Using decision trees to determine participation in bundled payments in sepsis cases

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Abstract

Rationale: The purpose of this research is to determine and develop a valid analytical method that can be easily implemented by providers to evaluate whether they should join the bundled payments for care improvement (BPCI) advanced bundled payment program, and analyze the projected impacts of BPCI advanced payment on their margins.

Methods: We have developed a decision tree model that incorporates the types of sepsis encountered and the resultant typical complications and associated costs.

Results: The initial cost of a sepsis episode was $30,386. Since Medicare requires that there is a 3% cost reduction under BPCI, we applied the model with a 3% cost reduction across the board. Since the model considers probabilities of the complications and readmission, there was actually a 3.36% reduction in costs when the 3% reduction was added to the model. We applied 2-way sensitivity analysis to the intensive care unit (ICU) long and short costs. We used the unbundled cost at the high end, and a 10% reduction at the low end. Per patient episode cost varied between $28,117 and $29,658. This is a 5.2% difference between low and high end. Next, we looked at varying the hospital bed (non-ICU) costs. Here the resultant cost varied between $28,708 and $29,099. This is only a 1.34% difference between low and high ends. Finally, we applied a sensitivity analysis varying the attending physician and the intensivist reimbursement fees. The result was a cost that varied between $29,191 and $29,366 which is a difference of only 0.595%.

Conclusion: This is the precise environment where decision tree analysis modeling is essential. This analysis can guide the hospital in just how to allocate resources in light of the new BPCI advanced payment model.

Abbreviations: BPCI = bundled payments for care improvement, CFO = Chief Financial Officer, CMMI = Center for Medicare and Medicaid Innovation, CMS = Center for Medicare and Medicaid Services, EV = expected value, HMO = health maintenance organization, ICU = intensive care unit, IV = intravenous, LOS = length of stay, SNF = skilled nursing facility.

Keywords: cost effectiveness analysis, decision analysis, decision trees, health economics

1. Introduction

The cost of healthcare continues to increase with new developments in pharmacology, technology, precision medicine, higher provider fees, and a society living actively longer than ever before. This has led Center for Medicare and Medicaid Services (CMS), that runs Medicare and Medicaid as well as private insurers to develop alternate payment approaches to address the perceived weakness of the fee-for-service method. One of the new methods is bundled payments meant to bring about lower costs and higher quality by omitting fee-for-service payments which are seen as incentivizing “unnecessary” treatment without any improvement in quality.

Capitation (in which providers are given a defined sum per patient regardless of how many services are rendered in a given period of time) has been used for many years in both healthcare maintenance organization (HMOs) and Medicare Advantage plans, also known as Medicare Part C. The Center for Medicare and Medicaid Innovation (CMMI) which is part of CMS has developed a hybrid that is in-between full capitation and fee for service called bundled payments or episode-based payments.[1] In this system, reimbursements to healthcare providers (both hospitals and physicians) are made on the basis of a calculated expected cost formula for clinically defined episodes of care. As of 2012 almost one-third of medical reimbursement are now from a bundling system.[2] The hane of capitation both in integrated delivery models and in HMOs has been the extent and thoroughness of patient care possible through episodes of care that involve different providers with sometimes different patient management objectives.

As a result, the purpose of this research is to determine and develop a valid analytical method that can be easily implemented by providers to evaluate whether they should join the newest bundled payment program now, bundled payments for care improvement (BPCI) advanced, and analyze the projected impacts of BPCI advanced payment on their margins.
upon the specific inputs in the model, a hospital can determine if
joining BPCI advanced is a profitable idea or not, so as to make a
more informed decision when choosing whether or not to
participate. Such a method should be able to consider the
variables/treatments all providers who treat a specific condition
use in treating patients with complex disorders.

2. Background

Bundling payments were first introduced by Dr Denton Cooley in
1984 at the Texas Heart Institute (THI). Dr Cooley charged a flat
fee for combined hospital and physician services for coronary
artery bypass grafts. THI charged an average of $13,800, when
the average Medicare payment for coronary artery bypass graft
(CABG) was over $24,500.[3]

In 2006 the Geisinger Health System tested another bundling
model, also for coronary artery bypass surgery.[3] This model
included all preoperative, in-patient and operative care and
follow up care within 90 days of the initial visit, at a fixed package
price. This experiment resulted in shorter hospital stays, a 5%-
reduction in hospital costs, an increased chance of being
discharged directly to home rather than sent to a skilled nursing
facility (SNF), and a decrease in readmission rates.

