An Economic Framework for Analyzing the Incentive Problems in Building Information Modeling Systems

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ABSTRACT

Building Information Modelling is arguably the most important advancement for the built environment in decades. However, project organizational structures and contracting strategies have not correspondingly advanced to accommodate this powerful technology. The result has been a pervasive limited application of collaborative BIM, with few projects taking part in the types of fully integrated and interoperable systems that provide the greatest benefit. In response, this paper reviews the concept of BIM incentives against currently espoused Integrated Project Delivery practices and within the context of theories which have, until now, never been applied to BIM. The paper draws on economic, management and psychological research to outline an analytical framework for designing effective BIM incentives, establishing whether incentives actually even promote the desired stakeholder actions and weighing monetary vs. intrinsic motivation, objective vs. subjective performance measurement and linear vs. non-linear contracts. The common concern of free-rider problems within the collaborative environment is addressed, as are other obstacles that inevitably arise from an increase in information sharing and departure from traditional project hierarchies. While the paper asks as many questions as it answers, the framework detailed within thoroughly outlines the conflicts, inducements and contractual considerations that will form the basis of any BIM incentive research effort.

Keywords

Building Information Modelling, Incentives, Performance indicator, Agency problems, multitasking

Introduction

In the nine years since the term Building Information Modeling (BIM) was first introduced in the AEC industry, it has progressed from a novel buzzword with a handful of early adopters to the centerpiece of AEC technology encompassing all aspects of design, construction, and operations for the built environment (Eastman, Teicholz, Sacks, & Liston, 2011). In fact, the percentage of firms utilizing BIM in the United States has risen from just 17% in 2007 to 71% in 2012 (McGraw Hill, 2012). This upsurge comes with a caveat, however, as the degree of utilization varies widely (Eastman, et al., 2011). Research shows that the industry is largely confined to Level 0, with 95% of industry stakeholders working non-collaboratively based on CAD models while very few projects are taking part in fully integrated and interoperable Phase 3 BIM systems (Oti & Tizani, 2010). This pervasive limited participation is a matter of economics and motivation, as research shows that not all stakeholders are receiving additional compensation for the efficiency and savings created when BIM technology is used, and these participants therefore have less incentive to utilize the system to its full potential (Thomson & Miner, 2006). Such asymmetrical rewards for investment make it impossible to realize BIM's exceptional capabilities, revealing an incentive problem which requires that the construction industry undergo a paradigmatic shift in its approach (McAdam, 2010).

Contractors will participate in BIM applications in order to be awarded a contract and be technically able to present their design (Eastman, et al., 2011), but simple obligatory participation cannot facilitate the information sharing necessary for the creation of an interoperable Level 3 model. Rather, the goal must be to incentivize participation in such a way as to avoid inhibitions or disincentives that discourage stakeholders from fully realizing BIM's potential (Thompson and Miner, 2006). These inhibitions likely include the disclosure of proprietary information (Azhar,

2011) and certainly an increase in the risk and information sharing inherent to a fully developed BIM model. As such, the advancements in information technology associated with BIM must be balanced by incentives in order for its full potential to be realized (Oti & Tazani, 2010). Despite their critical role for economic decision making, incentives are greatly under-addressed within BIM literature. For example, in the 16-page index of the BIM handbook there is only one entry associated with incentives: "shared incentive plan"(Eastman et al., 2011).

Currently there is one broad incentive approach for project owners seeking participation in BIM systems: Integrated Project Delivery (IPD). IPD seeks to improve project outcomes through a collaborative approach of aligning the incentives and goals of the project team through shared risk and reward, early involvement of all parties, and a multiparty agreement (Kent & Becerik-Gerber, 2010). Since both BIM and IPD compel a dramatic increase in information sharing, these concepts have become intertwined (Eastman, et al, 2011) with some going so far as to claim that IPD is pivotal to BIM implementation (Sebastian, Haak & Vos, 2009). In practice, shared incentive plans are often utilized to facilitate team collaboration in support of IPD's overarching aim of promoting project performance over that of the individual stakeholder(s). Yet, there is also the perception that "*[t]hese plans are often difficult to define and implement*" (p.184, Eastman et al. (2011)). Generally, while there is an increase in awareness as to the importance of this issue, how to resolve incentive problems in BIM is still at a nascent stage. The primary purpose of this paper is to develop a framework to systematically address the questions that should be taken into account in the design of contractor incentive plans for BIM systems. The majority of the theories drawn upon to build the framework are from economics and accounting. Despite being prominent in other esteemed fields of social sciences (e.g., finance, marketing, accounting, sociology and political sciences), we have not seen much influence of these works on the analysis of incentive problems in project management. The framework set out in this research can provide a one-stop guide for the well-grounded theories useful for designing incentive mechanisms in construction procurement in general, and in BIM-enabled projects in particular.

Literature Review

In a review of trends in international BIM research, five major themes emerged (Whyte, 2012): Lifecycle and Sustainability, BIM in Design and Construction, BIM Technologies, Using BIM, as well as Professions and BIM. Only the theme "Using BIM" is directly relevant for this research. Under this theme, current research centers on several areas, including the development of tools and metrics to assess the economic impacts of BIM (Barlish, 2011; Riese and Peake, 2007), the attitudes and behaviors affecting communication strategies (Brewer & Gajendran 2012; Hatem, Kwan & Miles, 2012) and the perception of BIM by various stakeholder classes (McGraw Hill Smart Report 2009 and 2012; Kent and Becerik-Gerber, 2010). These themes are explored in greater detail in the following section as they relate to BIM drivers and barriers to adoption.

Research into the specific focus area of structural incentives driving BIM uptake is severely limited. Studies exploring incentives for IPD have been conducted by O'Connor (2009), Dal Gallo, O'Leary and Louridas (2010) and Ballobin (2008), but none of these research efforts have taken the successive logical step in examining how the incentive vehicles inherent to IPD affect the uptake of BIM – this despite the well documented correlation between these project practices.

