Using Flexibility to Improve Value-for-Money in Hospital Infrastructure Investments

Richard de Neufville, Yun S. Lee, Stefan Scholtes

Abstract—Flexibility is a key value driver for hospital infrastructure in a highly unpredictable health care environment. This is illustrated by the example of the development of a major UK teaching hospital over the past 80 years. We then lay out some principles for the articulation of the value of flexibility to enable the designer to make an economic case for flexible infrastructure. Finally, we argue that hospital procurement under Public Private Partnership (PPP), in particular under the UK Private Finance Initiative (PFI), can be an inhibitor to the design and development of flexible infrastructure. To realize the value of flexible infrastructure systems, the PFI parties need to create a genuine long-term partnership. The private parties have to stay engaged during the lifetime of the infrastructure to help adapt it to developing circumstances and thereby minimize value risks, maximize opportunities if and when they arise, and allow the public sector to reap as much social benefit from the infrastructure as possible.

I. INTRODUCTION

Hospital infrastructure is typically designed for a lifespan of more than 30 years. During this life, demands on the infrastructure will change significantly. Unpredictable local and national demographic changes in the wake of globalization, unforeseeable advances in medical technology, changing epidemiological patterns driven by lifestyle changes, and rapid regulatory changes make scale and scope of the demand on any individual hospital over its lifetime highly unpredictable.

A good value-for-money hospital infrastructure therefore needs to be flexible, to allow effective adaptation to changing circumstances. The design of flexible hospital infrastructure is the focus of this paper.

Examples of flexible design features in hospital buildings include shell space where areas are built but not yet medically equipped, or suitable structural foundations of a building to allow additional floors to be added at a later time. Such flexibilities can be used to expand capacity in the future in response to increased demand, if and when this demand materializes. Another example is flexible layout of functional rooms, such as operating theatres, which would allow a change of usage in the future, e.g., to adapt to changing technology.

This paper is structured as follows: We will first illustrate the value of flexibility, using the development of a major UK teaching hospital over the past 80 years as a case study. Then we explore some principles and processes that may help designers and their clients articulate an economic case for flexible infrastructures in a transparent manner. Finally, we will argue that procurement under Public Private Partnership (PPP) arrangements, specifically the current Private Finance Initiative (PFI) in the UK, can be an inhibitor to the establishment of flexible infrastructure.

II. USE OF FLEXIBILITY AT ADDENBROOKE’S HOSPITAL, CAMBRIDGE, UK

The development of the infrastructure at Addenbrooke’s Hospital in Cambridge, UK over the past 80 years provides an excellent case for successful long-term use of flexibility. The hospital is the major teaching hospital of Cambridge University, with a current capacity of 1100 beds. The hospital serves the local population as a general hospital and is also a specialist centre with an international reputation. The hospital’s history goes back to the 1760ies. It was located in the centre of Cambridge until 1962, when the New Addenbrooke’s site was opened at the outskirts of town. Both sites were operated in parallel, until the old site was finally closed in 1984. The following charts give an illustration of the changing demand and supply of the hospital over the past 80 years.

During the first half of the 80-year period the hospital had relatively stationary demand for inpatient service, with a marked increase during the World War II. Considerable increase in inpatient activity since the mid 70ies can be explained by gradually rising number of daycases. Significant advances in medical technology and treatment processes have led to a reduction in the length of stay in the hospital of inpatients and thus there has been a shift of less severe cases from inpatient to outpatient treatment. This partially explains the increase in outpatient demand together with demographic pattern over the period.

Addenbrooke’s Hospital has gone over a number of adaptation and expansion schemes to respond to...

1 The gaps indicate missing or unreliable data in the hospital archive. The accuracy of the data could be somewhat affected by inconsistent data formats and descriptors in the various sources.
unforeseeable political events and changes in demand. There is a distinctive rise in bed numbers during 1940-45 when World War II broke out. The capacity increase at the time was achieved by making use of a school and university space. In the late 1940ies, planning begun to move the hospital to a new site by acquiring 67 acres of land. In 1962, the new site was opened at the outskirts of town, initially with 94 beds. Over the next years, capacity was increased at the new site with staged developments and reduced at the old site in the centre of town which eventually closed in 1984. A substantial increase from 400 to 800 beds occurred in the 1970ies when major developments of the new site were completed. Currently, the hospital has expanded to accommodate around 1100 beds. Indeed, in 1999 the Trust announced an ambitious long-term development plan, called the 2020 Vision, which will expand the hospital campus by an additional 70 acres of land, doubling the size of the existing site.