3. Current environment

In 2012, Medicare introduced BPCI program as a result of the
Affordable Care Act.[4] Participants, in this voluntary program,
could choose 1 of 4 payment models for 48 possible clinical
episodes. Most participants opted for Model 2 which included an
inpatient stay plus outpatient follow up for a period of 30, 60, or
90 days. Payments were reconciled comparing actual Medicare
Payments to a payment target set by Medicare based on previous
payments for similar cases. Spending generally trended lower,
and in the case of hip/knee replacement there was an estimated
savings of $1273 per episode, which came mostly from a
reduction in SNF use in the postoperative period.

In 2016, CMMI introduced a mandatory bundled payment
program for hip and knee replacement called the comprehensive
joint replacement model (CJR).[5] This experimental program
involving 800 hospitals resulted in a savings of $1134 per
episode.

In 2018, CMMI Medicare also introduced a variation called
bundled payment for care improvement advanced (BPCI
advanced).[6] This voluntary Medicare program was designed
as an alternative to the traditional fee for service payment model.
In theory it was designed to support healthcare providers who
invest in practice innovation and care redesign to better
coordinate care and expenditures. It involves paying the
physician, hospital, and other healthcare services in one single
payment that is based on the expected costs during an episode of
care. The incentive is for providers and suppliers to coordinate
and deliver care with increased quality and less cost.

There are several differences between the original BPCI and the
new BPCI advanced programs.[7] First, all participants will be
responsible for 90-day bundles. In the original BPCI, there was an
option to choose 30, 60, or 90-day bundles. Next, there are fewer
exclusions, so that the bundle includes all part A services,
including the hospital stay, hospital procedures, and post-acute
care services, plus all part B outpatient services unless they are not
related at all to the admission diagnosis related group (DRG).
Furthermore, up to 10% of payments are at risk for quality
measures. There is also only a single track for treatment of
outliers. And reconciliation reports will only be sent to
participants bi-annually. This new iteration of BPCI is voluntary
and involves a single retrospective payment for a 90-day clinical
episode. This has been designed by CMS. There are 31 inpatient
and 4 outpatient clinical episodes included. Payment is tied to
performance on certain quality measures defined by CMS.

For BPCI Advanced, 4 payment models were available, with
Model 2 being the most common.[6] All payment bundles are
fixed to a 90-day episode, up to 10% of payments in the bundle
are at risk based upon certain quality measurements, and there is
only a single track of downside financial risk, effective
immediately. With downside risk, failure to improve quality or
decline costs (bills to Medicare) leads to hospitals having to
return money to Medicare.

Studies of the joint replacement bundles have shown no
decline in quality and a small decrease in expenditures.[8]
However, there are several limitations to using joint replacement
as a template for how bundling will work for different episodes.
Notably, joint replacement, an elective surgery, is a standard and
defined procedure. The surgery is virtually the same for each
patient. Since joint replacement is an elective procedure, it can be
assumed that all patients undergoing the surgery have been
screened to reduce the risk of perioperative cardiovascular or
pulmonary complications. In fact, studies show that most all of
the cost savings for bundles of hip and knee replacement result
from patients going home after being discharged for rehabilita-
tion after discharge from the hospital or outpatient surgery center
instead of to a SNF. This is not possible for many of the other
medical episodes included in BPCI Advanced. For example, other
episodes included in BPCI Advanced are congestive heart failure,
chronic obstructive pulmonary disease, sepsis, acute myocardial
infarction, and pneumonia. There is a wide variation in the degree
of illness and the course of therapy with these diagnoses, and
there is no uniformity in treatment guidelines for these diseases.
For example, Sepsis includes 3 DRGs which range from
uncomplicated sepsis to septic shock. Unlike elective surgery
such as hip and knee replacements, patients cannot be screened
to avoid complications. In fact, many sepsis patients develop
complications and/or have significant comorbidities resulting in
extreme variation in length of stay (LOS) and unpredictable costs
associated with each hospitalization. Most cases would likely not
to need to go to SNF after discharge from a hospital but would
most likely need home health care and close medical follow up to
avoid readmission.[9]