Drivers of BIM adoption

In the construction industry, the concepts of competitive advantage, process problems, technological opportunity and institutional requirements generally drive the adoption of emergent tools such as BIM (Mitropoulos & Tatum, 2000). However, these drivers are only as effective as their correlation to potential increases in profit, with monetary evidence being a strong driver for any technology adoption (Kent & Becerik-Gerber, 2010). For this reason, a number of studies have been undertaken that examine the return on investment (ROI) from the use of BIM. These studies, including those conducted by Stanford's Center for Integrated Facility Engineering (2005 & 2007), Giel, Issa and Olbina (2010) and McGraw Hill Construction Analytics (2009 & 2012), universally report positive returns. However, the reliability of these results are in question as ROI values are reported without providing the data collection and analysis methodology details needed to validate results (Lee, Park & Won, 2012). Additionally, while these ROI studies do provide evidence of positive returns, they do so from only a surface level perspective.

To truly measure the draw of BIM, other drivers must also be taken into account, including the primary driver of overall efficiency with the ability to reduce material waste, conserve information and increase productivity (Ngo, 2012). To address these efficiency factors, researchers have utilized key performance indicators other than ROI, including schedule reduction (Khemlani, 2007 & 2008) and the incidence of change orders (Cannistrato, 2009) or RFI's (Riese & Peake, 2007). While research shows that these metrics are the most quantifiable (Barlish & Sullivan, 2012), there are many factors outside of BIM to which their variance can be attributed, meaning that no singular measure of effectiveness has yet been established. The end result is that despite the industry-accepted potential for BIM, most construction organizations and researchers do not recognize a formal methodology to evaluate its benefits (Becerik-Gerber & Rice, 2010).

Barriers to BIM Adoption

There are both real and perceived risks associated with any change in work processes, and the implementation of BIM is no exception. Such barriers generally fall into two categories: process barriers to the business organization and technology barriers related to readiness and implementation (Eastman et al., 2011). Relevant to the current research are process barriers, including contractual issues catalyzed by the departure from traditional hierarchies in favor of interrelationships (Tolson, 2012), ownership of the final project model and rights of the creators (Udom, 2012) and risk/liability issues resulting from the blurring of input borders within the collaborative environment (Ngo, 2012).

The focus on process barriers is supported by a 2012 qualitative study on the construction industry's response to the requirement of BIM for public UK projects, which found that none of the construction professionals interviewed expressed technical difficulties in using BIM software. Rather, their concerns were focused on process changes including standards, information and coordination, and changes in culture such as collaborative attitudes, leadership and education (Ngo, 2012). Given the widespread acceptance of BIM technology and equally prevalent concern over its follow-on changes to organizational processes, it is argued here that rather than view BIM as a technology it should be analyzed as a project delivery method with novel risks, rewards, and relationships (Ashcraft, 2009).

Mechanisms of Incentivization in BIM-Enabled Procurement Systems

BIM, as a coordination platform, is alleged to have two effects on contracting behaviour. First, digitizing design into a set of parametric 3D objects could reduce the incidence of misinterpretation of design information arising from human errors in the transfer process between parties. This inherently reduces the incidence of change orders, leaving the owner less exposed to holdup payments (Chang, 2013; Chang & Ive, 2007). Second, the use of BIM could make it possible to incorporate the subcontractors' input into design at an earlier stage as well as facilitate the detection of clashes that would result in rework during construction, both of which also reduce the owner's exposure to changes. With these in mind, a fundamental question becomes why general or trade contractors would consummately (rather than perfunctorily) participate in BIM collaboration to realize the full benefits of BIM.

To answer this question, one must first establish how contractor incentivization works in practice. A review of IPD practices illustrates that no matter what contractual arrangement the owner chooses for achieving integrated project delivery, the driving incentive is based upon a performance-linked payment scheme in which the cost is jointly established by IPD members and used as a benchmark in the determination of bonus pools in which all parties share. Table 1 illustrates the incentive structures of two of the most popular forms of IPD:

Further clues can be found in the case of the Sutter Medical Center in Castro Valley, California as reported in Eastman et al. (2011). The reward structure for this project can be described in general notations as follows:

1. The owner sets out a budget envelope as the target cost ($\overline{C}$)
2. The payment to any of the non-owner members (c_i) should be agreed upon with the owner so that the total payments can be controlled not to exceed $\overline{C}$, i.e.,

$$\overline{C} \leq \sum_{i=1}^{11} c_i = C_T$$

3. Eleven project members signed into an IPD agreement with a clause stipulating how a contingency fund resulting from cost savings (i.e., $\overline{C} - C_T$) is shared among them. The provision of this fund aims to motivate non-owner members to work towards cost reduction. For an individual agent, the payment is dependent upon both the forecast cost of his work and his share of cost savings from the whole project. The sharing ratio changes with the savings made. In the first tier ($\overline{C} \geq C \geq \overline{C}_1$), the savings are equally split between the owner and the non-owner members. An individual member can only take a share proportional to his cost in the total project cost (x_i). When the savings rise further, the non-owner members' shares increase to 75%. The total bonus is capped if the outturn cost falls below $\overline{C}_2$.

$$\begin{aligned} P_i &= c_i && \text{if } C \geq \overline{C} \\ &= c_i + 0.5x_i(\overline{C} - C) && \text{if } \overline{C} \geq C \geq \overline{C}_1 \\ &= c_i + 0.5x_i(\overline{C} - \overline{C}_1) + 0.75x_i(\overline{C}_2 - C) && \text{if } \overline{C}_1 \geq C \geq \overline{C}_2 \\ &= c_i + 0.5x_i(\overline{C} - \overline{C}_1) + 0.75x_i(\overline{C}_2 - \overline{C}_1) && \text{if } C \leq \overline{C}_2 \end{aligned} \tag{1}$$

From a normative perspective, this incentive plan poses some interesting questions: is there an efficiency ground to suppose the use of linear compensation plans? How effective is it to vary the slopes with degrees of cost savings in eliciting the contractor's effort? Have the range of cost-saving bands been appropriately chosen? If no, how much does it matter to the contractor's performance in BIM participation? None of these questions have yet been answered in the engineering/project management literature. Towards the theorization of BIM incentive design, a useful first step is to identify the essential issues through a review of the preeminent literature on the study of incentives.

