, which can be selected independently and which are linked together via a user front end. Extensive use of XML as a means of passing information around the application allows the system to be customised for the applications usage and for fast transfer of data. No database is utilised removing the accompanying drag on resources that is needed to run a database engine. The coding language C#(C Sharp) is used for the majority of the application, which allows the importing of other DLL's written in languages such as C++ and COM to be accessed via C# code. This helps future proof the application as add-ons can be written in the developer's language of choice.

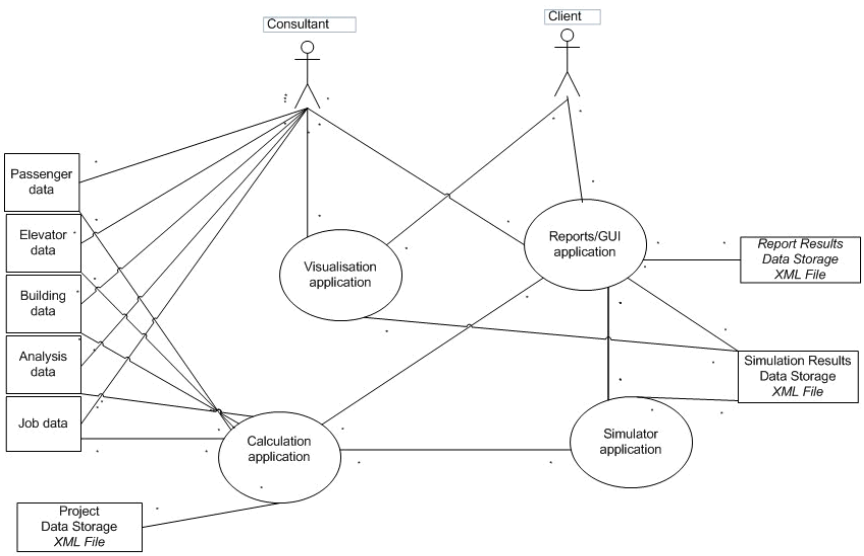

Fig. 2 Software structure

5 3D Drawing Information and Visualisation

There is a growing movement in the architectural world to produce drawings in 3D. Our application constructs a Building Information Model (BIM) for the essential 3D structure of the lift shafts and lobbies and exports it applying IFC – the Industry Foundation Class (IFC Wiki, 2009), a file format that is now a well established standard in industry. This model is built using either data directly involved in the simulation process or automatically derived from the specification of the lift system chosen by the user, with most parameters exposed for further manual tuning. Once the final structure of the lifts, shafts and lobbies is decided, the information model may be easily and effortlessly fed forward to the architects using CAD tools.

The 3D structural model of the building is also used internally, by the 3D Visualisation Subsystem. This module, based on a FreeWill 3D animation framework developed at Kingston University for several years (Szarowicz et al 2005) provides a facility to observe the movements of passengers and elevator cars in the building. It may strongly influence the decision making process as it provides highly visual content to illustrate the performance of the lift services. For example, by introducing colour coding of the intending passengers based upon their expected waiting times, an instant visual cue is provided that allows the user to easily spot queues of lift users with excessive waiting times.

The visualisation module renders the building structure and populates it with 3D animated human characters (Fig. 3). They are driven by the simulation subsystem outcome. To achieve the proper 'look and feel' a normal human-like behaviour must be reconstructed, or simulated, automatically by the system. The population of passengers is therefore modelled as a swarm of autonomous distributed agents. The goal of each individual is to fulfil their "script" but, in the same time, to behave like a human, and first of all to avoid collisions with other passengers as well as architectural elements. To achieve this, a novel algorithm for time and space constrained crowd simulation has been developed.

