Flexibility in Hospital Infrastructure Design

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November 2008

Abstract—**Flexibility is an important value driver for hospital infrastructures in today's highly unpredictable health care environment. We illustrate this by way of a case study based on 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 a 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.**

Keywords— **Flexible Design, Hospital Infrastructure, Demand Uncertainty, Public Private Partnership**

I. Introduction

Hospital infrastructure is typically designed for a lifespan of more than 30 years. During this time, demands on the infrastructure will change significantly and unpredictably. Local and national demographic changes in the wake of globalization, changing epidemiological patterns driven by lifestyle changes, unforeseeable advances in medical technology, and rapid regulatory changes make scale and scope of the demand on any individual hospital over its lifetime highly uncertain. A good value-for-money hospital infrastructure therefore needs to be flexible, to allow effective adaptation to unpredictably changing circumstances. The design of flexible hospital infrastructure is the focus of this paper.

Examples of design features that make hospital buildings flexible 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. If demand is lower than anticipated it will be important to be able to downsize, e.g. by sub-letting or selling part of the infrastructure for other purposes. The capture of value in these circumstances requires that the infrastructure can be made attractive for secondary usage. A third example is the flexible layout of functional rooms, such as operating theatres, which would allow a change of usage in the future, e.g. in response to changing technology. Such design flexibilities are the subject of this paper.

The paper is structured as follows: We will first outline a typical hospital designing process, in particular the process of projecting future demand on the infrastructure. We then explain the notion of flexibility. Specifically, we distinguish between operational, tactical and strategic flexibility. Using the development of a major UK teaching hospital over the past 80 years as a case study, we then illustrate how hospitals react to changes in patient activities in terms of altering overall bed numbers and layout design and how flexible design can add values in volatile environments. We also 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. Hospital Infrastructure Design[1]

In designing new hospitals, a top-down approach is typically taken. The process begins with the projection of the demand on the infrastructure. It is useful to think of two factors of health services demand: The number of patients to be treated in any one year (the demand volume), and the infrastructure resources required for their treatment. In its simplest form, one can think of the number of patients across hospital departments in any one year and the average length of stay of these patients as a proxy for resource requirement. In reality, more complex volume patterns, including finer categorization of diseases, demand seasonality and variability, and more complex resource requirements, e.g. operating theatre hours, are taken into account.

To arrive at a hospital level demand projection, demand in suitably segmented disease categories is first considered at a national level, and then broken down to regional levels

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[1] Discussions with people who are involved in designing new hospitals helped shape our thinking on the issues addressed in this section. Interviews were conducted with Martin Allinson from Laing O'Rourke, Mathew Harker from New Church, Norman Brasher from Addenbrooke's Hospital. Proposed steps of a designing process are simplified from what happens in practice.

(Strategic Health Authority), to local levels (Primary Care Trust) and finally to hospital levels. Demand, both by volume and resource requirement, is driven by three factors: demographic projection, epidemiological changes and advance in medical technology. Projections of these factors are combined to project historical trends in national demand forward into the future. This leads to projections of system level clinical activity, which is factored into different types such as inpatient, outpatient and A&E activities. Models of care then define how the local demand for health care provision is allocated to different healthcare providers. Demand for a particular acute hospital is thus derived from this top-down system-wide projection and allocation process.

For example, the population of elderly patients with chronic disease is rapidly increasing, creating high demand for inpatient activity in acute hospitals with long length of stay under the current model of care. However, the projected model of care for such patients may well lead to diverting these patients from acute hospitals to other healthcare providers, such as community hospitals and nursing homes. This will result in reduced bed capacity requirement in hospital departments that would traditionally treat these patients.

Projected clinical activity of each care group at hospital levels will give an estimate of the required sizes of each department with detailed design inputs, such as required bed capacity and number of operating theatres. Finally, departments are arranged according to operational adjacency requirements between departments. This process will typically take several iterations. The figure below summarizes key steps of a typical hospital capacity planning process.