Within the joint replacement modeling, the decision of whether
a provider should participate is generally simple to calculate.
However, in cases where there is a wide variation in cost factors,
a model able to address numerous variables attributable to
different patients is imperative for a provider to make an
informed decision about whether to participate in BPCI
Advanced. Our tested and recommended model for these
calculations is a Decision Tree Model. Decision tree models
offer both the flexibility and complexity of interaction to more
accurately predict costs than just a linear model which is
commonly used. Since sepsis is a complicated disease that can
lead to many possible outcomes that would affect costs, this type
of modeling lends itself to such an analysis.

Previous studies of cost analysis on BPCI have only compared
total costs to what has been predicted. Meyer[10] found that
bundled payments cut spending on joint replacement but not for
other conditions. Agarwal et al[11] looked at the impact of
bundled payment on healthcare spending utilization, and quality and came to a similar conclusion. The Rand Corporation[12] found costs went down only 5% compared with 15% predicted. All such studies look at total cost but did not incorporate different clinical outcomes.

We have developed a decision tree model that incorporates the various types of sepsis that are encountered and the resultant typical complications and their associated costs. Sepsis affects 1.7 million adults in the United States each year and potentially contributes to 250,000 deaths. It is present in 34% to 53% of hospitalizations in which the patients died.[13] Sepsis is an overwhelming bacterial infection in the body. Bacteria are present within the bloodstream and can lead to organ damage, especially to the kidneys and lungs, and the vascular system. This can become septic shock, which has risen by 10% in the last 3 years. These patients are intubated in the intensive care unit due to respiratory failure, are on dialysis for acute renal failure, and on vasopressor medication to keep their blood pressures high enough to perfuse their brains. Only with the aggressive use of IV antibiotics, IV fluids, and other supportive care will the patient even survive. Reported mortality rates vary between 37% and 45%. Hospital charges are now up from $58,000 to $70,000 per even survive. Reported mortality rates vary between 37% and 45%. Hospital charges are now up from $58,000 to $70,000 per case (although actual costs are less).[14] Overall, hospitals spent $1.5 billion more in 2018 on sepsis than in 2015.[15]

4. Methods

The decision tree model was developed in Tree Age Pro Version 19.2.1. We constructed 2 branches, 1 for bundled payments, and 1 for non-bundled payments. Figure 1 shows the entire decision tree.

There was no need for an ethics committee as we used no individual patient data for the research and did not offer any type of treatment in this study. The possible complications which are analyzed in the model include: acute renal failure, respiratory failure, hypotension, and readmission for sepsis within 1 month of the first admission. However, based on past experience, on a provider-by-provider basis, other complications can be included. Both the number of complications and the specific complications are virtually unlimited and may be customized to reflect the actual use of an individual provider organization or groups of organizations.

In this decision tree model there are different “branches” for the different treatment variations, and each branch has an associated cost and probability of occurrence. In the case of the sepsis model for BPCI, there are 2 main branches, 1 for the bundled payment plan (BPCI) and 1 for the unbundled, traditional fee for service payment plan. The branches are identical except for the costs of the different branches. Sepsis has 3 major branches: systemic inflammatory response syndrome (SIRS), sepsis (with complications but not septic shock), and septic shock. The major complications include acute renal failure, hypotension (low blood pressure) that needs pharmacologic support by medications called vasoconstrictors, and septic shock where the patient is in respiratory failure and is intubated. Costs for these complications include the cost of the ICU, the ventilator, dialysis for renal failure, and cost and administration of the vasoconstrictors. These costs were derived from the medical literature and are the average national costs of ventilator, and dialysis management.[16,17] The cost of vasoconstrictors came from the pharmaceutical company that manufactures it.[18] Furthermore, the cost per day of the ICU and subsequent regular floor beds are added to the cost. We got these costs from the CFOs of community/hospitals in the California Hospital Association. These costs therefore are illustrative how the model works, but as costs for ICU and regular floor beds may vary across the country, one may not be able to necessarily rely on the specific conclusions of this manuscript. However, if a hospital includes their own values, the model will give an accurate representation of the expected values for their facility. This cost was the per day cost to stay in either an ICU bed or a regular floor bed. We used the average length of stay from the literature in the ICU and subsequent regular floor bed for septic shock, sepsis with complications, and simple sepsis. Finally, we added the daily cost of the physicians involved in the care of each patient. We assumed that the hospital will reimburse the physician at the Medicare payment rate. This rate was derived from the Medicare reimbursement for physicians for their particular level of service. One of the branches of the model is devoted to readmission within the 90-day period prescribed by Medicare BPCI. Therefore, there are 4 branches for the main possible outcomes: SIRS, sepsis (with complications), septic shock, and readmission for sepsis. For both bundled and unbundled, the probabilities are identical—it is only the costs that vary.

