GLITCHES, SNAGS AND CRISES: A STUDY OF CHANGE IN HOSPITAL ADAPTATION PROJECTS

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Design and programme changes during refurbishment projects remain a considerable cause of concern for UK National Health Service (NHS) Estates managers, due to their potential to disrupt or delay projects and increase cost uncertainty. Similar concerns also impact on the engineering sector, especially in the production of complex, highly engineered products. The techniques developed to study and manage engineering change may have positive benefits for construction. This research looks at the mechanisms of change that operate in refurbishment projects with the aim of identifying commonalities with engineering change. Hence, the research adopts an engineering approach to change and evaluates three very different NHS refurbishment projects, to explore change events and identify options for limiting the consequences of change. The projects chosen for this study were markedly different, with specific drivers, procurement methods, contracts and building systems. One project concerned the construction of a factory-fabricated, modular extension to a UK hospital, whilst a second entailed a "state of the art" refurbishment of an existing neo-natal unit. A third project involved a heavily constrained ward refurbishment. Factors which influenced the level and complexity of change frequently resulted from the lack of accurate information at crucial stages, particularly related to the existing building structure and condition. However, the necessary changes followed very different trajectories. This study forms part of a much larger investigation which aims to develop sustainable adaptations for hospital buildings in response to the changing climate.

Keywords: change propagation, refurbishment, hospitals, constraints, engineering.

INTRODUCTION

The issue of project change has been highlighted as a major cause of delay and cost escalation (Buratti *et al.* 1992; Love and Li 2000; Olawale and Sun 2010, etc). The aim of this research is to investigate the problems associated with changes made during refurbishment projects. In engineering, the development of highly complex products presents similar change issues and the techniques that have been developed to understand, predict and manage the consequences of engineering change may have significant application for construction. A key concern is the risk of a change in one project area proliferating and hence, requiring further widespread changes across the project. This expansion of change is known as "change propagation".

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Change Propagation

Change propagation can be described as a cascade of unplanned changes that result from a necessary change (Eckert *et al.* 2004). For example, the late discovery of a structural problem during a refurbishment project may entail additional changes to floor plans; increased structural support; revision of designs including Mechanical & Electrical systems (M&E); circulation; fire-safety and surveillance systems; in addition to sustainability concerns. The problem may be compounded by the need for revised project documentation, additional costing and the need to renegotiate contracts with sub-contractors. Still further effects may include delays to schedules and the depletion of float-time, reducing project resilience. Hence, a single change can result in the need for further significant changes, which can propagate widely across the project. The increased volume of change is a significant problem both for construction and engineering projects. By exploring patterns of change propagation it may be possible to develop a deeper insight into the process of change and how changes spread from anticipated or planned areas to other unintended areas. This research will contribute to the development of a tool, designed to assist decision makers in identifying the consequences of change. Two detailed but very different case studies are examined here to explore the range of change patterns that occur. A third study has been included to validate the methodology adopted. This research does not attempt to compare the benefits of one system over another, but highlights that change issues can emerge regardless of the construction system and that an understanding of the change process will improve the prediction and management of such change.

LITERATURE REVIEW

Research by Sun *et al.* (2006) highlighted the ad hoc way changes are managed during construction projects and presented a toolkit comprising of a change dependency framework; a change prediction tool; a workflow tool; and a knowledge management guide, to assist decision-makers in coping with changes. They developed an integrated system which related project characteristics, initial causes and major effects and this clear linking of the multiple context-related factors to a change effect, significantly developed the understanding of the change process in construction. Analysis of very similar change problems had been taking place in Product Engineering research (Eckert 2004). The engineering approach, rather than trying to link the multiple causes and constraints to individual change events, instead sought to locate individual change events within pathways or sequences of connected changes that resulted from a common cause. In consequence, the engineering change process has been closely modelled; change propagation pathways identified; and the risk of change propagation has been quantified and analysed (Jarrett *et al.* 2011, provides a comprehensive review). Research in engineering has also been directed towards investigating how changes flow across a system (Eckert *et al.* 2004). They documented a range of "mechanisms" involved in change propagation (see Table 1.).