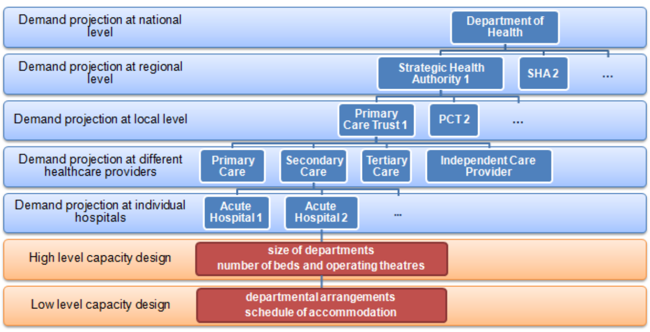

Fig. 1. Key steps of a typical hospital capacity planning process

A. *Design for Change: Flexibility*

The output of the demand projection process above is a projection of patient activity in one hospital over time, typically over more than 30 years. Patient activity patterns over such time horizons are of course highly uncertain. Demographic and epidemiological patterns and medical technology change unpredictably, affecting the number of patients, their conditions, and their length of stay. Also, models of care will change in unpredictable ways. Finally, in a world of patient choice, competitive forces will be a significant driver of hospital demand, in particular in metropolitan areas. It is impossible to predict future patient activity with a reasonable degree of accuracy. Nevertheless, such patient activity projections are the key input in the capacity planning process. Designers will optimize the design of an infrastructure to cope with whatever demand projection they have been given – even though this particular course of activity is unlikely to unfold. The associated design is optimal under the design brief but sub-optimal in reality. Instead of asking designers to optimize infrastructure for one possible future we should challenge them to design infrastructures that can be adapted and can therefore cope with many possible futures. Flexible infrastructures will not only optimize for a single planned activity pattern but also for changes in planned activity.

Flexibility is often described as an option - 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 “on” or “off”, and “off” acts as a default setting. Switching to “on” will change the way the system operates. Building switches into the system costs money – the cost of the option - and switching from “off” to “on” will often also cost money - the cost of exercising the options. In some situations one can switch “on” or “off” as often as one likes, sometimes one can only use the switch once. A 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”. With hindsight, the capital that we invested to build in the switch in the first place is lost. However, a priori the switch has value, because in other circumstances we will use the switch and benefit from improved value that we extract from the infrastructure.

The cost of the switch is off-set by its value, which has two components: the probability of switching on, and the additional value extracted if switched on.

B. *Operational, Tactical and Strategic Flexibility.*

It is useful to categorize flexibilities as strategic, tactical and operational, largely depending on how fast one would expect to use the switch. Operational flexibility could be used on a daily or weekly basis and can quickly adapt the infrastructure usage to deal with short term volatility. A flexible furniture system that can be configured in various ways is an example of operational flexibility. Wards that can accommodate different types of patients allow hospitals to deal with suddenly changing demand patterns. Operational flexibility is typically not “one-off”; switching is cheap, fast, and reversible.

Tactical flexibility is somewhat slower. Examples of tactical flexibility include ‘shell space’, and flexible design of footprints and operating theatres. The use of a tactical flexibility switch requires a more significant commitment of capital and is more difficult and expensive to revert. One would not expect to exercise tactical options very quickly. They enable a reaction to medium term uncertainty.

The final category is strategic flexibilities, options that we may in fact only exercise years from today. The effect of such strategic flexibility is often a substantial increase of the life-time of the infrastructure. For instance, a hospital can be designed in a way that the expansion of the hospital can take place incrementally by initially acquiring a sufficient amount of extra real estate, or an option on buying neighboring farmland. A hospital can be expanded in height if the structural elements are adequately sized to allow for higher loadings in the future. In the case of falling demand, a part of hospital may be sublet for secondary usages such as the office space or space for pharmaceutical research or production.

