Bayesian Theorem-based Prediction of Success in Building Commissioning

Dr. Borinara Park[1]

Abstract: In recent years, building commissioning has often been part of a standard delivery practice in construction, particularly in the high-performance green building market, to ensure the building is designed and constructed per owner's requirements. Commissioning, therefore, intends to provide quality assurance that buildings perform as intended by the design and often helps achieve energy savings. Commissioning, however, is not as widely adopted as its potential benefits are perceived. Owners are still skeptical of the cost-effectiveness claims by energy management and commissioning professionals. One of the issues in the current commissioning practice is that not every project is guaranteed to benefit from the commissioning services. This, coupled with its added cost, the commissioning service is not acquired with great acceptance and confidence by building owners. To overcome this issue, this paper presents a unique methodology to enhance owner's predicting capability of the degree of success of commissioning service using the Bayesian theorem. The paper analyzes a situation where a future building owner wants to use a pre-commissioning in an attempt to refine the success rate of the future commissioned building performance. The author proposes the Bayesian theorem based framework to improve the current commissioning practice where building owners are not given accurate information how much successful their projects are going to be in terms of energy savings from the commissioning service. What should be provided to the building owners who consider their buildings to be commissioned is that they need some indicators how likely their projects benefit from the commissioning process. Based on this, the owners can make better informed decisions whether or not they acquire a commissioning service.

Keywords: Bayesian decision tree; commissioning; value measurement; multi-stage decision making

I. INTRODUCTION

In recent years, building commissioning has often been part of a standard delivery practice in construction, particularly in the high-performance green building market, to ensure the building is designed and constructed per owner's requirements. Commissioning, therefore, intends to provide quality assurance that buildings perform as intended by the design and often helps achieve energy savings. The sustainable building certification system such as LEED by USGBC makes it mandatory for any certification-seeking projects to include the commissioning function as an integral part of the project delivery system [1]. Commissioning, however, is not as widely adopted as its potential benefits are perceived. Owners are still skeptical of the cost-effectiveness claims by energy management and commissioning professionals [2]. One of the issues in the current commissioning practice is that not every project is guaranteed to benefit from the commissioning services. In fact there is a wide margin of the energy savings in terms of payback time ranging roughly from from 1 year to 20 years [3]. This, coupled with its added cost, the commissioning service is not acquired with great acceptance and confidence by building owners.

To overcome this issue, this paper presents a unique methodology to enhance owner's predicting capability of the degree of success of commissioning service using the Bayesian theorem. The paper analyzes a situation where a future building owner wants to use a pre-commissioning in an attempt to refine the success rate of the future commissioned building performance.

II. PROPOSED FRAMEWORK

The author proposes the Bayesian theorem based framework to improve the current commissioning practice where building owners are not given accurate information how much successful their projects are going to be in terms of energy savings from the commissioning service. What should be provided to the building owners who consider their buildings to be commissioned is that they need some indicators how likely their projects benefit from the commissioning process. Based on this, the owners can make better informed decisions whether or not they acquire a commissioning service. They may be given general commissioning performance data but are not necessarily aware of ways to increase the chance to predict how much savings the commissioning service would likely bring for their projects. The following sections explain how this type of owners can be better informed in such decision situations using the Bayesian theorem.

A. Bayes' theorem

The Bayes' theorem is a mathematical mechanism to update probabilities as new information becomes available. In other words, the probabilities we already know (prior probabilities) are revised into the refined probabilities (posterior probabilities) after some information from an event becomes available [4]. As shown in Figure 1, a prior

[1] Professor, Department of Technology, Illinois State University, Normal IL 61790-5100, bpark@ilstu.edu (*Corresponding Author)

probability, $P(A_t)$, is converted to a posterior probability, $P(A_t|B)$, which represents our updated understanding of the probability of A_t based on the new information from an event B. The Bayes' rule to get the posterior probability is presented in (Eq.1).

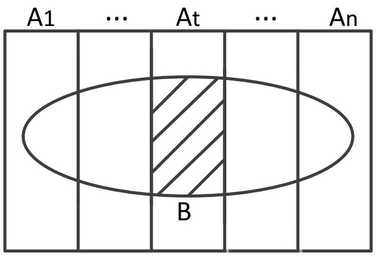

Figure 1. Bayesian Theorem

$$P(A_t|B) = \frac{P(B|A_t)\cdot P(A_t)}{P(B|A_1)\cdot P(A_1)+\cdots+P(B|A_n)\cdot P(A_n)} \quad \text{(Eq. 1)}$$

Where,

- $P(A_t)$: *chance event A_t could occur*
- $P(B|A_t)$: *likelihood of event B given event A_t*
- $P(A_t|B)$: *likelihood of event A_t given event B*

To understand the implications of this theorem in a layman's term, let's assume you are a senior executive of an oil company, who wants to decide to drill for oil in a particular field in a potentially oil-rich field. You have a certain level of understanding how probable you are going to hit wet oil (prior probability, $P(A_t)$). However, before drilling for potential wet oil, you could hire a geologist at a relatively much smaller fee to gauge the likelihood of the oil presence. This is additional information referred to as the event B. Even if the geologist's recommendation cannot guarantee the outcome of the oil exploration, at least his/ her opinion could improve the prior probabilities of the site to contain oil (posterior probability, $P(A_t|B)$) [4].