The probability of SIRS is 26%, sepsis (with complications) is 24%, septic shock is 32%, and the probability of readmission is 29.2%.[19] Essentially, there is an expected value calculated (probability times the cost) for each branch, and the expected values of costs are then summed to determine the cost of each branch. The cost of a sepsis admission is the sum of the expected values of all the branches for a particular arm of the model.

Data on hospital costs (cost per day in ICU or regular floor bed) were given to us by hospitals that are members of the California Hospital Association. While these data are not representative they are not meant to be. We use them only to illustrate the methods of using decision trees. A similar analysis can be conducted for private patients as well. The payment of physicians was derived from the Medicare Fee Schedule for physicians for the appropriate current procedural termino (CPT) codes. Costs of dialysis and ventilation were derived from the literature. Costs of vasopressors were taken from the drug manufacturer information on their website.

The Payoffs for the decision tree, including all costs and probabilities, are listed in Table 1. For this study, the expected value (EV) of each branch (probability times cost) was calculated, then the EV of all branches summed to get total cost. Two-way sensitivity analysis was also calculated using the software to explore the effects of changing various costs upon the overall model.

5. Results

We used the model to realistically analyze the effects of varying certain costs on the overall cost to the hospital of a sepsis admission. In that way, hospitals can determine whether likely revenue from bundled payments will be large enough to allow them to both provide care more efficiently and also take on the risk and be rewarded by a share in the savings. The decision tree takes into account 3 major complications: acute renal failure, hypotension, and septic shock with respiratory failure. It also considers the 30-day readmission rate for sepsis, which is quite high. Costs included in the model are short (3.5 days) and long (9.5 days) ICU stay, short (5.1 days) and long (15.4 days) length...
of stay in a regular room, dialysis costs, respirator costs, medication costs (specifically vasopressors), and costs of the attending physician, intensivist, pulmonologist, and nephrologist.

The results are summarized in Table 2. The initial cost of a sepsis episode was $30,386. Since Medicare requires that there is a 3% cost reduction under BPCI, we applied the model with a 3% cost reduction across the board. Since the model considers probabilities
of the complications and readmission, there was actually a 3.36% reduction in costs when the 3% reduction was added to the model.

We next applied 2-way sensitivity analysis to the model and monitored how this affected the model. The purpose of this analysis is to evaluate how either a change in therapy, or a change in costs administratively, can optimize the revenue hospitals and physicians receive under the bundled payment system. Since total revenue is fixed under bundled payments, it is important to minimize costs either by changes in the therapeutic regimen, or a change in costs for a particular episode of care.