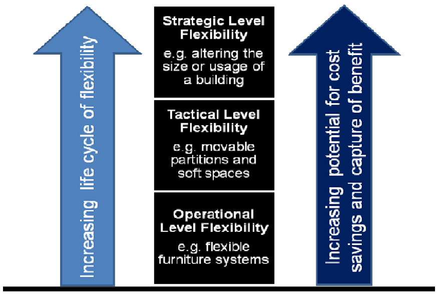

Fig. 2. Categorizing flexibilities

III. 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 to illustrate dramatic changes in patient activities and successful long-term use of flexibility. Addenbrooke's is the 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, e.g., in oncology and neuroscience. 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.

A. *Changes in Demand and Supply*

The following charts (Fig.3 – Fig. 6) give an illustration of the changing patient activities and how the hospital reacted to this change by altering the number of beds over the past 80 years[2].

During the first half of the 80-year period the hospital had relatively stationary patient activity, with a marked increase only during World War II. Since the mid 70ies, the number of patient episodes, both inpatient and outpatient, has increased considerably. Advances in medical technology and processes have led to a significant reduction in the average length of stay, thereby increasing daycase activity, and to a shift from inpatient to outpatient treatment.

Addenbrooke's Hospital has gone through a number of adaptation and expansion schemes to respond to continuously changing demand. There is a distinctive rise in bed numbers during 1940-45, as a consequence of the war. The capacity increase at the time was achieved by making use of a school and of university space. In the late 1940ies, planning began to move the hospital to a new site of 67 acres at the outskirts of town. In 1962, the new site was opened, 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. Since then, the hospital has further expanded and now accommodates around 1100 beds. 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.

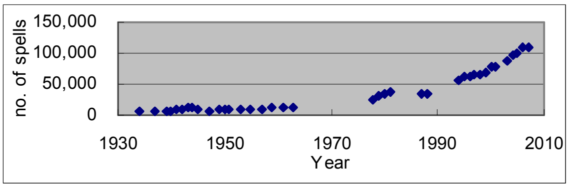

Fig. 3. Inpatient activities (inpatient episodes and daycases) over the past 80 years at Addenbrooke's Hospital, Cambridge

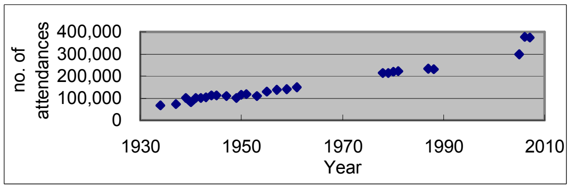

Fig. 4. Outpatient activities over the past 80 years at Addenbrooke's Hospital, Cambridge

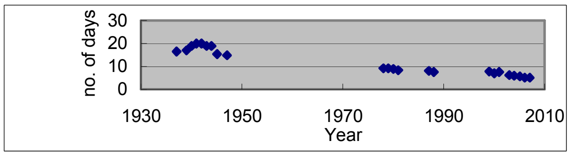

Fig. 5. Average length of stay over the past 80 years at Addenbrooke's Hospital, Cambridge

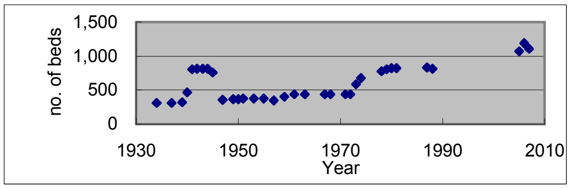

Fig. 6. Number of beds over the past 80 years at Addenbrooke's Hospital, Cambridge

Addenbrooke's Hospital has experienced dramatic changes, not only in terms of overall bed numbers but also in its layout. "People at the hospital have been living with design changes at their work spaces" in the words of a senior manager in the hospital's estate and facility department. Minor changes such as demolishing and adding walls occurred frequently leading to unavoidable disruptions. There were also major changes in layout design in some parts of the hospital, e.g. in the day surgery unit. Improvements in treatment processes led to a reduction in length of stay and ultimately shifted some inpatient activity to daycases. The day surgery unit had to be

[2] 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.

expanded to react to increasing demand in daycases. Incremental expansion was carried out through the redeployment of 'soft spaces' such as staffs' changing rooms, storage rooms and the relocation of some clinical spaces adjacent to the existing day surgery unit, e.g. Accident & Emergency theatres. In 2007, all available space had been used and a decision was made to move the day surgery unit to a newly built hospital area, roughly five-folding its size. Of course the vacated site was subsequently re-used and became the eye surgery unit.