As much as the oil exploration decision could be enhanced due to the additional information from the geologist, the commissioning decision can benefit from some type of prior information before the building owners' decision to acquire the commissioning service. This can be a pre-commissioning test using some of the selected building systems before full commissioning gets launched.

B. Scenario

To explain the framework briefly mentioned above, let's consider a fictional situation where a commissioning agent advises a building owner that, based on his/ her experience most buildings have, on average, a good chance of getting energy savings by implementing the commissioning process. Such a claim can be supported by a summary of the historical data as shown in Table 1 in which the different levels of energy savings over the years are presented.

Table 1. Prior probabilities of commissioning savings

Savings Probabilities based on Commissioned Buildings' Performance		
High, P(CH)	Fair, P(CF)	Low, P(CL)
0.25	0.35	0.4

Where,

- *P(CH): chance of commissioned buildings to achieve "high savings"*
- *P(CF): chance of commissioned buildings to achieve "fair savings"*
- *P(CL): chance of commissioned buildings to achieve "low savings"*

The "Fair" energy saving is assumed to yield a median payback time on the commissioning cost of 5 years. The "High" energy saving means less than 2-year median payback time and the "Low" energy saving means the commissioning does not yield any practical value. Their respective probabilities are coded as P(CH), P(CF), and P(CL), respectively. Therefore, the chance that the owner's future commissioned building is going to get "fair savings" P(CF) would approximately be 35 %, for example. In fact, these are all prior probabilities of the commissioning savings, which represent general understanding of the building performances in the past. According to this, the owner does not have a great chance of getting his future building to achieve some energy savings, which is expected to be 60% (= 25 % high savings + 35 % fair savings). This puts the owner in a situation where it is difficult to either approve or reject the acquisition of the commissioning service. Simply the owner needs additional information to make a more informed decision.

As a way of assisting further in owner's decision, the commissioning agent could additionally share some more specific historical data. Such data is presented in Table 2 where the past pre-commissioning tests are shared in the format of conditional probabilities. The pre-commissioning could be done as a way of providing preliminary evaluation of the selected system of the buildings before the owners would commit full commissioning services.

Specifically, P(PH|CH) = 66% in the table, for example, should be interpreted as follows: out of all the commissioned buildings whose energy saving were turned out to be high, 66% of them were predicted to be high savings by the pre-commissioning tests. This pre-commissioning testing would be optional and equivalent to the geologist's report for the drilling project mentioned previously. Listed as well are all the values of all the other conditional probabilities such as P(PF|CH), P(PL|CH),

P(PH|CF), P(PF|CF), P(PL|CF), P(PH|CL), P(PF|CL), and P(PL|CL). Their full descriptions are provided at the bottom of the table. In a nutshell, these are breakdowns of the past commissioned building performance according to the levels of pre-commissioning testing outcomes.

Table 2. Likelihoods of pre-commissioning test, Given the commissioning savings

		Savings Probabilities based on Commissioned Buildings' Performance		
		High, P(CH)	Fair, P(CF)	Low, P(CL)
		0.25	0.35	0.4
Savings Probabilities Prediction baseed on Pre-Comm. Test	High, P(PH)	66 %, P(PH|CH)	25 %, P(PH|CF)	13 %, P(PH|CL)
	Fair, P(PF)	20 %, P(PF|CH)	60 %, P(PF|CF)	23 %, P(PF|CL)
	Low, P(PL)	14 %, P(PL|CH)	15 %, P(PL|CF)	64 %, P(PL|CL)

Where,

- P(PH|CH): proportion of buildings predicted to be "high savings" by pre-commissioning tests out of all "high savings" commissioned buildings
- P(PF|CH): proportion of buildings predicted to be "fair savings" by pre-commissioning tests out of all "high savings" commissioned buildings
- P(PL|CH): proportion of buildings predicted to be "low savings" by pre-commissioning tests out of all "high savings" commissioned buildings

- P(PH|CF): proportion of buildings predicted to be "high savings" by pre-commissioning tests out of all "fair savings" commissioned buildings
- P(PF|CF): proportion of buildings predicted to be "fair savings" by pre-commissioning tests out of all "fair savings" commissioned buildings
- P(PL|CF): proportion of buildings predicted to be "low savings" by pre-commissioning tests out of all "fair savings" commissioned buildings

- P(PH|CL): proportion of buildings predicted to be "high savings" by pre-commissioning tests out of all "low savings" commissioned buildings
- P(PF|CL): proportion of buildings predicted to be "fair savings" by pre-commissioning tests out of all "low savings" commissioned buildings
- P(PL|CL): proportion of buildings predicted to be "low savings" by pre-commissioning tests out of all "low savings" commissioned buildings

Pre-commissioning testing information certainly provides additional information to the owners at a much smaller fee than the full commissioning service. The problem is, however, they are all past data and they do not necessarily predict future building performance. For example, P(PH|CH) is the probability of the pre-commissioned testing outcome to be high given the commissioned building's performance is high. But the real interest for the owner is to know how his/ her future commissioned building would perform if the pre-commissioning test indicates a high performance.

