

Medical Technology Investment Decision-Making at U.S. Hospitals: A Comparative Case Study of Four Organizations

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Abstract

Investments in expensive medical technologies, ranging from computed tomography (CT) scanners to proton beam accelerators, consume a major share of hospitals' capital budgets. The demand by physicians, patients and other stakeholders for medical technologies often exceeds a hospital's financial resources. When allocating their tight budgets, hospitals also need to account for multiple organizational objectives. The objective of this paper is to analyze current practices in medical technology investment decision-making at U.S. hospitals. Through semi-structured interviews of administrators at four hospital organizations, we obtained information on their medical technology investment decision approach. Findings from our interviews confirm that a systematic decision process that considers all organizational objectives, analyzes and integrates comprehensive data, and is objective and consistent is rarely applied. We propose that hospital organizations develop and implement such systematic processes and do so by building upon decision analysis principles and approaches, such as the Simple Multi-Attribute Rating Technique (SMART).

1. Introduction

Medical technologies play a critical role in the United States (U.S.) healthcare system, not only because they are essential for effective patient care, but also because they account for a major share of its high and ever rising costs. Healthcare spending in the U.S. has been growing at an average rate of 7.8% per year over the past 35 years, compared to just 5.6% gross domestic product (GDP) growth, and has reached over \$3 trillion, i.e., 17.5% of GDP, in 2014 [1]. Medical technologies have been the main driver of the rapid increase in healthcare costs. Estimates attribute 25-

75% of the growth in healthcare costs to medical technologies, exceeding other factors such as aging patient population and their income growth [2, 3]. Since hospitals are the main purchasers and users of these technologies, their adoption behavior affects system-wide healthcare costs.

Medical technology adoption (i.e., investment and use) also plays an important role in the financial and clinical performance of a hospital. Physicians rely on technology for diagnosis and treatment, and patients expect and demand the latest and most advanced medical equipment. Medical technologies have become a competitive differentiator for hospitals that compete not only for patients, but also for physicians (employed by the hospital, or self-employed affiliates). The problem is that these technologies, even relatively common ones like computed tomography (CT) scanners or surgical robots, are expensive, while financial resources are limited at most hospitals [4].

When deciding which equipment to buy given a limited budget, hospital executives should prioritize acquisitions by considering their organization's objectives. Studies have documented that financial performance is the most common decision criterion [5, 6], while quality of patient care is the most important one [7]. Other decision criteria include strategic aspects (e.g., market share), the needs of different stakeholders (e.g., physicians' equipment preferences, access to care for patients), and the impact on research and teaching, among others [8]. Factors that further complicate the medical technology investment decision, particularly for new equipment, are uncertainty and lack of data on insurance coverage and reimbursements, patient demand, competition, and technological advancements [9, 10]. Obtaining reliable data, accounting for uncertainties, quantifying how an investment would perform with respect to organizational objectives, resolving trade-offs between these objectives and meeting the needs of various stakeholders is challenging.

Given these challenges and the importance of the decision, hospital executives would benefit from a structured and systematic process that supports their investment decision-making. The academic literature on this topic is sparse, but the little information available is consistent with the insights we gained during interviews with hospital administrators: the investment process at most hospitals is ad-hoc, unsystematic, not sufficiently data driven, and often dominated by politics and favoritism [9, 10]. Healthcare organizations are lagging behind organizations in other industries, which more routinely use rigorous and quantitative approaches for capital investment decisions [11].

The objective of this paper is to document and analyze current practices in medical technology investment decision-making at hospitals. The information presented in this paper provides valuable input, justification and guidance to hospital organizations that seek to improve their medical technology investment decision process, and to researchers and companies that seek to develop decision support systems in this domain.

2. Literature on investment decision-making in hospitals

Investment decisions at many hospitals have been described as ad hoc, informal, political and not sufficiently data driven [12, 13], and in general not sufficiently cognizant of the hospital's mission and strategy [9, 10]. Healthcare organizations rarely use rigorous and quantitative approaches for capital investment decisions, and are thereby lagging behind organizations in other industries [11].