Table 1. Change Mechanisms

Mechanism	Effect	Example
Change "multipliers"	Generate more changes than they absorb.	A change to the position or size of a lift shaft may require many further design and M&E changes.
change "absorbers"	Pass on less change than they receive.	Ensuring adequate float time; or including flexible or multi-purpose spaces in designs.
change "resistors"	Highly connected elements that restrict or reject change.	Changes to the building footprint, legislative requirements, or executive office size.

Looking at change in this way helps to provide an alternative perspective, focusing on both the predictable and the less obvious causes of change. This type of analysis encourages the consideration of options for managing change during a project by including "change absorbers" at appropriate points, or by ensuring that design effort is directed away from "change resistors". Giffin *et al.* (2009) studied 41,500 change requests and identified recurring change patterns or "motifs". These "motifs" helped to identify components that resisted or rejected change, pin-pointed areas of wasted effort, and revealed relationships between successful changes. This has led to improved methods for predicting where problematic or repeated changes will occur.

RESEARCH METHOD

The approach to this research derived from a critical realist perspective, based on the work of Bhaskar (as in Collier 1994). In essence, this view recognises that interpretations of the world may be inconsistent and that there is a consequential requirement to investigate widely, using a range of methods, to relate knowledge as closely as possible to reality. The case studies presented here were undertaken during the course of a larger EPSRC funded project, which has developed low-cost adaptive and sustainable solutions for UK hospital buildings in response to the changing climate. A review of the literature was carried out and selected case studies were investigated. Project teams were invited to take part in semi-structured interviews, either on an individual basis or in groups. The format of interviews differed slightly for each study, depending on the availability of key actors at each site. Notes were taken throughout case-study meetings and compared for consistency. In addition the meetings were recorded and transcribed. A deep "grounded theory" analysis was not attempted owing to the volume of interviews; however the transcripts were evaluated against themes that were identified in an initial post-project review. A framework was then developed to clarify and map the change process in refurbishment projects (see Figure 1). Documentary evidence, in the form of reports, change orders and drawings has been reviewed and the process is ongoing. Two case studies were undertaken and a further study was drawn on, to validate the outcomes.

Analysis Framework

The framework illustrated below was developed to assist in understanding how change may propagate from one area of a project to other connected areas (Fig. 1). Specific strands or project "layers", which encapsulated particular project activities, were identified. These "layers" were organised to connect the range of possible change pathways. This process resulted in the development of an organising framework, which differentiated between project activities, for each of the case-studies. A change can propagate along any of the layers at any time, from project start until handover. A change can also cross between layers and the framework allows this complex sequence of change to be mapped. The framework also includes external influences or drivers of change, along with the possible consequences to associated systems that extend beyond the project boundary. In this way, the total trajectory of the all changes related to an initiating change can be identified.