B. *Recognizing the Need for Flexibility*

The designers of Addenbooke's Hospital were aware of uncertainties in future demand and recognized the need for flexibility as a 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 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 was emphasized during the planning phase for the New Addenbrooke's Hospital in the late 1940ies and the 1950ies. Murray Euston, the appointed architect for the 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].*"* 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 already recognized 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 new site 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.

In addition to lateral expansions, 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 by a new surgical ward for women with 27 beds on the opposite side of the third floor.

Improved construction technology, such as modular off-site construction, allows the exercise of expansion flexibilities in relatively short time and at acceptable cost. 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 m^2 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. An example in case is the old site of Addenbrooke's Hospital in the centre of town which was converted in the early 90ies to house the then newly founded Business School of Cambridge University. The fact that the Old Addenbrooke's Hospital was an iconic Cambridge building in the centre of town, which was not spoilt by over-development, made it an excellent prospect for re-development.

IV. Articulating value of Flexibility in infrastructure design

The case of Addenbrooke's Hospital illustrates that hospital infrastructure can undergo significant unplanned changes, in response to changing and unforeseen circumstances during the life-time of the infrastructure. The designers of the hospital were very much aware of the value-enhancing characteristic of flexibility in a volatile environment and were knowledgeable about different kinds of flexibility design. Nevertheless, there was no evidence-based argument for flexibility. Clients often require "design for 25% extra capacity", or "make floor-to-floor height greater" based on their past experience and budget rather than systematic evaluation. We need to have a way of making a clear economic case that the value of flexibility exceeds its cost.

A. *Forecasting Capacity Requirements*

The driver of the value of flexibility is the unreliability of forecasts. Forecasts, in particular long-term ones, are "always wrong" in that what actually happens "never" conforms to predictions.

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 at Addenbrooke's Hospital.

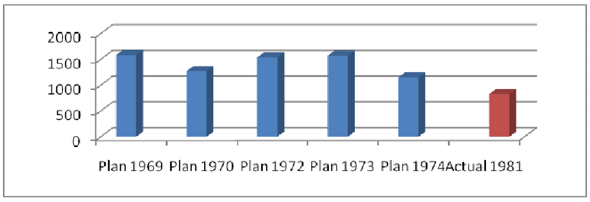

Fig. 7. Forecasting bed numbers for 1981 at Addenbrooke' Hospital, Cambridge

Clearly, the plan overestimated the capacity requirements. The unanticipated reductions in length of stay and shifts from inpatient to outpatient activity as consequences of rapid advances in medical technology and processes 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. 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].

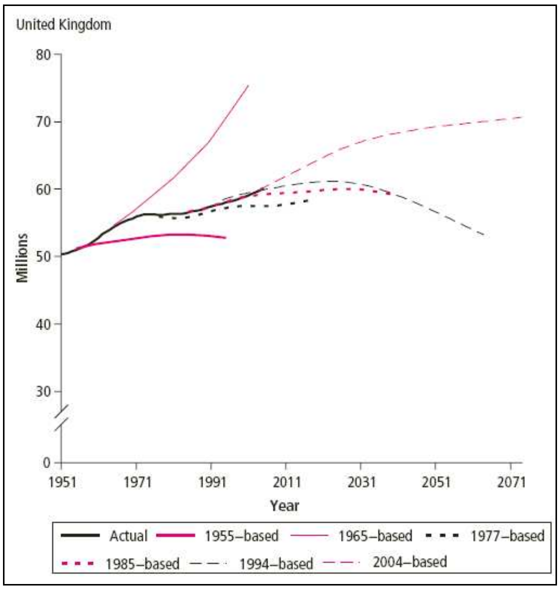

Fig. 8. Actual and projected population [1]

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 design is then a very natural step.