Medical technology investment decisions are typically driven by physicians' needs and requests to which hospitals administrators react [6]. When submitting requests, physicians are often tasked with providing clinical and business relevant information to justify the investment. Supplemental information may be provided by the vendor of the equipment, or is in some instances the main source of information [12, 14]. Administrators often find themselves having insufficient or biased data for their resource allocation decision [9]. Physicians have to take on the role of advocates for their purchase requests, which undermines administrators' ability for an unbiased, objective and system-oriented capital allocation [12]. Most hospitals rely on local knowledge and individual expertise to determine the value of an investment, and lack a rational, evidence-based process of medical technology assessment [14].

The use of financial performance criteria, such as

return on investment (ROI), to inform medical technologies investment decisions is discussed and advocated for in a variety of papers, e.g., [6, 12]. However, a survey conducted in 2004 among 417 hospitals revealed that less than 12% of hospitals use sophisticated financial tools to assess medical technology investments [15]. One explanation for the surprisingly low use of such financial tools may be that ROI and other financial performance criteria are often difficult to quantify in healthcare settings [12], or are dominated by other considerations (e.g., patient safety) [16].

Many internal and external stakeholders participate in medical technology decisions, which are carried out in multiple stages and represent a compromise between clinicians and administrators [13]. When evaluating new equipment, decision makers face uncertainty or lack of data on insurance coverage and reimbursements, patient demand, competition, life cycle cost, and technological advancements, all of which further complicate the decision [9, 10, 12].

Hospitals in areas with more competition have a higher adoption rate for state-of-art technologies [17, 18]. This tendency is further amplified by the share of private insurance coverage of a hospital's patient population [19]. Additionally, the intensity of medical research, patent development, and the presence of medical device companies in a region may also affect hospitals' adoption of medical technology [20]. However, the literature has not discussed how each of these influencing factors are accounted for in the investment decision-making process.

To address the challenges facing hospitals' medical technology assessment and investment decision-making, prior studies have proposed various analytical frameworks and mathematical models. Approaches such as economic evaluation [21, 22] and real option analysis [23, 24] quantify the financial impact from investments using measures such as ROI and net present value. Goal programming [25, 26] and multi-objective optimization [27] also account for financial aspects, but focus more on hospitals' budgets and other constraints. Advanced modeling approaches incorporate the interdependencies of other stakeholders and subsystems using on game theory [28] and multiscale decision theory (MSDT) [29-35]. By applying MSDT, Zhang et al. [36, 37] found that the medical technology investment made by hospitals affects the downstream technology use by physicians; hence such influence should be accounted for in hospitals' decision process. The aforementioned studies are sophisticated and quantitative in nature, but have not yet found their way into practice, in part due to complex data needs and mathematical background and knowledge requirements.

Insights from the literature are limited to those discussed above. Literature describing current medical technology decision-making practices is sparse. Most sources only provide recommendations, but do not describe or analyze the way in which decision makers allocate budgets or decide on investments. We therefore collected primary data through semi-structured interviews with administrators and executives at four hospital organizations in the U.S. The following section provides our interview method followed by the findings.

3. Hospital interviews

3.1. Method

We conducted semi-structured interviews with administrators and executives, many of whom are also physicians, from four different hospitals across the US. We selected four hospitals organizations, which cover a wide spectrum of institution types, size and characteristics. Table 1 provides an overview of the organizations. To encourage openness and allow participants to discuss organizational problems and shortcomings, we stated that we will not report the organizations' names, but merely their characteristics.