C. Application of Bayes' Theorem

If Bayes' rule is applied to the data in Table 1 and Table 2, then the prior probabilities can be refined into the posterior probabilities using the Bayes' Rule in (Eq. 1). For example, the calculation for P(CH|PH) can be done as follows:

$$P(CH|PH) = \frac{P(PH|CH)\cdot P(CH)}{P(PH|CH)\cdot P(CH)+P(PH|CF)\cdot P(CF)+P(PH|CL)\cdot P(CL)}$$

$$= \frac{0.66\times 0.25}{0.66\times 0.25+0.25\times 0.35+0.13\times 0.4} = 54\%$$

The Table 3 summarizes all the calculation outcomes through the Bayesian conversion.

Table 3. Posterior probabilities of commissioning savings

		Savings Probabilities based on Commissioned Buildings' Performance		
		High, P(CH)	Fair, P(CF)	Low, P(CL)
Savings Probabilities Prediction baseed on Pre-Comm. Test	High, P(PH)	54% P(CH|PH)	29 %, P(CF|PH)	17 %, P(CL|PH)
	Fair, P(PF)	14 %, P(CH|PF)	60 %, P(CF|PF)	26 %, P(CL|PF)
	Low, P(PL)	10 %, P(CH|PL)	15 %, P(CF|PL)	75 %, P(CL|PL)

Where,

- P(CH|PH): probability of a future commissioned building to achieve a "high saving" if the pre-commissioning test indicates a "high saving"
- P(CH|PF): probability of a future commissioned building to achieve a "high saving" if the pre-commissioning test indicates a "fair saving"
- P(CH|PL): probability of a future commissioned building to achieve a "high saving" if the pre-commissioning test indicates a "low saving"

- P(CF|PH): probability of a future commissioned building to achieve a "fair saving" if the pre-commissioning test indicates a "high saving"
- P(CF|PF): probability of a future commissioned building to achieve a "fair saving" if the pre-commissioning test indicates a "fair saving"
- P(CF|PL): probability of a future commissioned building to achieve a "fair saving" if the pre-commissioning test indicates a "low saving"

- P(CL|PH): probability of a future commissioned building to achieve a "low saving" if the pre-commissioning test indicates a "high saving"
- P(CL|PF): probability of a future commissioned building to achieve a "low saving" if the pre-commissioning test indicates a "fair saving"
- P(CL|PL): probability of a future commissioned building to achieve a "low saving" if the pre-commissioning test indicates a "low saving"

From a conceptual perspective, this Bayesian conversion has created significant meanings by making the past data into something that can predict the future. For example, P(CH|PH) = 54% means that there is a 54% chance that a future commissioned building to achieve a "high saving" if the pre-commissioning test indicates a "high saving". In other words, if the owner wants to test the building system using the pre-commissioning test and it indicates a high saving, then the fully commissioned building in future to achieve a high saving has a 54% chance. Of course, the pre-commissioning test is an extra cost but it helps the owner have better understanding how much saving he can anticipate from the commissioning. If we recall, the original prediction that the owner is going to have the high saving was expected to be 25% (= P(CH)) in the previous section (as shown in Table 1 and Table 2). Now with the additional low-cost pre-commissioning testing the owner has improved the confidence in deciding whether or not full commissioning is acquired from the commissioning agent.

On the other hand, if the pre-commissioning test indicates a low saving, then the fully commissioned building has a 10% chance of achieving a high saving as indicated by

P(CH|PL) = 10% and 75% of chance of having a low saving as indicated by P(CL|PL) = 75%. In this case, the chance the future building with full commissioning is very low, which almost implies owner's rejection of hiring the commissioning agent. It is worth to note that originally the savings probability for a fully commissioned building to be a low-saving performance was expected to be 40%. Therefore, the posterior probability helps the owner make a decisive decision not to acquire a full commissioning service.

Additionally, if the pre-commissioning turns out to be a fair saving, then the future project is likely at a fair saving level with 60% chance as shown by P(CF|PF) = 60%, which is also a drastic improvement compared to the originally anticipated fair saving probability 35% as indicated by P(CF) = 35% of Table 1 and Table 2. Again this improved information can help the owner decide with much confidence.

III. CONCLUSION

The application of Bayesian theorem was used in this article to convert the past building performance data into futuristic information to make the owner to decide more confidently for a full commissioning service. Technically, the proposed methodology demonstrated that the prior probabilities on the commissioned building performances could be refined into the posterior probabilities using the pre-commissioning test data, which in turn would help the owners predict a future commissioned building performance with much increased confidence. This would help the owners decide more easily on a commissioning acquisition situation.

The success of the proposed methodology depends on 1) how well the commissioning professionals and owners document the pre-commissioning test outcomes and commissioned building performance data; and 2) how well they share such data in a publicly accessible format for others to use. If these conditions are not met, the owners and commissioning professional are likely to rely their decisions on their usual perceptions and gut feelings.

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