B. 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 in comparing system designs. 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 acute 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 predict a continuous rise of inpatient bed days, eventually requiring a large hospital with 1000 beds. Forecasters quote the aging population, the obesity trend, but also the increasingly successful recruitment of wealthy private patients from developing countries as drivers of increased demand. However, some analysts warn that the trend could well reverse and the hospital design should also take account of the possible alternative future. Regulatory proposals are in discussion that could give the competing public and even new private hospitals easier access to the hospital's local catchment population. Polyclinics may be introduced at a local level, possibly taking away much of the bread-and-butter work from the acute hospital. Also, over the lifetime of the hospital, medical technology may drastically reduce length of stay for some diseases. Along with a rigid design of a 1000 bed hospital, alternative design involving staged developments are therefore discussed: Build 700 beds initially but invest in an option to expand to 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 rigid 1000 bed hospital stack up?

The starting point for the articulation of the economic value of a flexible design must be the recognition of many possible futures as discussed in the previous section. Hospital demand is assumed to be driven by four key factors, none of which is predictable: (i) demographic patterns, including the age profile of the population (ii) advances in medical technology, which has historically attributed to reduced length of stay and therefore a reduction of required bed capacity, (iii) epidemiological patterns, driven for example by life-style changes, which can lead to reduced demand e.g. non-smoking policy or increased demand e.g. obesity, and (iv) regulation and policy, e.g. around patient choice or private practice. A range of possible future hospital demands can be obtained by developing ranges for these effects and then combining them to a list of future demand scenarios. 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 will not expand." With this contingency plan we can calculate the Net Present Values[3] or any other cost-benefit metric for the two hospital designs for each future F1,…,F10[4]. The results can be summarized in a bar-chart as follows:

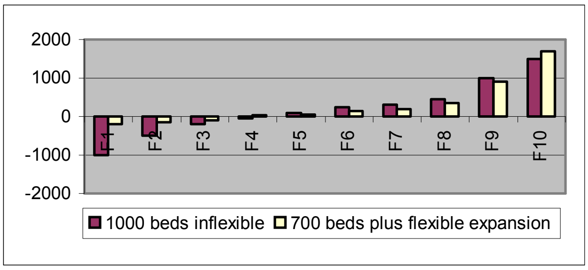

Fig. 8. Net Present Value for different demand scenarios

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 enough 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 capture revenues from the high realized demand. In summary, the flexible design cuts downside risks and amplifies upside opportunities, at the expense of foregone economies of scale in the base case scenario.

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, i.e. the white elephant legacy, the flexible system can be a better choice. But the hospital trust may well have reasons to believe that chances are low that these low demand scenarios will materialize– 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, then no new information is added to the bar chart above. If, 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 as follows:

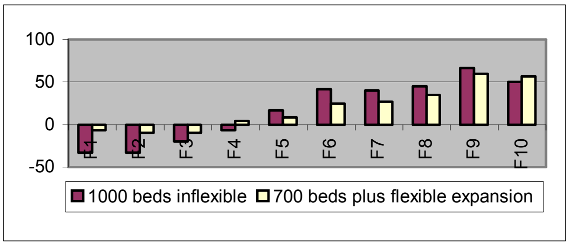

Fig. 10. Likelihood-adjusted Net Present Value for different demand scenarios

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.

One interesting metric is the sum of the bars, which gives the expected value of the respective system, i.e., the outcome over all considered futures weighted with their estimated likelihood of occurrence. In this particular example the expected value of the inflexible design is £166 as opposed to £189 for the flexible design. In this case, flexibility has added value on average. However, the variation of values across futures reflects more fully the value of flexibility.

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 or more effective flexibility in the system to further improve performance in some worrisome scenarios without too much negative influence on others.

V. PRIVATE FINANCE INITIATIVE AND VALUE-FOR-MONEY

Infrastructure investments, in particular in the health sector, are increasingly carried out within a public private partnership (PPP) framework. The UK Department of Health reported in 2007 that investments in 80 major PPP hospital projects alone exceed a total of £60 billion [4]. Our final concern in this paper thus lies in investigating the effect of PPP procurement, in particular within the so-called private finance initiative (PFI) in the UK, on flexible infrastructure design.