Table 1. Characteristics of hospitals

ID	Type of Organization	# of beds	Patients/year	Characteristics
#1	Private, for-profit hospital, part of a multi-hospital corporation	100 - 200	3,000 - 5,000	Community hospital with specialty services
#2	Private, non-profit hospital network, medical school in public-private partnership with university	1000 - 2000	800,000 - 1,000,000	Level 1 trauma center, major healthcare provider in the region
#3	Public owned, non-profit, university-affiliated hospital	500 - 1000	30,000 - 50,000	Level 1 trauma center, ranked nationally for specialty services
#4	Private, non-profit hospital network, largest integrated system in its state	> 2000	> 3,000,000	Acute-care and high performing specialties with urban competition

Table 2. Interview questions

A. Investment Framework
1. What is your overall investment decision process for new medical devices/technologies, such as CT, MRI, PET, robotic surgery devices, or cyber knives?
2. What are your investment objectives (e.g., quality, cost, technology leadership)?
3. What are your performance metrics for the investment objectives (e.g., length of stay, re-admittance rate, patient numbers, hospital ranking), and how do you assess them (data available through hospital's ERP system, subjective assessment by experts)?
4. What external factors do you consider in your decisions regarding which medical technologies to buy? E.g., equipment at other hospitals/competitors, insurance coverage, government regulations, economic trends, technological development etc.
5. Do you evaluate your investment decisions retrospectively?
6. Do you employ a specific framework for different kinds of projects (technology replacements, IT, new medical devices; high vs. low cost equipment)?
B. Software and Decision Support
7. What software/system tools do you use to make investment decisions?
8. How useful is the current software and what do users like or dislike about it?
9. What would be your needs and ideal configuration of a decision support system for budgeting and investment decisions?
C. General Budgeting Process
10. What is the general process for allocating the investment budget at the highest level of your organization? What role does the hospital system leadership play?
11. How are budgets at lower levels such as departments/units allocated?
12. Who is typically involved in the budgeting process and what are the time frames?

In total, eleven people participated in our interviews. The number of people interviewed at each organization and their roles varied and are described in Section 3.2. The interviews were performed or directed by the lead author, Wernz, who was accompanied by research associates, including graduate and undergraduate students. Each interview lasted approximately one hour. The interviews were recorded with verbal consent by the participants, and later transcribed for our analysis.

Our objective of the interviews was to obtain first-hand information about hospitals' medical technology investment decision processes, the systems they use to

support their decision and the challenges they face. The interview questions that guided our discussion are provided in Table 2. The questions cover three aspects: (1) investment framework, (2) software and decision support, and (3) general budget process. The development of the research questions was informed by decision theory, which distinguishes between decision makers, objectives, and alternatives. Decision makers can be individuals or groups, internal or external; multiple decision objectives may exist and reflect hospitals' mission and priorities; decision alternatives can be single investment options or investment portfolio.

3.2. Findings

We summarize and compare the key findings of the interviews in Table 3, followed by the details of each interview.

Table 3. Interview key findings

ID	Decision makers	Methodology	Criteria	IT support
#1	Hospital executives, upper organizational levels	ROI, payback, rule of thumb	Immediate needs, competitive advantage, market share, physicians' requests, customer demand	Capital Asset Management System (CAMS)
#2	Local hospital executives, capital investment committee	A tiered system that represents priorities	Medical needs, financials	StrataJazz software suite
#3	Hospital executives, departments	SMART	Financials, quality, capacity, strategic importance, infrastructure, ease of implementation	StrataJazz software suite
#4	Hospital executives	Bottom-up, ad-hoc	Cost, physician needs, market share	StrataJazz software suite

3.2.1. Organization #1 is a private owned hospital and is part of a large hospital corporation in the U.S. The corporation is divided in multiple main groups, each

with multiple divisions. The division our hospital is part of includes more than a dozen hospitals and 30 outpatient centers. In 2014, this division served more than one million patients. The executives across groups and divisions in the corporation are responsible for different aspects of the medical technology decision-making process. The interview was held with the CFO of organization #1 in March 2012.