B. Recognizing the Need for Flexibility

Addenbrooke’s Hospital was aware of uncertainties in future demand and recognized the need for flexibility as means of coping with uncertainties to ultimately produce a “living infrastructure” that delivers good value-for-money. For example, the East Anglian Regional Strategy Team warned in 1974 “In general terms therefore while we consider that our estimates of population growth in the Cambridge area cover

A. Forecasting Capacity Requirements

Forecasting required capacity, in terms of bed numbers, is a crucial input into the design of a hospital. The following figure shows the forecast bed capacity in 1981 for various planning years.

Fig. 5. Forecasting bed numbers for 1981 at Addenbrooke’s Hospital, Cambridge

Clearly, the plan overestimated the capacity requirements. The unanticipated reductions of length-of-stay and shifts from inpatient to outpatient activity are likely to be responsible for keeping the capacity of the hospital lower than planned. A second significant source of error is probably the underlying demographic forecast. Indeed, the following chart shows how far off the demographers can be at the national aggregation level. In particular, the 1965-based projection was significantly higher than the eventual realization. An analysis of projections made in Western countries indicates that the birth rate predictions made in the 1950ies, based on the assumption of a continuing baby boom, were up to 80% too high [1].

Fig. 6. Actual and projected population [1]
most contingencies on present knowledge, we recognize that there is a great degree of uncertainty in this case. (...) our view would be that any commitments made should be designed to be adaptable to a number of possibilities, both in the provision of services, and its relationship to transport facilities giving people access to these services [2]."

It is also remarkable how much the need for flexibility has been emphasized during the planning phase for the New Addenbrooke’s in the late 1940ies and the 1950ies. Murray Euston, the appointed architect for a new site development said in 1947 “the hospital authorities should keep in mind the need to secure a larger area than the 60 acres to allow for any eventual developments [3].” without which the 2020 Vision, initiated 50 years later, would not be realizable. The 1953 annual report states that “The construction of a large new hospital centre will have to be undertaken in stages, and work is proceeding to evolve an outline plan which will permit sections to be constructed according to a flexible order of priority.”

C. Exercising Flexibility

Flexibility is only valuable if it is exercised effectively (“when the time is right”) and efficiently (“at acceptable cost and disruption”). The importance of proper timing of expansion plans was recognized already back in 1960, when the hospital’s architect reported that “The speed with which medical and technical changes were taking place meant that it would be to the Hospital’s advantage to extend the point at which final decisions were taken on plans for new buildings to the latest moment [3].” Cost-efficient exercise of flexibility requires thoughtful engineering design at the outset of the project, long before the flexibility is actually employed. Cost and disruption of service due to continuous site development were a major concern at Addenbrooke’s from the initial stage of the development. The 1962 Annual Report states that “The further development (...) will mainly be along the East-West axis of the site (...). The present buildings have been constructed with ‘free ends’ to permit future extensions to departments with the least possible disruption of the service of the hospital.” A further design feature that improves efficient use of expansion flexibility is the decision to locate critical servicing at sub-ground level, thus building an expandable spine, which allows the efficient accommodation of additional servicing requirements for ward expansions.

Together with expanding the hospital in lateral directions, hospital buildings are also extended in height to react to increases in demand. In fact, height extensions were already used for the Old Addenbrooke’s building. In 1915 two new operating theatres, including anesthetics and sterilizing rooms were built on the north side of the third floor, complemented in 1930 with a new surgical ward for women with 27 beds on the other side of the third floor.