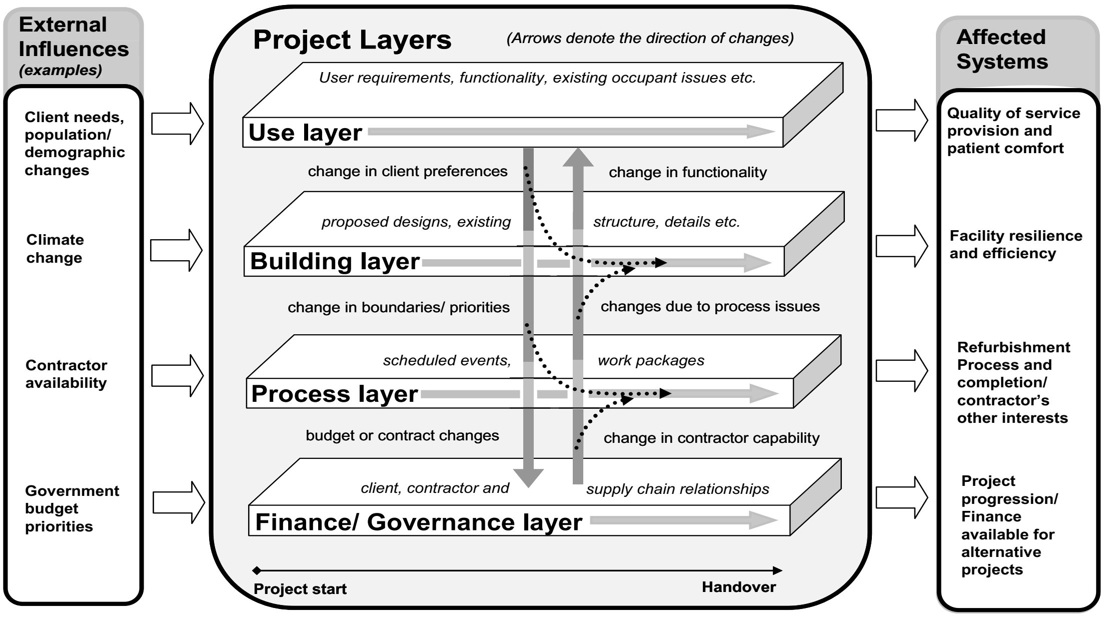


Figure 1. Project layers showing direction of changes (Garthwaite and Eckert 2012)

Case Study 1: The Neo-natal Unit Refurbishment

This case-study followed the refurbishment of a neo-natal unit based on the second and fifth floors of an aging NHS hospital building. The hospital is a Foundation Trust and provides maternity and neo-natal services for a population approaching 300,000 people and delivers 10,000 babies each year, attracting clients from well beyond the catchment area. The hospital had planned a major new-build Private Finance Initiative (PFI) facility but late cancellation meant that the Trust's portfolio of aging existing buildings required a significant level of upgrading.

The neo-natal service was split between two distant sites and this was felt to present the Trust with a high risk situation. Hence, rationalisation to merge the two sites was a high priority. The total value of the project was in the region of £10m and the Trust adopted the relatively new NHS procurement system "P21" to accelerate progress. The requirement to limit disturbance to patients in adjacent wards severely restricted the survey process and there was scant information regarding the condition of the existing structure and services. Although the original plan was to refurbish both floors of the unit, concerns over budget issues limited the project scope and work to the upper floor was postponed until further funding could be secured. The refurbishment of the lower level continued as planned. As part of the P21 process, a post project review was carried out with all parties represented and the authors (as observers) were given access to this critical meeting. Follow-up interviews were arranged with key actors (Table 2) and transcriptions were analysed using themes identified in the post-project review.

Table2. Neo-natal Unit (Case Study 1) Interview Participants

Team	Role	Description	Time (mins)
Client	Client Project Director	Project lead. Liaison with Trust Board	48
	Internal Project Manager	Develop and coordinate Trust projects	103
	Clinical Lead	User group design development lead	31
	Nurse Manager (Matron)	User group design development	55
	Consultant Project Manager	External consultants (procurement)	59
	Cost Advisor	Project cost control	41
	Project Site Supervisor	Site supervision	41
PSCP*	Construction Manager	Strategic support (all projects)	32
	Project Manager	Project planning /liaison	15
	Design Manager	Management of design information	55
	Senior Quantity Surveyor	Cost control and advice	42
	Quantity Surveyor	Cost control and advice	53

**Principal Supply Chain Partner*

Case Study 2: The Modular Extension to Foundation Trust Hospital

This study explores a very successful £10m modular ward extension to an existing hospital building. A key feature of this project was the highly condensed timescale for the work. The pressing need to meet government infection control targets was a key driver for the project, as failure would expose the Trust to penalties in excess of £1m. In addition, the lack of overflow beds for seasonal 'flu patients and the need for decant space made a strong case for an extension to the existing accommodation. In July of 2007, the estates department were tasked with finding a solution which could meet the government reporting deadline of 24th December 2007. The Estates Team posed a challenge to the Trust's selected Framework partners, to work together to achieve what appeared to be an impossible task and surprisingly, the contractors "bought in" to the project with real enthusiasm. The risk register identified planning permission as the most significant early risk factor but in the event, permission was granted within five weeks. Weekly team meetings were programmed and important project meetings were arranged to coincide with Trust Board meetings.