New technology investments are made using various assessment criteria, but not necessarily in a systematic or consistent fashion. The most important evaluation criterion is the hospital's immediate needs, e.g., equipment that requires replacement due to malfunction, age, or unavailability of spare parts. Competitive advantage and market share are the second most important criteria; if other hospital systems are utilizing new technologies, this can have a direct impact on the hospital's competitive positioning in the region and its market share. Physicians' requests and customers' demand for new technologies are also evaluated. Decision makers estimate the new equipment's ROI and payback period, and apply the following rule of thumb: if a given technology has a payback period of three years or less, the technology receives a high purchase priority. However, if the ROI and payback period do not support the investment decision, additional factors such as reimbursement from Medicare and commercial payers are considered.

Once hospital executives make the decision to purchase a new medical technology, the ensuing process depends on the investment amount. If the cost of the new technology is greater than \$500,000, the purchase is evaluated during a strategic planning meeting where corporate executives make the final funding decision. The hospital uses the Capital Asset Management System (CAMS) to present the investment case to the corporate decision makers. This off-the-shelf portfolio management software helps executives to determine the revenue that will be generated from the proposed investment. If the cost of the new technology is less than \$500,000, the hospital can make the decision to invest using its routine capital budget. However, if the hospital is unable to self-fund the technology, the purchase request can be escalated to division or group level executives, who have the ability and resources to allocate discretionary funds.

3.2.2. Organization #2 is a not-for-profit healthcare organization with a network of hospitals, outpatient specialty centers, and primary care practices. It provides care for nearly one million people in the region annually, and its major hospital features a Level 1 Trauma Center. We interviewed the Director of the Center of Innovation in February 2012.

Given the overall smaller corporate size of the

hospital network, the necessary funding for new technology investments is not as readily available as at Organization #1's corporation. Another difference is that patients' medical needs are considered more important than financial aspects. Still, the overall investment decision-making process is similar to that of Organization #1. Medical technology investments are made using a tiered system that represents Organization #2's priorities: Tier 1 - replacement of equipment that does not meet regulatory standards, Tier 2 - replacement of equipment considered unsafe, Tier 3 - replacement or repair of malfunctioning or non-operational equipment, Tier 4 - replacement of equipment with few life years left, an expired warranty, or no replacement parts available, Tier 5 - investments in new technologies.

Medical technology investment requests are initiated by different functions (e.g., cardiac group) within the hospital. Requests are evaluated on a first-come, first-serve basis, where each investment request is assessed on its own merit and is re-evaluated when new requests are submitted. In contrast to Organization #1, the hospital executives at Organization #2 do not have the opportunity to rely on upper organizational levels to receive additional investment funding and have to allocate a strictly limited budget. For low-cost medical technologies, committees within the hospital are in charge of making investment decisions. In the case of larger investments, these committees perform an initial review and then pass it on to the financial board for evaluation and the final investment decision. This process is supported by the StrataJazz software suite.

3.2.3. Organization #3 is a non-profit teaching hospital funded by the state, the federal government, and private and public insurance companies. The hospital is affiliated with a public university. The hospital has multiple specialties that are ranked nationally and a number of other high-performing specialties. We interviewed five administrators from the finance and operations excellence departments in October 2011.

Investments are divided into three categories: major projects, information technology (IT) investments, and routine replacements. The hospital has decentralized their decision process, giving departments the ability to decide on the implementation of minor projects independently. Investment decision-making follows a capital budgeting calendar and a predetermined workflow, so that investment requests are completed within approximately three months. Users submit budget requests between the end of March and mid-April of every year. After an initial review, these requests undergo financial planning and administrative

reviews. Thereafter, either the Vice President or the Dean determine when the project is ready for evaluation and prioritization. As at Organization #2, the prioritization process is supported by the StrataJazz software.

To increase the objectivity of the decision-making process and reduce the influence of hospital politics, Organization #3 has begun to explore a process that uses elements of the decision analysis approach SMART, the Simple Multi-Attribute Rating Technique.