Analytical Framework for Designing Incentivised BIM

Conflicts of interest are present throughout the procurement process, and such issues will not disappear owing to the use of BIM. To achieve a Level 3 BIM application, a fundamental unresolved issue is how to motivate contractors and subcontractors to genuinely utilize BIM as a facilitating mechanism for digital information exchange so as to create value for the project, e.g., through improving the constructibility of design and reducing rework. There exists a rich body of literature reporting theory and evidence in support of incentives as effective measures in aligning interests among parties. As shown in Figure 1, this research draws on these works to develop a framework for identifying the logical sequence of questions that should be answered in the design of incentive schemes in BIM systems.

Does monetary rewards lead to the desired result?

Whereas incentives play a central role in economic theory as the most important driver of human behavior (Bolton & Dewatripont, 2005; Hart & Holmstrom, 1987), literature is full of examples that incentives may actually motivate the wrong behavior (Kerr, 1975; Kohn, 1993; Lawler, 1990). A key issue to address first is whether monetary rewards are more likely than not to yield desired results (Box 1 in Figure 1). In the standard setting of the Principal-Agent model, the principal cannot ensure that the agent would exert the best effort at the point of contract signature, owing to the premise that effort is not observable and verifiable by an impartial third party. With no recourse towards an external mechanism for dispute resolution, effort cannot be contracted upon. A remedy for this problem is to “force out” desirable effort through a forcing contract, under which undesirable actions can be detected by comprehensive monitoring and then penalized accordingly. However, costliness of this solution precludes it from being a universal solution. In most cases, it is more efficient to provide financial reward by allowing the agent's payoff to condition on the value of his output (Hölmstrom, 1979).

Yet, psychologists tend to argue that the use of extrinsic rewards may have a detrimental effect on intrinsic motives (Deci, 1971; Lepper, Greene, & Nisbett, 1973). The harmful effect of extrinsic rewards stems from their tamper with people's right of self-determination (autonomy) (Ryan & Deci, 2000). This line of inquiry, known as the cognitive evaluation theory (Deci & Ryan, 1985), contends that people have "*the psychological needs for autonomy and competence*", "*rewards can be interpreted by recipients primarily as controllers of their behavior"* and thus may *"thwart satisfaction of the need for autonomy",* leading to lower intrinsic motivation (Deci, Koestner, & Ryan, 1999).

The possibility that monetary rewards would actually result in weaker intrinsic motives is known as the crowding out effect in economics, which is then theorized as the motivation crowding theory (Frey & Jegen, 2001; Frey & Oberholzer-Gee, 1997). Generally, the reception of this theory in economics is mixed. Provided it holds, monetary rewards will result in a decrease of supply rather than an increase (Frey & Jegen, 2001), which will work against the fundamental assumption behind the law of demand and supply. In the face of this anomaly, economists take three different stances: ignore, wait and see, and explain why.

An example of the first stance is Prendergast (1999). Whereas he agrees the crowding effect has an intuitive appeal, "*there is little conclusive empirical evidence (particularly in workplace settings) of these influences*" because the effect reported in psychology experiments can also be ascribed to an alternative explanation (footnote 12 in Prendergast (1999)).

Gibbons (1998) seems to take a more sympathetic stance. He acknowledges the possibility that use of monetary incentives may harm intrinsic motivation and social relations, but more field experiments are needed to demonstrate the significance of this effect in practical settings.

By contrast, Kreps (1997) is more interested in supplying an explanation for why the effect is observed. It is argued that "*[j]obs high in intrinsic motivation often involve a great deal of task ambiguity*." As such, the job undertaker's performance becomes multifaceted. Use of high-powered incentives in a multi-tasking environment would lead the agent to focus on reward-linked aspects of the job at the expense of those aspects that would potentially add value but do not affect reward (Holmstrom & Milgrom, 1991). Attracting people with an intrinsic desire for the job (e.g., passion) is a low cost solution for incentive provision. Nonetheless, the introduction of a performance-linked reward scheme to the job would obscure the nature of the employment relationship, as it signals "*that the relationship is a market exchange and reacts accordingly*". When the adherence to norms is replaced with the mentality of taking advantage of opportunities when they arise, the agent will divert effort away from the valuable activities that are hard to monitor (Rebitzer & Taylor, 2011).

Whereas the debate over the effectiveness of monetary compensation looks set to continue, this research subscribes to the thoughtful observation of Baker, Jensen, and Murphy (1987):

> *We believe that careful examination of the criticisms of monetary pay-for-performance systems indicates not that they are ineffective but rather that they are* ***too*** *effective: strong pay-for-performance motivates people to do exactly what they are told to do. Large monetary incentives generate unintended and sometimes counterproductive results because it is difficult to adequately specify exactly what people should do and therefore how their performance should be measured. (p.597)*

This position leads to an immediate question: what is the best way to harness incentives? Some guidance can be found in the experiment results. Through the review of 74 experimental papers, Camerer and Hogarth (1999) believe the answer lies in what type of task/decision incentives have been applied to:

> *Incentives improve performance in easy tasks that are effort-responsive, like judgment, prediction, problem-solving, recalling items from memory or clerical tasks. Incentives sometimes hurt when problems are too difficult or when simple intuition or habit provides an optimal answer and thinking harder makes thing worse. In games, auctions, and risky choices the most typical result is that incentives do not affect mean performance but incentives often reduce variance in responses. (p.34)*

Similarly, a review of 131 experiment results shows the efficacy of incentives is closely related to complexity of tasks (Bonner, Hastie, Sprinkle, & Young, 2000). The tasks that subjects are asked to do in the laboratory vary in terms of complexity of information processing: vigilance and detection; memory; production and simple clerical; judgment and choice; and problem solving, reasoning, and game playing. Generally, the more complex the task, the less efficacious financial incentives are in improving performance. These results all point towards the same idea: that the attributes of the task hold the key to establishing the best way to harness incentives.