Improved construction technology, such as off-site construction, allows exercising some of the flexibilities in relatively short time and at acceptable cost. The new modular operating theatres were placed on top of the Food Court at the New Addenbrooke’s over two weekends in 2004. Another example is a new Emergency Assessment Unit which was opened in 2002 using the 450 m² empty courtyard at the heart of the hospital. The new unit was assembled from 70 modular units manufactured off-site over 6 months without huge distractions to the current hospital work.

If demand is lower than expected, or indeed if it disappears altogether, one can look for alternative, secondary usages. In the Addenbrooke’s case, the old hospital building which was emptied due to new site development was converted to accommodate the newly formed business school of Cambridge University in the early 1990ies. The fact that the Old Addenbrooke’s Hospital was housed in an iconic Cambridge building in the centre of town, which was not spoilt by over-development, made it an excellent prospect for re-development. Thinking of resale and reuse value during the design phase can thus turn out significantly beneficial.

III. FLEXIBILITY IN INFRASTRUCTURE DESIGN

Forecasts, in particular long-term ones, are highly unreliable, in fact are “always wrong” in that what actually happens “never” conforms to predictions. The forecasting figures in the Addenbrooke’s case provide some evidence for this. The figure below, which gives a sample of errors in traffic demand estimates, is a further illustration of the wide variations in infrastructure demands.

Therefore, the first and arguably most important step towards more flexible infrastructure is to stop asking for accurate forecasts of the future. Instead we ought to ask our forecasters for a wide range of possible futures. Given such a range, it is the designer’s challenge to build an infrastructure that can cope with many of these futures. The incorporation of flexibility into the system design is then a very natural step.

Flexibility is often described as the right but not obligation to a specific future action. One way of thinking about any particular type of flexibility is to regard it as a system switch which is either in “on” or in “off” (default) setting. Switching to “on” will change the way the system operates. Building the switch in costs money – and switching from “off” (default setting) to “on” will often also cost money. In some situations one can switch on or off as often as one likes, sometimes one can only use the switch once. Of course a good flexible system
will typically have several switches to allow a reaction to different circumstances. In some futures we will not use the flexibility, will not “switch it on,” in others we will.

A. Stylized Example of Economic Valuation

Designers who build flexibility into their systems have to clearly demonstrate the economic value of flexible designs to prove “value-for-money.” Sometimes additional flexibility will come at an additional cost which needs to be justified. However, flexibility can also help to save on initial capital expenditure, for example by building a less costly smaller initial infrastructure with the potential for efficient scale-up later on. To date there is no standard systematic way of demonstrating the economic value of flexibility to compare system designs for an investment project. This section attempts to provide some guiding principles towards such a standard.

Stylizing the case of New Addenbrooke’s Hospital, we will use a simplistic fictional example of a new hospital development to illustrate the process that allows the articulation and discussion of the value of flexible design. The main reason for the new hospital is assumed to be an anticipated increase in inpatient activity. A key design input is therefore the growth of annual inpatient bed days over the next 25 years. Suppose forecasts say that inpatient bed days will continue to rise, eventually requiring a large and rigid hospital with 1000 beds. They quote the aging population, the obesity trend, but also the increasingly successful recruitment of wealthy private patients from developing countries as drivers of further demand increase. However, some analysts warn that the trend could well reverse and hospital design should also take account of possibility of this particular future realizing. Regulations are discussed that they could give the competing hospitals and private sectors more access to the hospital’s local catchment area. Also, over the lifetime of the hospital, medical technology may drastically reduce length of stay for some diseases. Along with a rigid design with 1000 beds, alternative design involving staged developments is thus discussed: Build 700 beds initially but invest in an option to expand up to 1200 beds in the future through the conversion of ground-level car parking space to additional hospital buildings and the building of multi-story car parks to cope with the additional traffic. How do the economics of the 700 beds + expansion option and the 1000 bed rigid stack up?

The starting point for the articulation of the economic value of a flexible design must be the recognition of many possible futures. This is because it is impossible to forecast hospital demand precisely due to uncertainties around the degree of effect of four key drivers on demand change as discussed above: (i) demographic pattern including ageing population (ii) medical technology advance, which is historically attributed with reduced length-of-stay and therefore a reduction of required bed capacity, (iii) epidemiological pattern, driven for example by lifestyle changes, which can lead to reduced demand (no-smoking policy) or increased demand (obesity), and (iv) regulation and policy, e.g. around patient choice or private practice. The range of possible future hospital demands can be obtained by assuming different combinational effects of key drivers on future demand changes. To keep things simple let us assume that we work with a range of 10 possible demand futures with different assumptions, call them F1, F2,..., F10.