Table 3. Modular Extension (Case Study 2) Interviews

Client Team: Deputy Director of Estates (Project Lead); Assistant Director of Estates (Project Team - Design); Assistant Director of Estates, Policy and Development (Trust Liaison); Director of Estates (Strategic planning).	90 minutes (group session).
Consultant Architect Team: Architect (Design Consultant); Design Specialist (Senior M&E Design); Design Specialist (M&E Design); Structural Specialist (Structural Design)	61 minutes (group)
Consultant Cost Control: Principal Quantity Surveyor (Cost and programme control)	44 minutes
Modular Contractor: Construction Manager (Strategic management); Project manager (Project management)	45minutes (group)

The architects, along with key Project Team members, prepared sketch layouts based on their knowledge of ward operations and hospital design guides. Due to the very tight timescale, modular construction was felt to be the only option. The design was based on 2 x 24 bed wards on two upper stories. The ground floor of the extension was to be added at a later date. A crucial aspect of the project was the choice of separate contractors for the enabling works and the modular construction. The Trust felt that separate specialist contractors would be better able to use their particular expertise to deliver on time. However, there was no contractual relationship between the contractors and this imposed a degree of risk for the project. Tender documents were prepared, sent out and returned within a few weeks, rather than the usual months. Work often began before formal documentation arrived, due to the level of trust engendered by the client Project Team. The site was very steeply sloping and the enabling works involved the removal of 12,000 cubic metres of earth and the construction of a 4.5m retaining wall. The key date for the critical path of the project was the module delivery date. All other project dates were determined by working back from this date. Problems that emerged related to supporting the crane (required for the placement of the modules) presented a crisis for the project. However, the Project Team hastily found a suitable solution and the 700 tonne crane was delivered on six lorries and assembled in situ. In the event, the placement of the modules was slightly delayed as the wind speed exceeded the maximum 12 mph crane operating conditions for two days.

Case Study 3: The Ward Refurbishment

This study concerned the refurbishment of an oncology ward in a large NHS acute hospital built in the late 1960's. A children's charity presented £2.9m to the Hospital Trust exclusively for the refurbishment of the teenage cancer ward and the Trust contributed £800,000. The donation would provide the trust with the opportunity to group the existing oncology wards together, and in addition, opened up the prospect of rationalising other clinical specialities to improve their connectivity with essential services. A complex sequence of ward decants coupled with additional refurbishment works to accommodate the transferred patients, was set in motion. Hence, for the oncology refurbishment to progress from design to construction, a considerable amount of "enabling" work had to be done. Clearly, this was not enabling work in the traditional sense, however the sequence of decants and refurbishments was essential for the cancer ward refurbishment to proceed (Kagioulou *et al.* 2000). The process was plagued with programme changes resulting from incomplete building information due to the constraints of carrying out surveys in an occupied hospital.

Table 4. Interviews with Case Study 3 participants

Team	Time
Hospital Trust Project Team (Four NHS project managers)	66 minutes (Group session)

The whole process took approximately twelve years and the total cost was in the region of £11-12m. The section of the building identified for the new teenage cancer ward had not been refurbished before and there was a total absence of current information regarding the condition of the structure or services. This resulted in some significant surprises and work was rescheduled accordingly.

PATTERNS OF CHANGE IN CASE STUDY PROJECTS

Each of the case studies showed examples of "within" and "across" layer propagation and each had developed strategies for mitigation. In comparison, engineering change is very highly constrained and few options exist for containing change propagation.