| Name                        | Description                                      | Root definition |
|-----------------------------|--------------------------------------------------|-----------------|
| cARF                        | Cost of acute renal failure                       | 5253            |
| cICU_long                   | Cost of long ICU stay                             | 20,933          |
| cICU_short                  | Cost of short LOS in ICU                         | 7809            |
| cIntensivist_Long           | Cost of intensivist in ICU long stay              | 2164            |
| cIntensivist_Short          | Cost of intensivist in ICU short stay             | 777             |
| cLOS_Long                   | Cost of LOS long                                 | 14,987          |
| cLOS_Medium                 | Cost of LOS for medium case                      | 4995            |
| cLOS_simple                 | Cost of LOS simple sepsis                        | 1654            |
| cMedical_Long               | Cost of medical doctor long stay                 | 3310            |
| cMedical_Short              | Cost of medical doctor short stay                | 2380            |
| cMedical_Simple             | Cost of medical doctor SIRS                      | 823             |
| cNephrology                 | Cost of nephrologist                             | 3196            |
| cPressors                   | Cost of pressors                                 | 2718            |
| cPulmonary                  | Cost of pulmonologist                            | 3196            |
| cICU_short                  | Cost of short LOS in ICU-unbundled               | 8043            |
| cICUARF                     | Cost of acute renal failure unbundled             | 5415            |
| cICUlong                    | Cost of unbundled ICU                             | 21,574          |
| cICUshort                   | Cost of unbundled ICU short                       | 8060            |
| cIntensivist_Long unbundled | Cost of intensivist in ICU long stay              | 2231            |
| cIntensivist_Short unbundled| Cost of intensivist in ICU short stay             | 801             |
| cLOS_long                   | Cost of unbundled LOS long                        | 15,450          |
| cLOS_Medium                 | Cost of unbundled LOS medium                      | 5150            |
| cLOS_simple                 | Cost of unbundled LOS simple                      | 2060            |
| cMedical_long               | Cost of medical doctor long stay                 | 3412            |
| cMedical_short              | Cost of medical doctor short stay                 | 2454            |
| cMedical_Simple             | Cost of medical doctor SIRS unbundled             | 848             |
| cNephrology unbundled       | Cost of nephrologist unbundled                   | 3295            |
| cPressors unbundled         | Cost of pressors unbundled                        | 2802.5          |
| cPulmonary unbundled        | Cost of pulmonologist unbundled                  | 3295            |
| cVentilation_unbundled      | Cost of ventilating patient unbundled             | 14,450          |
| cVentilation               | Cost of ventilating patient                      | 14,017          |
| effModSepsis                | Effectiveness of septic shock                     | 1.0             |
| effSepsis                   | Effectiveness of simple sepsis                    | 1.0             |
| effSepticShock              | Effectiveness of septic shock                     | 1.0             |
| pARF                        | Probability of ARF                               | 0.45            |
| pARF_Pressors               | Probability of ARF and pressors during hospital   | 0.15            |
| pARF_Pressors_RE            | Probability of ARF and pressors during hospital-readmit | 0.11 |
| pARF_RE                     | Probability of acute renal failure readmit       | 0.32            |
| pPressors                   | Probability of use of pressors in complicated sepsis | 0.29 |
| pPressors_RE                | Probability of use of pressors in complicated sepsis-readmit | 0.21 |
| pReadmissionComplic        | Probability of readmission complication           | 0.292           |
| pReadmissionShock           | Probability of readmission septic shock           | 0.292           |
| pSepsis                     | Probability of SIRS                              | 0.26            |
| pSepsis_Comp_Course         | Probability that SIRS becomes complicated         | 0.24            |
| pSepsis_Complic             | Probability of complicated sepsis                | 0.25            |
| pSepsis_Course              | Probability of SIRS                              | 0.75            |
| pSeptic_Shock               | Probability of septic shock                      | 0.32            |
| pVentil                     | Probability of ventilation alone septic shock     | 0.26            |
| pVentil_ARF                 | Probability of ventilator and ARF in septic shock | 0.25 |
| pVentil_ARF_RE              | Probability of ventilator plus acute renal failure | 0.18 |
| pVentil_Pressors            | Probability ventilation and pressors in septic shock | 0.29 |
| pVentil_Pressors_ARF        | Probability of pressors and ARF and ventilation in septic shock | 0.14 |
| pVentil_Pressors_ARF_RE     | Probability of pressors and ventilator and ARF in septic shock-readmit | 0.10 |
| pVentil_Pressors_RE         | Probability of ventilator and pressors in septic shock-readmit | 0.21 |
| pVentil_RE                  | Probability of ventilation alone septic shock-readmit | 0.18 |
When deciding what may need to change, it is imperative that one knows what would have the largest impact for a particular change in therapy or cost. This is where sensitivity analysis in a cost effectiveness model can provide insight into what aspect of the care episode needs to be examined more closely.