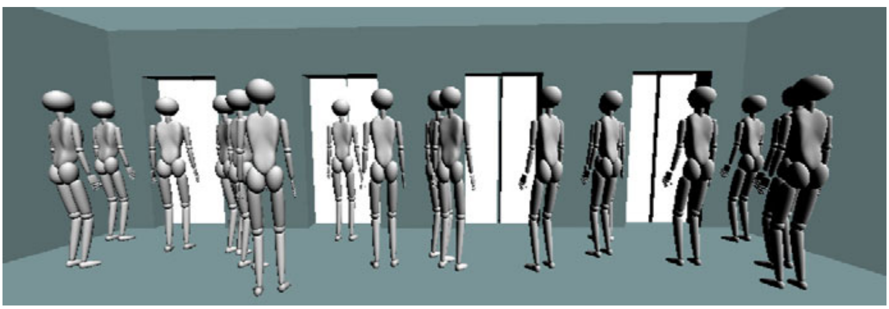

Fig. 3 Lift lobby rendering

6 Conclusions

The novel design tool developed in this project has opened many interesting research avenues and will benefit the project stakeholders in the future. At Kingston University the project has contributed to the development of teaching case study materials and used at undergraduate and postgraduate level. Furthermore, the partners have co-authored an academic paper that was submitted, accepted and presented at the *International Conference on Systems Engineering* in Coventry in September 2009. The company now has the capability to express the expertise it can bring to projects in an instantly impressive and conclusive manner which is accessible & understandable by all who view it, regardless of their seniority and / or technical expertise. Additionally, it provides a stream-lined and polished reporting tool, again boosting the quality of client-facing documentation. Finally, it has created a platform which is both powerful & flexible enough to continue delivering these competitive advantages to the company partner.

The current knowledge transfer relationship Lerch Bates and Kingston University is excellent and this association is advertised widely through case studies, publications, posters and video interviews. Further undergraduate and postgraduate projects to improve the system capabilities are in place. The Company will also provide new employment opportunities for Kingston University graduates in the future in the fields of system simulation and computer science.

The Knowledge Transfer Partnership contributed to this relationship by bringing together the academic and industrial partners to develop the novel products and services now supplied by the Company. Every member of the project team gained tremendously from the experience.

The knowledge transfer process between the partners has developed a new design tool which will enable a more informed selection of lift design to be made by comparing the relative traffic performance, space-take and capital cost of each solution It will also be possible to quickly analyse the effect of changing input variables e.g. occupational densities upon the performance of the lift system.

The project benefited the Company, the Knowledge Partner and the Research Associates involved.

For Lerch Bates, the main benefits are in:

Market position and reputation. Ever more ambitious construction projects that utilise ongoing advances in civil engineering will require an understanding of the entire people moving system. There is also a growing need to design more flexible buildings that can adapt to a variety of uses, a requirement that can only be met by accurate modelling. The efficiency and predictive nature of the developed system will enhance LBs position and reputation as lift consultants, making them the preferred supplier of consultancy services in this area.

Improved efficiency / profitability. The system will enable engineers to efficiently design, specify and model options. The developed system will be able to apply company knowledge to bespoke building specifications, saving consultant engineers time and thus improving efficiency.

Increased turnover / growth. The system will increase the efficiency of the existing LB workforce and consequently the volume of contracts that LB can undertake. This, combined with synergy with industry standard architect systems, and the facility to visually present preferred options to developers, will secure a major competitive advantage that will improve LBs tender success rate as the preferred supplier.

For the University, the main benefits are:

All academics involved in this project benefited by gaining or improving practical knowledge and experience in the following topics:

- Operation of elevator systems, machinery used, electronics, modes of operation, elevator industry standards,
- Modelling and simulation of elevator systems,

- Optimisation and control algorithms for elevators, real life constraints and current approaches in industry,
- Crowd simulation in time and space constrained environments.

During the progress of this KTP project it became apparent that the technologies to be employed were among those considered “hot research topics” in the fields of advanced control design and in the field of visualisation and animation software. This forced the academic supervisors to get deeper into those subject areas and it will benefit future research at Kingston University. It is hoped that the research on this subject will be continued, benefiting from experience gained in this project.

The research in 3D visualisation, animation and, more recently, computer games, have been carried out in Digital Image Research Centre at Kingston University for almost 10 years now. The visualisation module delivered within this Knowledge Transfer project is based on Free Will, an animation framework developed in 2003-2005 as a part of a EU-funded research project. Realistic crowd simulation was a vital part of that project and a new algorithm for time and space constrained human character control is a valuable contribution to this research. New experience in animation of the human behaviour within architectural interiors contributed also to enrichment of the curriculum of the newly opened Games Development course, taught at the Faculty of Computing, Information Systems and Mathematics.

For the associates the main benefits are:
A Professional Development Plan is put in place for each associate, highlighting strengths weaknesses and areas for improvement through training. Each associate is encouraged to complete a degree during their associateship and it is one of the main reasons that people become KTP associates. The degrees are based on the work being done and are supervised by the university – Work Based Learning. Time is allowed during the KTP for professional development (10%). A budget is allocated to each associate for extra training. The Associates are encouraged to attend professional/scientific conferences, if relevant, industrial visits are also pursued. In the particular project, all the above activities took place and they were generally, positively received by the Associates.

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