PFI is a route to the procurement of the public project financed from private sources. Whilst the specifics of PFI projects can vary substantially, most of them share a common

[3] Present value of net cash flows. Each cash inflow/outflow is discounted back into its present value (PV).
[4] In a professional analysis these scenario-by-scenario values would be calculated through a Monte Carlo Simulation.

responsibility structure: A private consortium, typically consisting of 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 this concession period, the public sector client provides public services using the infrastructure and in turn makes agreed rental payments (unitary charge) to the private consortium.

To explore the value provided by PFI projects we fill focus on three main components: Construction Cost and Time, Maintenance Cost, and Social Benefits / Revenue.

A. *Controlling Cost and Time under PFI*

PFI is arguably a success with regard to delivery on time and on budget, as evidenced in [5] 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 the public sector client only start when the infrastructure becomes operational gives the private sector an incentive to keep the construction period short because they will otherwise loose part of their income stream.

	On-Time	On-Budget
PFI projects	76%	79%
Conventionally procured projects	30%	27%

Fig. 11. Performance of PFI projects compared to conventionally procured projects in terms of building on-time and on-budget [5]

But 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 consortium's best interest to find a good balance point between spending money upfront for a robust infrastructure and spending money later on maintenance.

The PFI framework is therefore effective in transferring two key risks, the risk of excessive construction costs and time and the risk of excessive maintenance costs, from the public to the private sector.

B. *Delivering Social Benefits and Revenue under PFI*

How does PFI fare in terms of generating social benefits or revenue over time? We have argued above that flexibility is an important driver of the benefits generated from infrastructure in the face of unpredictably changing demand. Flexibility, however, requires the right to change the infrastructure. Under PFI, the infrastructure belongs to the private consortium. The income of the consortium is the fixed annual rent, which is not affected by changing demand. The consortium does not face demand risk and has no incentive to incorporate appropriate flexibility in the design, in particular if the added flexibility is costly and the extra cost is difficult to justify. The consortium is only responsible for maintaining the infrastructure to pre-specified criteria. More importantly, even if flexibility exists, the consortium still needs to give consent to the desired change of its asset, unless this change is clearly specified in the contract. However, the use of flexibility in situations that were not foreseen or for cases that were not planned can be most useful.

An example is a UK hospital whose design included, structurally and contractually, the flexibility to build an additional floor for hospital ward space if and when the hospital client wanted this. It turned out that the client wanted to use this flexibility to build office space instead. Structurally this was much easier and cheaper to accomplish than an extra floor of ward space. However, the use of the flexibility for office space was not specified in the contract and could therefore not be done without significant additional costs, which made it uneconomical for the public sector client. Such costs can have various sources. Firstly, the private consortium is likely to demand the contract for the additional cost and is now in a monopoly situation. Its shareholders will expect monopoly profits. Secondly, the asset, as was the case in the above mentioned hospital, may be bond-financed, in which case the bond may have to be re-rated at significant cost and time. Thirdly, 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 asset may be lacking.

In summary, the existing PFI framework can be a significant obstacle in exercising flexibility to manage situations where the infrastructure does not create the expected value. 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 Public-Private Partnerships*

One way to realize the value of flexibility in infrastructure design is to move public private partnerships away from the current contractor-client, "fee-for-service" relationship to a more genuine partnership, where the public and private partners remain engaged in both, the containment of cost and the delivery of benefits over the life-time of the infrastructure, exploiting complementary expertise, and sharing risks and rewards. Under such genuine long-term partnerships, public and private partners together design high-value flexible systems, "living infrastructures", and deliver value from these systems over time. Maintenance of such a flexible system goes beyond making sure the infrastructure satisfies pre-agreed operational criteria but requires the private parties to stay engaged during the operational period to help adapt the infrastructure to developing circumstances and thereby minimize value risks and maximize opportunities if and when they arise.

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