First, we applied the analysis to the ICU long and short costs. We used the unbundled cost at the high end, and a 10% reduction at the low end. The result was that the per patient episode cost varied between $28,117 and $29,658. This is a 5.2% difference between low and high end. Next, we looked at varying the hospital bed (non-ICU) costs. Again, we used the unbundled cost at the high end and a 10% reduction at the low end. Here the resultant cost varied between $28,708 and $29,099. This is only a 1.34% difference between the low and high ends. Finally, we applied a sensitivity analysis varying the attending physician and the intensivist reimbursement fees. The result was a resultant cost that varied between $29,191 and $29,366 which is a difference of only 0.595%.

### 6. How to use this analysis

This analysis can guide the hospital in just how to allocate resources in light of the new BPCI advanced payment model. Since revenue is essentially fixed and predetermined, it is imperative that the hospital analyze and then cut back unnecessary costs while still maintaining excellent delivery of healthcare to the sepsis patient. Our analysis shows that the biggest impact would be to cut back on the length of ICU care, and/or to cut some of the costs that are incurred in the ICU.

One can see that a combination of savings through medical methodology plus administrative efficiency can lead to a savings of $3873 per admission. See Table 3. Since revenue is fixed, this would go straight to profit. If using the same example of a hospital with 25 ICU beds, based on the available data it would save $2,649,132 during the course of year which would go to profit under a fixed revenue model such as BPCI advanced.

### 7. Discussion

Bundling payments versus the traditional fee-for-service (FFS) presents a different paradigm in not only how to treat the patients and communicate with specialists, but also how hospitals and hospital administrators and physicians can undertake a different approach to revenue generation in light of the costs that are experienced in a typical episode of care. In the previous payment methods, it is simple to charge for certain fees as it is just a matter of submitting a number where the payment exceeds the costs so a profit can be obtained. In traditional existing payment methods, charges are effectively agreed to base upon existing Medicare and Medicaid Payments or in the case of Private Insurers contractual terms negotiated between insurers and the physician, hospital provider or system and calculated through the coding schemes that apply to the different providers. DRG groupers and other software applications attempt to maximize those charges, but those are based on small changes with the system rather than changes in physician care to reduce costs.

This is not the case with the bundled payment models. The interactions among hospital, primary physician, and all the physician specialists are more complex. They must discuss new styles of practice and where patient care costs may be reduced without jeopardizing patient outcomes. Furthermore, payment is somewhat based on outcome which is not the case at all in a FFS model. The combined interrelatedness and matrix interactions require a much more complex analysis in order to decide if the hospital is making money or losing money for a particular disease/diagnosis.

This is the precise environment where decision tree analysis modeling is essential. The probabilities of specific outcomes were obtained from the literature. Decision tree modeling takes into

| Table 2 |
| --- |
| Illustrates both the ranges between high and low costs aggregated from among participating hospitals, but also the percent differential. |
| Parameter | Low | High | PCT Diff |
| Baseline | $ 29,366 | $ 30,386 | 3.36 |
| ICU | $ 28,117 | $ 29,658 | 5.2 |
| Hosp Bed | $ 28,708 | $ 29,099 | 1.34 |
| Physician | $ 29,191 | $ 29,366 | 0.595 |

As is shown, it is the ICU cost that carries the greatest variances and therefore the greatest opportunity for cost management. The least volatile is the physician charge.

Low: 10% below bundled cost.
High: Unbundled cost.

Bundled≈97% unbundled (BPCI requiring 3% cost savings).
ICU=ICU long and short stay.
Hosp Bed=regular bed LOS cost.
Physician=cost of internist and hospitalist.

### Table 3

| No. of ICU beds | ICU bed days | % Sepsis | Sepsis Bd/d | Avg LOS | Calculated admissions | Savings per admission | Total annual savings |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 25 | 9125 | 45% | 4106 | 6.0 | 684 | $ 3873 | $ 2,649,132 |

Calculations for Table 3: Enter actual number of ICU Beds, Bed Day calculated as ICU beds times 365, percent sepsis based on reference data averages, Sepsis bed days calculated as percent sepsis times ICU bed days, Calculated sepsis admissions, based on sepsis bed days divided by average sepsis LOS, from reference material, savings per admission is calculated sepsis admissions times the difference between Low and High ICU costs from Table 2 above. Total annual savings is the savings per admission times the calculated sepsis admissions. ICU=intensive care unit, LOS=length of stay.
account the assorted itemized costs associated with a readmission, which is especially important in a bundled payment model, as readmissions in 90 days will not be paid additional revenues. Even without different therapeutic arms or different measurements of quality adjusted light years (as in a cost effectiveness analysis), this analysis can give much insight into what costs to look at while operating a sepsis case.