SMART was originally developed by Edwards in 1970s [38]. Since then, SMART has been extended and widely applied as a way to systematically assess and compare decision alternatives with multiple objectives. A complete SMART analysis includes ten steps and can be summarized as calculating the overall value of a given alternative as the sum of the performance score (value) of each attribute (criterion) multiplied with the weight of the attribute. The advantage of SMART is that its explicit accounts of multiple, often conflicting, objectives. SMART considers alternatives independently and the attribute scores are added linearly based on the assessed weights.

At Organization #3, six organizational objectives relevant to medical technology investments are considered and assigned a relative importance (weight): financial, quality, capacity/access, strategic importance, infrastructure, and ease of implementation. Each project is given a score for each criterion. The scores are then multiplied by the corresponding weights. NPV and ROI are used as financial criteria; however, there is no clearly defined threshold that any given project has to reach in order to be implemented. A lower scoring project can be preferred, if its costs are significantly lower than those of a higher scoring one.

Medical technology investments below \$500,000 are prioritized by the department placing the request, while larger investments require a strategic write-up, and are assessed by an enterprise resource strategy group. Funding approvals are usually made by mid-June of every year, and are followed by final price adjustments. Each capital request is tracked to monitor its actual development. Although the use of software and decentralization efforts are generally regarded positively at the hospital, financial analysts expressed the need for improved evaluation techniques.

3.2.4. Organization #4 is a non-profit, private-owned hospital system that has over a dozen hospitals. It is one of the largest hospital delivery systems in the nation. We interviewed four system-level and hospital-level executives in February 2014.

Physicians typically initiate equipment requests, and system-level executives decide on capital

investments with costs larger than \$75,000. Our interviewees affirmed that capital investment evaluations are not sufficiently data-driven, and are usually performed subjectively. Their process is unstructured, and can vary depending on the purchase cost, the type of technology requested, and the person placing the request. Replacements of critical equipment are prioritized over other investments. Once the necessary funds have been allocated to these replacements, executives decide how to allocate the remaining budget based on new business opportunities or expansion requirements.

Market share is an important evaluation criterion for the hospital executives because of fierce competition with other hospitals in the region. Medical technologies have become significant differentiators in the healthcare sector, and can determine a hospital's market share and growth. The trade-offs between growth opportunities and equipment replacement requirements add to the complexity of the investment decision.

As at Organization #2 and #3, Organization #4 also uses the StrataJazz software. Hospital personnel, in particular physicians, use the capital planning module to submit their medical equipment requests. Executives analyze this information during request review. This capital planning module, however, is primarily used to track previous purchases and monitor the progress of ongoing projects. Executives do not assess purchase requests using the built-in evaluation criteria in StrataJazz or systematically established criteria associated with their organizational objectives. Rather, investment decisions are in many cases made on an ad-hoc basis, and executives have to rely on their individual judgment and past experience. Moreover, hospital executives do not perform retrospective analyses of medical technology investments to evaluate their previous decisions; i.e., no organizational learning occurs.

With no information about the performance of past investments, physicians and other individual who initiate equipment requests face a challenging task. They are asked to provide detailed life cycle information about the equipment by the software (e.g., life expectancy, patient demand, and operating and maintenance costs). In the absence of readily available data and given the effort it takes to obtain reliable estimates, they oftentimes choose not enter any data. At decision time, the hospital executives then find themselves without decision-relevant information, and the chance of granting the purchase request is significantly reduced.

4. Discussion

All four hospitals we interviewed had established criteria for making investment decisions; however, significant improvement opportunities exist. Organization #3 and #4 used weights to quantify the importance of different evaluation criteria. However, the weights were chosen without sufficient rigor or input from the organizations' highest levels, such as the CEO or the board of directors.