Next we develop a contingency plan for each design. Of course if the design is rigid as in the case of the 1000 bed hospital, then there is no contingency plan. But for the 700 bed hospital a contingency plan might be of the following form: “We will decide whether to expand the hospital or not in 5 years time. If total growth in demand over these 5 years exceeds 10% then we expand to a total of 1000 beds, if growth exceeds 15% then we will increase to 1200 beds. Otherwise we do not expand.” With this contingency plan we can calculate the Net Present Values2 of the two hospital designs (or other cost-benefit metric) for each future F1,...,F10. The results can be summarized in a bar-chart as follows:

![Net Present Value for different demand scenarios](image)

In the low demand scenarios F1,..., F4 the flexible design performs much better because the 1000 bed hospital would be a white elephant. In the medium scenarios F5,..., F9 the flexible hospital is expanded from 700 to 1000 beds. The overall performance is worse – the saved capital costs due to delaying part of the investment were not sufficient to balance out economies of scale and the cost of operational disruption during the expansion. In the very high scenario, F10, the flexible design performs better again because the hospital can be expanded to 1200 beds to amplify gains from high realized demand.

It is not immediately clear from the bar chart which hospital design should be preferred. If one were very worried about the low demand scenarios, the flexible system can be a better choice. But the hospital trust may have a reasonable analysis to believe that the chance of these low demand scenarios is unlikely – and be prepared to take the risk.

This brings us to the second useful ingredient of a valuation – the relative weight assigned to any of these futures, in other words, subjective estimates of the likelihood of occurrence of the futures. If the futures are rated equally likely to be realized, then no new information is added to the bar chart above. If,

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2 Present value of net cash flows. Each cash inflow/outflow is discounted back into its Present Value.
3 In a professional analysis these scenario-by-scenario values would be calculated through a Monte Carlo Simulation.
however, they are perceived to have different likelihood, then one way of incorporating this into the bar graph is to multiply every bar value with its probability of occurrence. This can result in a bar graph like this:

![Bar chart showing likelihood-adjusted Net Present Value for different demand scenarios]

Note that this graph has a different scale because the bars have been multiplied by the estimated probability of occurrence of the respective future. But what is more interesting is that the shape of the bar chart has changed. The inflexible design now performs better in the medium demand scenarios because these were assumed to be more likely to be materialized.

Bar charts like the above, or similar multi-future representations of economic value, can be usefully employed to illustrate where the value of flexibility lies. They do not disguise the fact that the value is uncertainty. They may well be uncomfortable for decision makers because they highlight negative value in some scenarios. However, this realization can be used as a challenge to design additional flexibility in the system that improves the performance in some worrisome scenarios without too much negative influence on others.

IV. PRIVATE FINANCE INITIATIVE AND VALUE-FOR-MONEY

Flexibility is a substantial value-driver for infrastructure investments evidenced by the development of Addenbrooke’s Hospital in Cambridge. Infrastructure investments, in particular in the health sector, are increasingly carried out within a PPP framework. Typically in the UK, Department of Health reported in 2007 that investments in 80 major PFI hospital projects alone exceed a total of £60 billion [6]. Our final concern in this paper thus lies in investigating the effect of PPP procurement, in particular under PFI framework in the UK on flexible infrastructure design.

PFI is a route to the procurement of project finance from private sources. Whilst the specifics of PFI projects can vary substantially, most of them share a common responsibility structure: A private consortium, typically consisting of private construction companies, service providers and banks, finances, builds and maintains the infrastructure to agreed specifications. The infrastructure is then rented to the public sector client for an agreed period, typically 25-35 years. During the concession period, the public sector client provides public services using the infrastructure and in turn makes agreed annual rental payments to the private consortium.