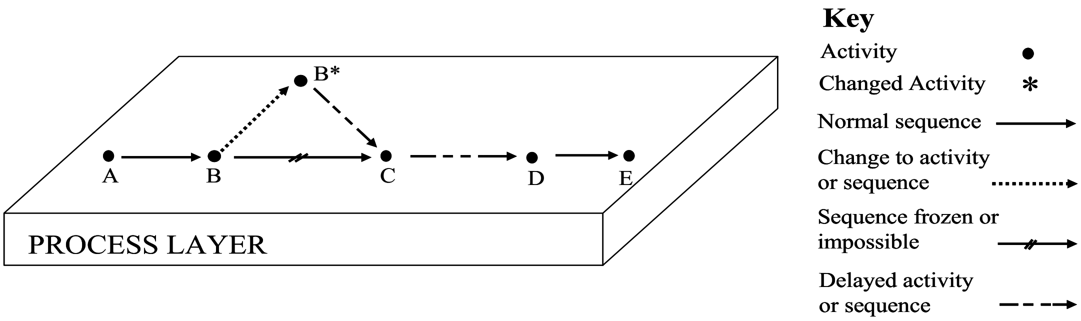


Figure 2. Neo-natal Unit: changes within a layer

Mapping changes across the framework (Figure 1) helped to reveal the patterns of change and the mechanisms that operated. Common problems within a project layer were often mitigated by well understood strategies, typically these included rescheduling a sequence of tasks or the inclusion of additional resources. The need to avoid disturbance to patients in adjoining wards, meant that a comprehensive survey was not possible (Figure 2). The Estates team were aware that asbestos was present, but the extent of the problem was greatly underestimated. Hence, the stripping out of the ward was delayed (activity C) while a second, more thorough asbestos survey was carried out (activity A*) and additional asbestos removed (activity B*). A very similar pattern was observed in the Cancer Ward case study, where again pre-construction survey information was limited. Changes due to the presence asbestos and unexpected details corresponded to the change patterns in the Neo-natal study. Where change patterns were repeated it was possible to identify "motifs" of change (See fig 5a).

Change propagating between adjacent layers

Changes to the Modular Extension project (Figure 3) involved supporting a 700 tonne crane, 2m from the top of a newly erected 4.5m high retaining wall. However, at a very late stage the enabling works sub-contractor intimated that their designers could not provide an adequate support solution (B) for the additional crane loads.

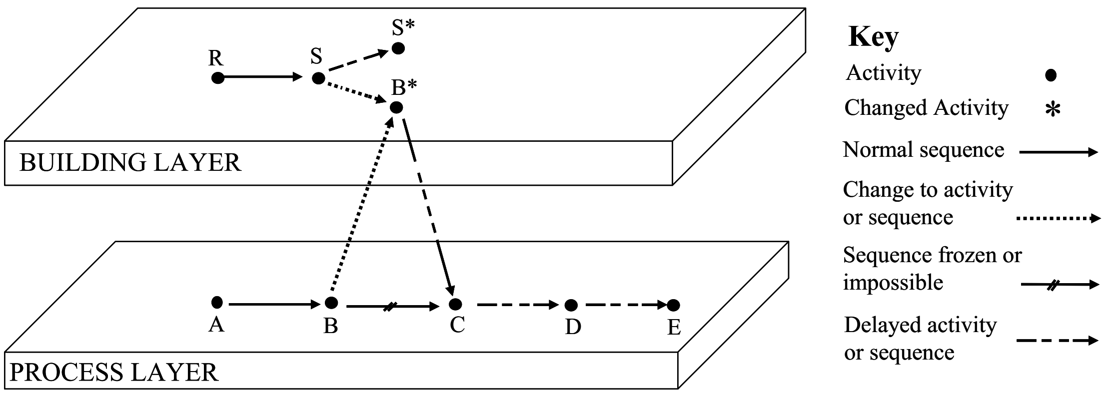


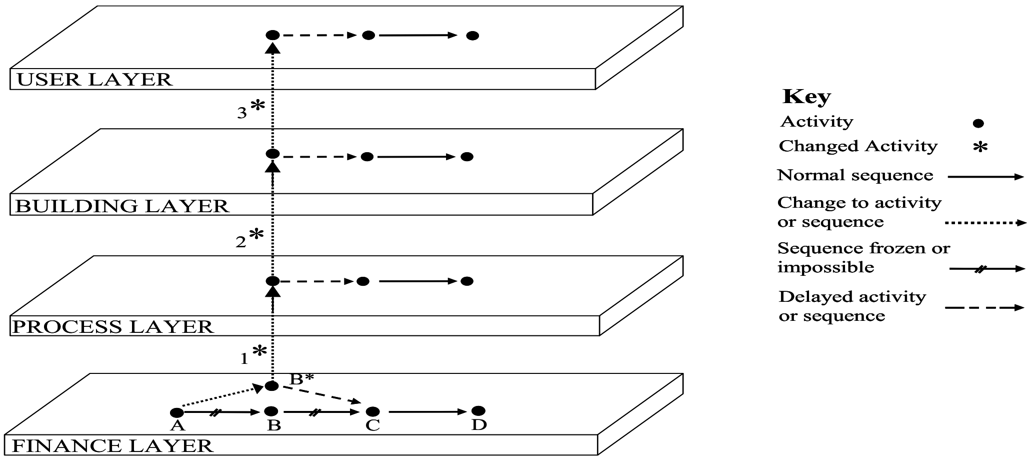
Figure 3. The Modular Extension: changes across layer boundaries