While multiple investment criteria were considered at all interviewed organizations, decision makers either do not take all relevant criteria into account simultaneously, or only consider a subset of these criteria. At Organization #2, investment alternatives are evaluated one criterion at a time, not allowing for trade-off evaluations. At Organization #1, decision-making is dominated by financial metrics such as ROI and payback period, and executives consider non-financial metrics only for certain investments after evaluating their financial performance (i.e., executives use only a subset of all relevant criteria). Decision makers thus cannot analyze trade-offs directly, and might select those medical technologies that seem more attractive with respect to the evaluation criterion considered first.

All interviewees stated that lack of funds currently represents a challenge in for their capital investments. Scarcity of resources makes an investment decision process that systematically evaluates tradeoffs between conflicting objectives (e.g., market share growth vs. immediate infrastructure needs) even more necessary and valuable. Instead, executives' arguments and motives to support one investment over another are often influenced by organizational politics and pressure exerted by the equipment-requesting physicians. Politics and favoritism are common at hospitals and results in suboptimal decisions [6].

Organization #2, #3, and #4 use the StrataJazz software to support the capital investment process. StrataJazz is a popular software suite used by 20% of U.S. hospitals, and includes cost accounting, budgeting, forecasting and planning functions. StrataJazz has a capital planning module that builds upon SMART principles [39]. However, it is unclear how many hospitals use this functionality; the software company does track this usage (we spoke to a senior executive of this company directly). The software does not guide decision makers through the capital investment evaluation process, nor does it provide them with recommendations on how to conduct this assessment. Organization #4, for example, has an installation of the capital planning module and merely uses it to record and track capital requests, but not to support capital investment and decision prioritization.

This study investigated the U.S. hospitals' practices in medical technology investment decision-making in recent years. There are several directions in which this research could and should be extended. First, follow-up interviews with these four organizations can uncover how these hospitals have modified and updated their organizational processes. We would anticipate that with data being more readily available and interactive data visualization tools (e.g., Tableau) more commonplace, organizations have advanced their processes. Further, additional software vendors may have entered the market place and their products have been adopted by hospitals.

The study has also laid the foundation for a future survey-based research, for which the questions developed and presented in this paper could serve as a foundation. Clearly, the questions would need to be modified to account for the switch from semi-structured, in person interview to online or paper-based surveys.

Due to the constantly changing health care environment and the political uncertainties, research in this domain, both interview and survey based, should be carried out simultaneously and frequently. Specifically, areas include the effect of possible medical device taxes, changes in the insurance market place, changes to technology-related reimbursement, healthcare price control, and emerging technologies, such as blockchain and artificial intelligence [40, 41].

5. Conclusion and recommendations

This study investigated the medical technology investment decision-making at U.S. hospitals through a comparative case study. We conducted interviews with hospital executives at four organizations. The interview results describe the current practices at these hospitals and reveal similarities and differences in their approach to capital budgeting and medical technology investment decision-making.

Based on our case study and the extant literature, we conclude that a comprehensive, consistent and data-driven decision-making framework for evaluating investment decisions is not widely used in hospitals. Among the four organizations we interviewed, Organization #3 was found to have the most advanced and rigorous decision-making approach. The organization has adopted elements of the decision analysis approach SMART, the Simple Multi-Attribute Rating Technique.

Our recommendation to hospitals is to adopt a decision analysis approach, such as SMART, to address their technology investment decision challenge. Companies in the oil & gas and

pharmaceutical industry have been pioneers and are frequent users of decision analysis for capital investment decisions [42, 43]. Their success in making better decisions in complex, high stake situations is evidence for the potential this approach could have in the healthcare industry. Moreover, it would guide hospital executive in making data-informed organizational decisions, in the same way that physicians make evidence-based clinical decisions.

Our findings are also a motivation for future research in developing and applying decision analysis and operations research methodologies to the medical technology investment decision problem. Data-driven and predictive analytics approaches such as system dynamics model integrated with decision analysis [44] or a structured value analysis approach [14] are examples of possible methods to explore.

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