Group-based v.s. individual reward

The second question is associated with the basis upon which reward should be allocated, i.e., the choice between team-based and individual compensation (Box 2 in Figure 1). The primary function of BIM is to enhance coordination among parties, but motivating this coordination and teamwork with material reward is tricky. In a modern economy driven by the trend of specialization, division of labour becomes prevalent. With few individuals owning all inputs necessary for non-trivial tasks, team production can be more efficient if the output of team production is expected to be greater than the sum of separate outputs of individual team members (Alchian & Demsetz, 1972). Organising into teams would present the problem of shirking. Theoretically, a team member faces a choice between spending their time on work and on leisure activity. A rational decision is to "*adjust his rate of work to bring his demand prices of leisure and output to equality*"(Alchian & Demsetz, 1972). The more highly valued the leisure time for a worker, the more he will shirk. Monitoring can help alleviate this problem, but will also result in metering costs. This is where the role of the firm sets in, where supervisors should be made the residual claimant to reduce their own shirking. This result mirrors the key characteristics of the modern corporation. According to Alchian and Demsetz (1972), the major problem of team incentivisation rests with the difficulty in reliably measuring individual output. When joint output is the only basis of compensation, it is in one's interest to free ride on others' hard work. The presence of the tendency to free ride in team production is independent of whether there is uncertainty in output. This enormously influential paper (Arrow et al., 2011) sparks another milestone contribution to the study of teamwork. Holmstrom (1982) develops a Principal-Agent model to prove that group incentives can serve as an alternative solution to free riding problems. In the model, the principal seeks to maximize the total surplus of an agency relationship under the budget-balancing constraint. This constraint requires the reward pool to be totally financed by the joint output of the team (i.e., the total of individual payoffs equal to the group output). Under this constraint, team workers can get a share of the joint output in accordance with predetermined sharing rules regardless of their efforts. An effective way to curb free-riding is through a joint contract between team workers and a third party (the principal) who has no input to the production, whereby group penalties can be imposed should the output fall below the Pareto-optimal level.

However, the effectiveness of "budget breaking" (in Holmstrom's term) in neutralizing externalities from team production depends on the credibility of this scheme (Eswaran & Kotwal, 1984). Also, a team consisting of risk averse agents can be induced to exert the first best effort by a budget-balancing contract (Rasmusen, 1987).

Other solutions have been explored for resolving free-rider problems, including the threat of discontinuing the relationship (Radner, 1986) and mutual monitoring by way of peer pressure (Kandel & Lazear, 1992). However, compared to monetary incentives, we have little understanding of how well they would work empirically.

Regarding the relative efficacy of team based and individual compensation in the workplace setting, Van Dijk, Sonnemans, and Van Winden (2001) reports an interesting experimental result, showing that a piece rate scheme (individual payoff equal to individual output) and team payment (individual payoff equal to average share of the team output) elicit the same level of effort for the employer. This result echoes Jeffrey Pfeffer's observation that individual merit pay is not necessarily superior to group-based reward schemes (Pfeffer, 1998).

Objective v.s. subjective performance measurement

Generally, the efficacy of the reward scheme in Eq.(1) rests on two preconditions: (1) that cost share is an unbiased measure of one non-owner IPD member's contribution and (2) payments are effectively linked to the chosen measure. Either of these two conditions failing to hold will lead to the dysfunction of the performance system. The choice of performance metrics is therefore a crucial decision for the owner, with the resultant key theoretical question being which incentive would work best to induce contractor effort to achieve the owner's objectives.

From a principal-agent perspective, the first best contract is feasible only when the agent's effort is observable and there is no uncertainty in output (Lambert, 2001). When asymmetric information is present, the right incentives should be built on the "informativeness" of the metrics (Hölmstrom, 1979). Most of the time, effort is not observable, so a proxy such as revenue is used to capture the agent's effort. The drawback is that a positive sales record may have more to do with luck than with actual sales aptitude. For this reason, it is sometimes useful to include an auxiliary metric in the compensation scheme, so long as it adds more information about the agent's effort and the agent has no control over it. An example would be the average sales of other salespersons in the same area, which is valuable because it can help remove some of the random effects. Equally useful is a principle developed by Baker (1992) that a viable performance measure should satisfy the condition that "the marginal product of the agent's actions on the performance measure is highly correlated with the marginal product of these actions on the principal's objective".

From the perspective of management accounting, Feltham and Xie (1994) emphasizes the importance of congruence and precision in the selection of performance measures. A performance measure is said to be congruent if the impact of the agent's action on the principal's objective can be mostly captured by the impact of the agent's action on the performance measure. In addition, a performance measure containing less randomness is preferred (higher precision). The ideal measure is noiseless (so the principal does not have to pay high risk premium to the agent) and can direct the agent to work for the principal's interest. Ittner and Larcker (2002) detail some practical issues involved in the design of incentive schemes, presenting four categories of factors to consider:

1. informativeness of the measures

(1) Strategy of the organization: For example, research and development expenditures as a percent of sales is a much more informative metric for innovation driven than cost driven companies.

(2) Pursuit of continuous improvement: incremental improvement may not be fully reflected in financial indicators. Thus, disaggregated, task-related non-financial measures could better gauge the achievement of the organization's goals.

(3) Regulation: For companies operating in a regulated industry, the requirements set by the regulator (e.g. customer satisfaction) will translate into the organization's goals and thus affect the relevant performance measures.