Sensitivity analysis of the model provides insight into how a hospital can identify specific cost centers for management or process changes to affect costs and improve margins within the framework of a bundled payment. We were able to show that affecting the costs of the ICU stay had the most impact on overall costs whereas changing the payments to the physicians registered minimal changes to costs at all. This type of analysis can therefore direct the administrators to concentrate on affecting costs to the particular areas that have the most financial impact.

There are however some limitations to this analysis. Firstly, many cases of sepsis can deteriorate from, for example, SIRS to sepsis with complications, or even to septic shock. This is difficult to model and was one thing we did not incorporate. Perhaps one can add the number of cases converted from SIRS to sepsis with complications, and call that the final probability of sepsis with complications. Notable that the complication rate would likely be minimized as practicable and not primarily related to financial compensation as the reputation of the hospital and its physicians in treating sepsis is logically the most important driver. The numbers used in the analysis are examples, and in practice one must use numbers generated from the local hospital to make up for geographical differences and differences in the success of how patients with sepsis are treated in a particular hospital. So even though the numbers presented in this paper are examples, in practice one can use the actual local numbers to help in making a decision about whether or not a hospital wants to participate in BPCI advanced (currently voluntary).

Sepsis, defined as infection with associated organ failure, was identified during the ICU stay in 2973 (29.5%) patients, including in 1808 (18.0%) already at ICU admission as of 2006.[20]

Occurrence rates of sepsis varied from 13.6% to 39.3% in the different regions. Patients with sepsis accounted for 45% of ICU bed days and 33% of hospital bed days. The ICU length of stay (LOS) was between 4 and 8 days and the median hospital LOS was 18 days.[21] If a hospital has 25 ICU beds, which accounts for 9125 ICU bed days, then at a savings of $3873 per admission based on cost containment in the ICU, a hospital would wind up with an additional $2,649,132 in profit if done correctly. (Table 3)

8. Appendix-example

To demonstrate how the model works, a 60-year-old woman, who is diabetic, comes to the emergency room. She complains of difficulty breathing. On presentation, she is hypotensive (systolic BP of 70), and also is in acute exhaust and has dif

The patient is transferred to the ICU, where she remains for 5 days. During this time she has to acute hemodialysis 4 times, and it takes 3 days to reduce the neosynephrine so that she maintains a systolic BP of 95 on her own. By the 5th day, the pulmonologist was able to remove her from the ventilator and she was extubated. After urine and blood cultures came back positive for a resistive form of Escherichia coli, she is maintained on the IV Imipenem to which it was sensitive.

The patient spends the next 6 days in a ward bed. She continues on IV antibiotics and IV fluids until discharge, but her renal function improved (BUN 32, Cr. 1.2) so that she does not need hemodialysis any longer. Her breathing is adequate and she oxygenated well. Her blood sugars are controlled with oral agents and subcutaneous insulin. She was discharged home in good condition.

Now unlike the decision tree, in this example the probability of certain things happening is one (and the other branches 0) so the costs are just summed. The costs for this stay:

| Department       | Cost (USD) |
|------------------|------------|
| ICU              | 11,500     |
| Floor stay       | 6000       |
| Dialysis         | 680        |
| Ventilator       | 2610       |
| Pressor          | 885        |
| Nephro           | 3295       |
| Pulmon           | 3295       |
| Intensivist      | 1192       |
| Primary Care     | 2231       |
| Total            | 31,688     |

In the model, there is a probability that each branch will occur. We multiply the probability of each occurrence (here the probability of septic shock is 14%) times the cost, so in the overall analysis this example would contribute (0.14 × $31,688) or $4436 towards the overall costs. When one does this with the costs of the different scenarios and sums the EVs, the calculated cost is $30,386, which is reported in the results section.

Author contributions

Conceptualization: William Matzner, Deborah Freund.
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Formal analysis: William Matzner, Deborah Freund.
Methodology: Deborah Friend, William Matzner.
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Writing – review & editing: Deborah Freund.

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