This diverted key team members from other tasks on the Building Layer (S) to provide an additional design support (B*). Hence, the process of constructing the crane support (C) was delayed. The crane positioning was slightly delayed (D), and severe weather delayed the module placement for two days (E).

Global Change: Change propagating across all layers of the project

Insufficient funding for the Neo-natal Unit (Figure 4) meant that refurbishing both floors of the unit would not be possible and pathway activity (A) could not advance.

Figure 4. Neo-natal Unit change propagation across all layers.



The project was re-scoped to concentrate on the refurbishment of Floor 1 and the change, originating in the Finance layer, propagated to all other project layers. This funding crisis affected the project globally requiring the reorganization of the design process; the project programming and work flow; the contractual arrangements; and ultimately it affected the user's operational processes and aspirations. However, later in the project, charitable funding along with unspent risk mitigation from the work to the lower floor enabled the work to the upper floor to be completed.

Mapping groups of change

Other patterns of change (at various scales) became evident as the individual changes were grouped and mapped. The illustration below (Figure 5) shows a representation of groups of changes or "motifs" similar to those described by Giffin *et al.* (2009) that were observed during the case-study analysis. The changes shown in (A) related to an emergent event: In this case, wild pigeons were found nesting on the Neo-natal site, and under UK legislation (Wildlife and Countryside Act, 1981), the birds could not be disturbed until the young had fledged. The site accommodation could not be installed and delayed the project by three weeks. However, work flows were rescheduled to make up for lost time. The changes in (B) map the processes involved when the water supply system to the Neo-natal unit and to the whole building, was found to be in extremely poor condition. The cast-iron water main had to be replaced and the resultant changes were costly and time consuming and affected all the central areas of the building and propagated to other layers of the project. The severity of the propagation was largely due to the stage at which the problem was identified.

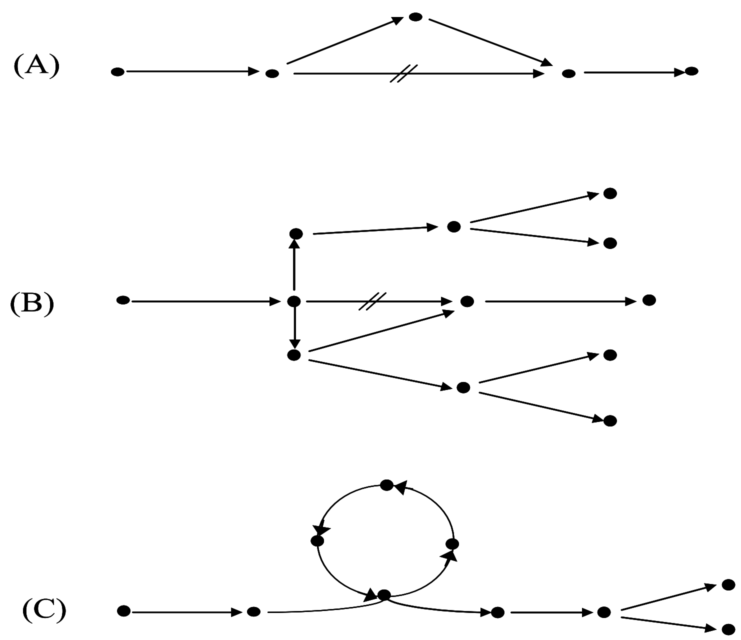


Fig 5. "Motifs" or representations of specific change episodes (note: not time dependant).

If the problem had emerged prior to the agreement of the Guaranteed Maximum Price, the costs would have been included in the contract. Eventually, the extra costs were agreed by the Trust Board, work schedules were reorganised and small but significant layout changes were included. The changes at (C) map the initial ward decant processes and refurbishments for the Teenage Cancer Ward (Table 3).