(4) Type of operation: financial measures are more informative for manufacturing companies than for service companies as cause-and-effect relations and standards can be relatively well established in the former.

(5) Past financial performance: The firms will emphasize financial measures more to avoid the cost of financial distress

2. Breadth of plan coverage

   Related to how widely the incentive scheme is applied within the organization, including the highest level covered by the plan, the number of locations covered by the plan, and the percentage of the company's employees who are covered by the plan.

Subjective performance evaluation plays an essential role in human resource practice (Murphy & Cleveland, 1995; Prendergast & Topel, 1993), and there are cases where performance evaluation should at least partly rely on subjective measures owing to a lack of valid objective ones. For example, stock price performance may be reflective of the CEO's contribution to firm value, but it contains too much noise for the evaluation of lower-level employees.

The working of a subjective performance system should build on trust between the employer and employee. In a one-shot game, the principal would skip the bonus payment even when the agent performs satisfactorily. However this opportunistic move would undermine the credibility of the incentive scheme in the long run. A remedy for this problem is to foster a reputation as an implicit "self-enforcing" mechanism for the scheme (Bull, 1987). Under certain circumstances, it could be more effective when objective and subjective measures are used together rather than singularly (Baker, Gibbons, & Murphy, 1994). An empirical investigation of the effects of human resource practice on productivity for steel finishing lines lends support to the superiority of the joint use of explicit profit-sharing scheme and discretionary bonus (Ichniowski, Shaw, & Prennushi, 1997).

However, subjective assessments are prone to supervisorial biases such as favoritism. Excessive personal preferences have two implications for compensation design (Prendergast & Topel, 1996): (1) additional noises caused by favoritism will make incentive contracts less desirable, leading to underuse of high-powered incentives; (2) could lead to the implementation of bureaucratic rules in place of supervisor appraisals for performance assessment. Establishing an optimal mix of subjective and objective measures is a topic worthy of further exploration.

Weightings of performance metrics

As explained previously, in theory objective and subjective performance measures can complement one another. The logical successive question is then how to balance the influence of different measures of compensation. A formula based plan would induce the agent to “game” the system to maximize measured performance instead of intended performance. Baker et al. (1994) proves that distortions caused by objective performance measures can be mitigated by the principal reserving its discretion over the weightings of these measures. The wide use of discretionary bonus schemes is an example (Baiman & Rajan, 1995; Hayes & Schaefer, 2000). Objective measures are used less in the evaluation of complex jobs (MacLeod & Parent, 1999). In an empirical study of compensation practice in car dealerships, Gibbs, Merchant, Stede, and Vargus (2004) finds the evaluator’s subjectivity plays a greater role in the determination of bonuses under four conditions: first, if the job entails the agent’s greater long-term investment in intangible assets; second, if the job requires great input from co-workers; third, if the target is set high and subject to recalibration in the event of environmental uncertainty; fourth, if loss occurs to make subjective judgment the only way to filter out “bad luck”.

With regards to the allocation of weights to measures, the principle of “informativeness” is influential in decisions on assignment of weightings (Antle & Demski, 1988; Bushman, Indjejikian, & Smith, 1995). The inclusion of a performance measure should be justified by whether it can add more information content about the agent’s actions than other included measures. However, the informativeness of a measure (relative strength of one measure over others) would vary with intra-firm interdependencies (e.g., product-line or geographic diversification)(Bushman et al., 1995).

Principal-Agent theory suggests that the weight given to a performance metric should be lower if it contains high variations, and higher if the measure can induce the responsive reaction from the agent (Banker & Datar, 1989; Hölmstrom, 1979). The relative weights of measures should consider both the precision and sensibility of the metrics (Banker & Datar, 1989). In statistical terms, the former indicates the reciprocal of the variance of the measure, while the latter is concerned with how much the signal would change owing to a unit change in the agent's effort. Bushman and Indjejikian (1993) shows "the ratio of the optimal incentive weights for a linear combination of two performance measures is the ratio of the sensitivity times precision of the individual performance measures."

In the face of multi-tasking problems, the provision of incentives becomes tricky. Datar, Kulp, and Lambert (2001) and Baker (2002a) develops some useful principles for assessing the weights of performance measures. For ease of exposition, assume there are two tasks facing the agent. The output of the agent (Q) depends on both how much effort he expends on task 1 (e_1) and task 2 (e_2)

$$Q = f_1 e_1 + f_2 e_2 + \varepsilon$$

where f_1 and f_2 are the marginal product of effort on the output. ε indicates normal random disturbances, $\varepsilon \sim N(0, \sigma_\varepsilon^2)$. The firm can offer an incentive contract to allow the employee to take a share of their output, b_v, plus a fixed wage *s*, so the employee will respond in order to maximize the expected value of employment, i.e.,

$$\text{Employee's Expected Utility} = E(s + b_v Q) - \gamma \operatorname{var}(s + b_v Q) - (\frac{1}{2}e_1^2 + \frac{1}{2}e_2^2) \qquad (1)$$

Eq.(1) shows the employee's expected utility is the expected value of the payoff from employment, net of risk premium (the second term) and cost of efforts (third term). The optimal risk-sharing ratio (b_v^*) can be easily found by maximizing Eq.(1) to find the agent's best actions and consider them as constraints to maximize Eq.(1) with respect to b_v.

$$b_v^* = \frac{f_1^2 + f_2^2}{f_1^2 + f_2^2 + 2\gamma\sigma_\varepsilon^2} \tag{2}$$

It is useful to simplify Eq.(2) in terms of the signal-to-noise ratio, $S_v = (f_1^2 + f_2^2)/\sigma_\varepsilon^2$,

$$b_v^* = \frac{S_v}{S_v + 2\gamma} \tag{3}$$

Eq.(3) indicates that the optimal risk sharing is jointly determined by controllability (f_1,f_2) and riskiness (σ_ε). When the effect of the agent's effort on output is large relative to the random noise, it is desirable to use high-powered incentives.