We will explore the value provided by PFI projects. The value proposition for any project has three main components: Construction Cost and Time, Maintenance Cost, and Social Benefit/Revenue. In the following two chapters, the performance of PFI projects under these three metrics is discussed.

A. Controlling Cost and Time under PFI

PFI can be perceived to be a success with regard to delivery on time and on budget, as evidenced in [7] on a sample of conventionally procured and PFI projects. Competition in the bidding process should keep total budgets down and the fact that positive cash flows from government rents only start when the infrastructure becomes operational gives the private sector an incentive to keep the construction period short because they will otherwise lose part of their income stream.

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<th></th>
<th>On-Time</th>
<th>On-Budget</th>
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<td>PFI projects</td>
<td>76%</td>
<td>79%</td>
</tr>
<tr>
<td>Conventionally procured projects</td>
<td>30%</td>
<td>27%</td>
</tr>
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![Table showing performance of PFI projects compared to conventionally procured projects in terms of building on-time and on-budget]

How well do PFI projects do after construction? PFI projects require the private consortium not only to build the infrastructure but also to maintain it during the lifetime of the contract. It is therefore in the private company’s best interest to find a good balance point between spending money upfront for a robust infrastructure and spending money later on maintenance.

PFI framework is thus designed to effectively transfer two key risks, the risk of excessive construction costs and time and the risk of excessive running costs, from the public to the private sector.

B. Delivering Social Benefits and Revenue under PFI

Let us now look at how PFI procured projects performs in terms of generating the social benefits and revenue. We saw that the ability to adapt to different circumstances is directly related to improving the social benefit and income stream. Flexibility can thus be a substantial value-driver for hospital infrastructures. However, the existing PFI framework can be a significant obstacle in exercising flexibility to manage situations where the infrastructure does not create the expected value.

Firstly, private consortium is the owner of the asset but it is not engaged in value proposition from incoming demand. Therefore, private consortium does not have incentives to
design infrastructure with flexibilities, which they do not get any benefit from unless the client initially specifies requirements of certain flexibility. Flexibilities may also increase capital expenditure and consequently reduce the chance of their bid being selected. In addition, the public client cannot change the asset unilaterally to improve its value without agreement from private consortium. Even if private consortium agrees to adapt the asset, they can overprice costs for adaptation as they have a bargaining power from being the owner of the asset. To make matters worse, the membership of the private consortium may have changed, and the design and construction knowledge and expertise necessary for a creative satisfactory restructuring of the failing asset may be lacking.

Secondly, the private consortium is naturally expected to act in the interest of its shareholders and therefore has no incentive to lower the contractually agreed rent even if projected revenues of the public sector do not materialize. In fact, it will have sold a significant proportion of the rental cash flows to the financial markets with asset as collateral. So the private consortium’s base position in any negotiation is that the public partner should honor the contractually agreed payments no matter how little the realized benefits and revenues are. Also any change in the asset which is not specified in the contract would potentially require a very costly re-rating of any bonds used to finance the project.

In summary, there is an inherent weakness in the PFI process: its preoccupation with cost control, rather than value delivery. If we define value as a benefit-cost ratio, then PFI works on minimizing cost – but does not specifically address the maximization of benefits.

C. Creating a Genuine Long-Term Partnership under PFI

In order to realize the value of flexible infrastructure, public private partnerships need to move from a current contractor-client, “fee-for-service” relationship to a genuine partnership, where both public and private partners engage over the entire life-time of the infrastructure in a genuine joint operation, sharing costs, rewards and risks in an efficient way.

One might even argue that much of what PFI achieves today, in terms of improvement on traditional project management metrics, could also be achieved with suitably modified traditional procurement routes. What cannot be achieved without a genuine public private partnership is the creation and maintenance of high-value flexible systems, of “living infrastructures,” where the operation, the reaping of value, is one part and the regular adaptation of the infrastructure, the exploitation of flexibilities is the other part. This might be coordinated, for example, by an on-site office, jointly run by the private and public partners, with a remit to monitor unfolding circumstances, understanding their impact on the operation of the system and exercising flexibilities in the design as appropriate for the maximization of the value reaped from the system.

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