Table 5. Sequence of events to enable the completion of the Teenage Cancer Ward Project

Decant 1	Level 5 patients (respiratory medicine) relocated elsewhere in the hospital.
Refurbishment 1	Level 5 ward refurbished
Decant 2	Level 9 (transplant) high dependency patients transferred to refurbished Level 5
Refurbishment 2	Level 4 VATC system rearranged and additional showering facilities added to accommodate Level 8 orthopaedic patients
Decant 3	Level 8 patients (orthopaedic) relocated to Level 4 (Short-term)
Refurbishment 3	Level 9 Survey and services work begun (knocking though to Level 8) and Level 9 refurbished
Patient Transfer	Teenage cancer ward opens on Level 9 and final transfer of patients to ward.

To provide a refurbished teenage cancer ward on Level 9, the high dependency transplant patients presently on Level 9, had to be transferred to Level 5. However, this could not occur until Level 5 had been refurbished. The patients occupying level 5 would be relocated elsewhere in the hospital (which involved additional work beyond the scope of the study). Following this transfer, Level 5 was refurbished. The orthopaedic patients on the floor below Level 9 (i.e. on Level 8) would also have to be temporarily transferred to Level 4, to allow essential survey and services work to be done. However, to accommodate the transfer of the orthopaedic patients from Level 8 to Level 4, the Vertical Terminal Air Conditioning (VATC) system on Level 4 would have to be completely refigured, following the installation of additional showers needed for Level 8 patients. The patient transfers had to be orchestrated with care, and additional funding streams established, hence the extended time-scale for the project.

DISCUSSION AND CONCLUSIONS

From the change patterns identified, what might be considered minor "hitches and glitches" can be surprisingly problematic. The need to replace the aging cast-iron water main for the Neo-natal Unit was originally considered an unexpected hitch and given low priority, but as the extent of the problem became clear, it propagated widely, becoming a significant change multiplier. This led to changes to all layers of the project and involved delays to schedules, layouts and additional costs, which required approval by the Trust Board. Similar costly "glitch" patterns were identified in the Cancer Ward Project, also resulting from the lack of survey information. Conversely, the failure of the sub-contractor to design a crane-support system at a critical point was immediately identified as a serious crisis for the Modular Extension Project. The critical event of placing the modules was directly dependant on the crane being in place and adequately supported. In consequence, this challenge galvanised key decision makers and a solution was promptly identified, absorbing the possible propagation effects that might have developed. A similar high-level intervention was observed as the Neo-natal funding crisis developed. Senior decision makers reduced the scope of the project and although change propagated widely, it did not get out of hand. This was because the strategies that were adopted to reduce the pressure on the project and increase tolerances, functioned as absorbers of further change. The pattern of decants and refurbishments required for the Teenage Cancer Ward to progress was particularly interesting. The changes propagating from the charitable donation of £2.9m resulted in the Trust spending £11 - £12m on a project that spanned 12 years. However, the project funding allowed the Trust to achieve other connected goals during the process and forwarded the Trusts rationalisation plans and the general refurbishment needs of the building. From the interview evidence, it appears that changes within the framework layers, tended to be less problematic than changes that escaped to other layers. This is not surprising because the tolerances and strategies designed to manage expected change within each layer are usually well understood. Propagation beyond layer boundaries may be more complex or untimely, with fewer options for mitigation, as these types of changes tended to be less predictable. However further research will be directed towards improved understanding and prediction for these "change pathway" risks. Towards the later stages of a project, tolerances or buffers may be exhausted and change may be difficult or impossible within the existing budget or time frame. The situation in product engineering is somewhat different. Changes are extremely constrained, often by the product volume restrictions or by other factors, such as vibration effects, overheating, electrical connections etc. so that changes are frequently refused and no option for change exists. From the case-studies, situations were very rarely encountered where a solution of some form could not be achieved and construction change appears considerably more malleable than engineering change and follows quite different trajectories. Further work will consider the effects of constraints on the change process and how, by varying the constraints, the probability of serious propagation may be reduced.

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