Yet, there are circumstances where the output of the agent is not a reliable signal and thus compensation should condition on a performance measure (P).

$$P = g_1 e_1 + g_2 e_2 + \phi \tag{4}$$

The effects of the agent's efforts on measured performance are captured by the coefficients g_1 and g_1, but are also subject to noise (σ_ϕ^2, variance of the random variable ϕ). The compensation scheme is $\pi = s + b_p P$. For the agent,

$$\text{Agent's Expected Utility} = E(s + b_p P) - \gamma\,\text{var}(s + b_p P) - (\frac{1}{2}e_1^2 + \frac{1}{2}e_2^2) \tag{5}$$

The first-order conditions of Eq.(5) with respect to a_1 and a_2 yield

$$\begin{aligned} e_1^* &= b_p g_1 \\ e_2^* &= b_p g_2 \end{aligned} \tag{6}$$

Eq.(6) are the participation conditions of the agent. For the principal, the goal is still to maximize the total surplus, i.e.

$$\text{Total surplus} = E(Q) - \gamma \operatorname{var}(s + b_p P) - (\frac{1}{2}a_1^2 + \frac{1}{2}a_2^2) \tag{7}$$

The optimal incentive scheme can be found by the first-order condition of Eq.(7)

$$b_p^* = \frac{f_1 g_1 + f_2 g_2}{g_1^2 + g_2^2 + 2\gamma\sigma_\phi^2} = \frac{FG\cos\theta}{G^2 + 2\gamma\sigma_\phi^2} \tag{8}$$

where F and G are the length of the vector of marginal products on real output and performance measure (i.e. $F = \sqrt{f_1^2 + f_2^2}$, $G = \sqrt{g_1^2 + g_2^2}$), θ is the angel between these vectors (see Figure 3). Cosθ is a measure of how distorted a performance measure is with respect to actual output. When two vectors are perfectly aligned (θ=0, cosθ=1), P provides the same incentive effect as Q. Lower distortion means higher weights should be placed on performance measures. So should a greater weight be placed for a performance measure with low variance. The goodness of performance measures can be easily seen on the noise (σ_ϕ^2) v.s. distortion (1-cosθ) graph. As elaborated in Baker (2002b), a good use of this framework can be seen in the design of compensation for the divisional plant manager in a multi-divisional firm. Compensation can be benchmarked against different levels of measurement, including firm value, firm-wide accounting profits, Divisional profits, Plant-level profits, and Plant-level costs. Choosing firm value as the manager's performance measure can avoid distortionary incentives, but contains too much uncontrollable noise (e.g., macroeconomic changes) for the manager. When moving down from upper-left to lower-right corner of Figure 3, the measure becomes more controllable (i.e., less noise beyond the manager's control), while it intensifies distortions.

Linear v.s. non-linear contracts

Hölmstrom (1979) sets out a rudimentary model for understanding agency problems. A key logical link of the model is that the agent's effort can yield higher profit for the principal. However, without imposing the monotone likelihood ratio property (MLRP), this is not necessarily true (Milgrom, 1981). It is also criticized by placing sole focus on the first-order condition in solving the agent's best action, as it cannot guarantee the answer is a global maximum (Grossman & Hart, 1983). In a well-known study of executive pay, Jensen and Murphy (1990) find that there is no low sensitivity between incentives and firm value (pay-for-performance slope=0.03). They resort to non-linear incentives as an explanation. Theoretical concerns aside, the complicated contract predicted by the Principal-Agent model appears at odd with the simplicity of real world contracts. In addition, some evidence from the field seems concerning non-linear contracts (Gibbons, 1997). As a result, it is imperative to examine the validity of linear contracts.

A strong justification can be found in Holmstrom and Milgrom (1987). It provides an ingenuous proof to show that a linear contract is coincidently the best compensation scheme for agents who can adjust their effort levels over time (technically control the drift rate of a Brownian motion over the unit time interval). This "as if" explanation provides a cogent justification for restricting research focus on linear contracts in compensation design. The assumptions used in the model, including linear contract, exponential utility function and normal disturbance, form the tripod of the influential Linear-Exponential-Normal (LEN) framework.

Banker and Datar (1989) work under this framework to demonstrate that it is possible to find a linear combination of performance measures upon which an optimal contract can be made conditional.

Basu and Kalyanaram (1990) evaluate the relative performance of compensation plans taking the form of $(A+Bx)^{\alpha}$ (A, B, α: parameters) using numerical simulations. The finding shows non-linear compensation plans would perform better than linear plans in the low-uncertainty environment.

Threshold

The monotonic effect of money on motivation in the Principal-Agent model may not be as straight as assumed (Gneezy & Rustichini, 2000). Firstly, low compensation might have no effect because of the agent's unwillingness to "work for peanuts". Second, the social norm would pose a hindrance to the acceptance of monetary reward. For example, the practice of paying small rewards for recycling bottles works less well than the norm of not recycling being deemed bad behavior by the society. Drawing on their experiment results, Gneezy and Rustichini (2000) call for a rethinking of the rule that "a small payment is better than nothing".

Setting a threshold is common practice in executive compensation. A significant element of executive pay is associated bonus awarded for above-target performance (e.g., annual bonus, long-term incentive plan) (Lambert & Larcker, 1991; Murphy, 1999). A general form of the one-kinked performance-threshold-based linear contracts can be depicted as follows (Gjesdal, 1988):

$$W(Q)=\begin{cases}(b_2-b_1)Q_0+b_1Q & Q\le Q_0\\ b_2Q & Q>Q_0\end{cases}$$

Where the line is kinked is the threshold performance. Zhou and Swan (2003) find that when risk is high (low), the optimal compensation plan will specify a low (high) threshold (Proposition 2 and 3).

Raju and Srinivasan (1996) explores the best sales compensation plan by comparing the efficiency of a threshold based linear plan and a curvilinear agency-theory-based plan using numerical simulations. In terms of the total profit generated by different compensation plans, the piece-wise linear plan is superior to linear plan by 7% for the parametric scenarios. In the similar vein, in terms of the ratio of the principal's utilities obtained from piecewise-linear-threshold contracts to those from linear contracts, Chen and Miller (2009) use simulation methods to demonstrate that relative efficiency is sensitive to the agent's utility function. For the agent with exponential utility, piecewise-linear-threshold contracts can do no better than linear contracts in most scenarios. This offers a justification to restrict focus on the single-period LEN model in the design of compensation plans. Nonetheless, this conclusion does not stand when the agent has a power utility function,

Design of Incentivised BIM: Research Opportunities

Figure 2 sets out a series of questions that should be carefully scrutinized in the design of BIM incentivisation. This section aims to explore the preliminary answers to these questions, thereby identifying the opportunities for further research.

The first question is whether the use of monetary compensation could actually lead to desired behaviour. The literature suggests that the answer chiefly rest upon the nature of the task. The famous puzzle that paying blood donors did not increase blood donation is a case in point (Titmuss, 1970). If the activity is currently motivated by altruism, monetary compensation would undermine the good cause that previously motivated people to participate and therefore result in a counterproductive result. Obviously, this is not the case in BIM incentivisation. Risk-sharing arrangements are prevalent in construction contracts, and monetary reward is well expected by all tiers of contractors for their contribution to the project. The real concern is then what way incentives can best be utilized.

The second question is to explore the basis upon which BIM participants should be rewarded. Simply speaking, individual based compensation is superior to team based compensation in cases where individual output can be easily measured and the underperformance of one party has low knock-on effects on the production of the whole team. Since pre-contract planning and design in construction projects involves great coordination and entails input from various parties, the close interdependency of one party's output with those from other parties can be expected in the majority of projects. It follows then that team based compensation would be more efficient. However, the downside of free-rider problems may cause concern. It is useful to explore further how difficult this could be detected practically, and whether it can be mitigated technically by changing the design of BIM.

Third, it should be noted that in spite of its prevalence within construction contracts, cost saving is only a relative measure. Provided performance is entirely measured against the target cost, BIM members would be lured to game the system by concealing cost information in order to justify a not-so-stretching target. Additionally, cost is only half of the story. How to bring benefit into performance formulas also merits research attention. Both of these factors will undermine the effectiveness of incentives, so subjective measures should have a role to play. If used wisely, the complementarities of these two types of measures should be able to improve the efficacy of BIM incentive systems. Again, how to harness the upside and mitigate the downside of subjective measurement is a pressing issue for BIM incentivisation.

Fourth, in BIM literature, the metrics chosen for measuring BIM performance are presented as four groups. The first group seeks to measure how much monetary payoff has been yielded compared to its cost (e.g., Return on Investment). Secondly, the benefits of BIM can be evaluated on the basis of how much cost would be saved owing to the assistance of BIM in detecting clashes in the early stages. The third group is concerned with the impact of BIM on the project in terms of subjective success criteria (e.g., coordination, scope, time). In the fourth group, the Key Performance Indicators commonly used in project management are resorted to as yardsticks for comparing BIM against non-BIM projects. Evidently, none of these metrics are without limitations. The two-dimensional framework (noise v.s. distortion) in Figure 4 can shed light on the desirability of these metrics. As shown in Figure 5, the owner's judgement can ensure bonuses are awarded only when contractors satisfy the project objectives. While from the contractor's point of view, excessive subjectivity would be regarded as containing too much bias and uncertainty and thus undermine the credibility of the incentive plan. Use of KPIs as performance measures can lower noise, but may cause distortion owing to the incongruence between KPI and the owner's overall objectives. Similarly, ROI can provide an even better measure of the contractor's contribution to a BIM system, but what is being captured diverges further from the owner's high-level objectives (such as green design, low environmental impact, speedy completion or low interruption of existing operation). Lastly, the most accurate indicator of contractor's BIM performance would be the cost savings arising from early clash detection owing to his effort, but avoiding rework would be of little importance relative to other main objectives. It is imperative that efforts be made in further research to measure the properties of main performance metrics in terms of noise and distortion.

Fifth, on account of its popular use in construction contracts, linear contracts can be taken as an approximation of reality to start with in the analysis. Nonetheless, to what extent non-linearity would cause sub-optimality compared to the first best contract and linear contracts should be explored further to form a more solid foundation for BIM incentive schemes using scientific methods, such as simulations and experimental methods.

Sixth, from the "kinky" linear form of compensation scheme in Eq.(1), there seems to be a practical need to vary the intensity of incentives for different levels of cost savings. This practice calls into question how the owner can ensure the division of bands and the slope attached to them are the optimal choice. Additionally the desirability of the compensation plan is bearing on the functional form assigned to describe utility, so how the owner's preference should be represented is an important empirical question in the future.

CONCLUSIONS

IPD is currently the only contractual incentive mechanism being utilized for BIM, and the project owner is the primary beneficiary of both practices (Eastman, et al., 2011). While all IPD agreements utilize some shared risk or reward to incentivize contractor participation (Kent & Becerik-Gerber, 2010), the question remains as to which mechanisms are the most effective and to what degree they drive contractor participation in BIM systems specifically. If the construction industry is to ever realize the full benefits of interoperable Level 3 BIM, the effectiveness of the various incentive structures outlined above must be purposefully addressed and their follow-on effects quantitatively tested. Based on that knowledge, researchers can then recommend methodologies that best incentivize BIM in various environments or establish whether there exist any novel incentive arrangements that could more effectively do so. The framework outlined above identifies the conflicts, inducements and contractual impediments that will form the basis of any such future research effort.

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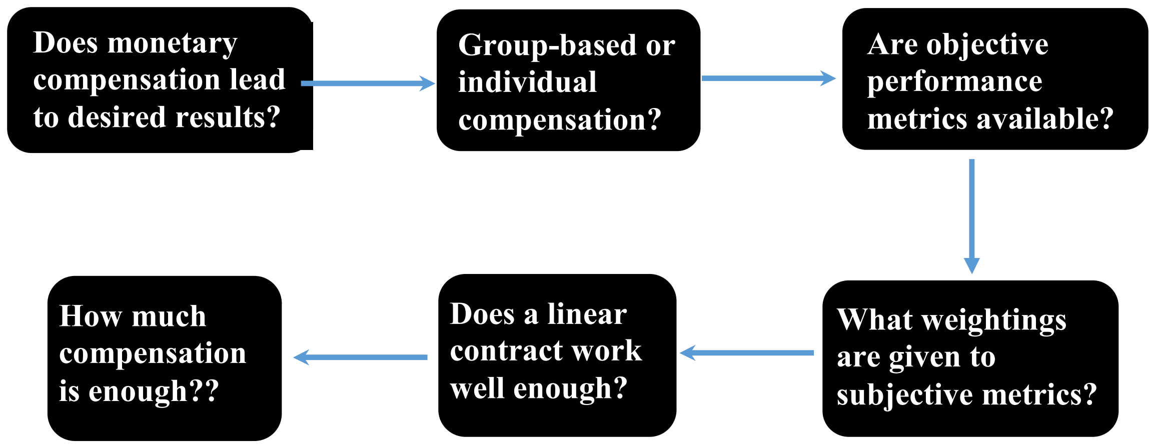

Figure 1 A framework for analyzing incentive problems in BIM-enabled projects

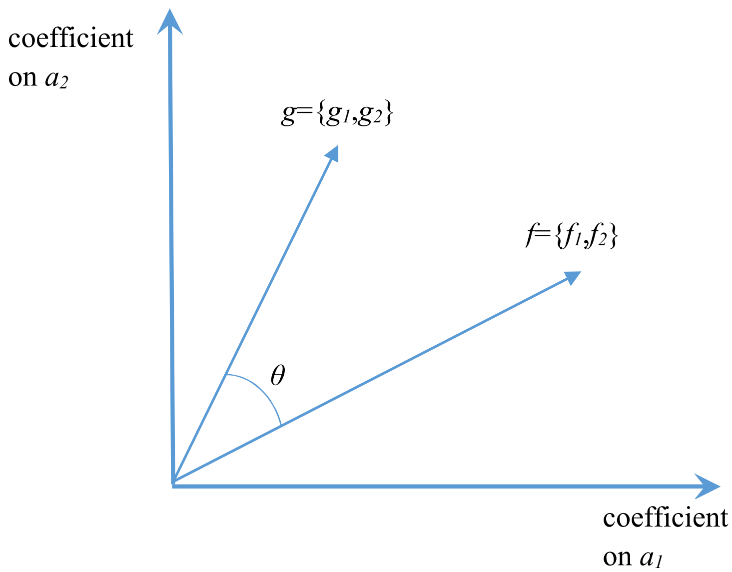

Figure 2 A graphical representation of the "goodness" of performance measures

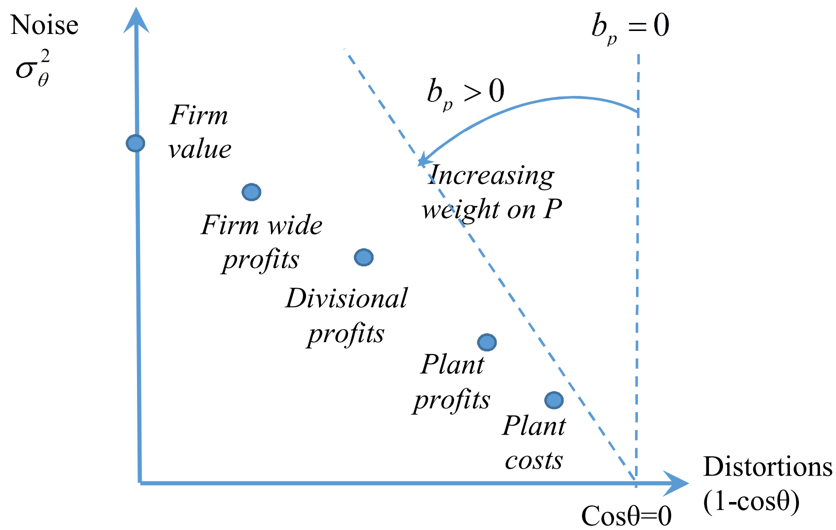

Figure 3 Relative strength of different measures

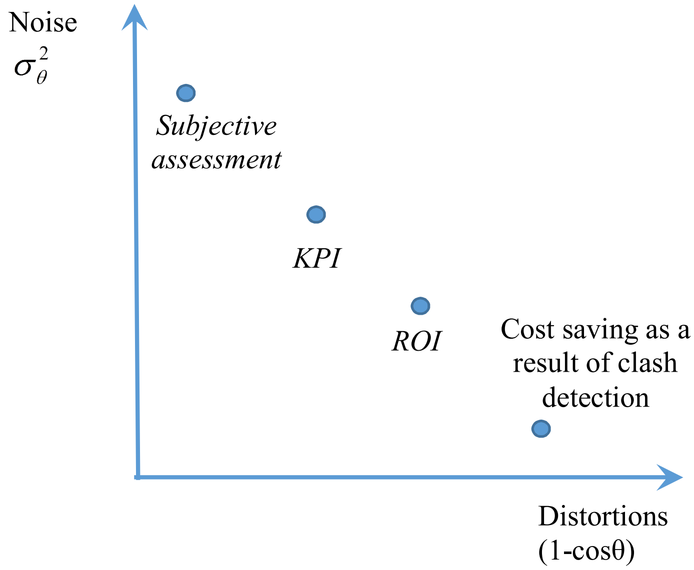

Figure 4 Relative strength of different measures