Integrated Project Delivery Using System Dynamics

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Abstract
The construction industry is a growth engine to improve economic growth, but most project construction delivery is usually in a linear process. Each process depends on previous work because of their interdependence. This paper strives to compare traditional project delivery and integrated project delivery using a system dynamics method based on a design-bid-build process for construction. The results of this research endeavor to prove that integrated project delivery is more effective than traditional project delivery.

Keywords: construction industry, traditional project delivery, integrated project delivery

1. Introduction

In an effort to improve its welfare, Indonesia needs to accelerate its economic transformation. Then mindset changes are done with not having a business as usual spirit. However, mindset changes should not be used with the government budget, but the changes can be encouraged to involve private sectors (MP3EI, 2011).

In many countries, the construction industry is vital for development. Economic growth in various countries can be measured by the physical development of construction projects, such as buildings, roads, bridges, and others. Therefore, the industry is the 'growth engine' and functions as a catalyst to stimulate the growth of other sectors in an economy. Consequently, the success of project construction development is a fundamental aspect for most governance, project implementations, users, and other communities (Takim, 2005).

According to Ciraci and Polat (2009), the lack of inaccuracies in an initial project estimation can be eliminated with a good assessment of the cost estimation method. Cost estimates are carried out in the planning stages.

According to Alaghbari *et al.* (2007), delays in project constructions vary greatly from project to project. Some projects can be delayed for a few days, while others can be delayed for up to several years. So, understanding the causes of project delays is important in order to minimize and avoid any delays in a construction project (cited in Ahmed et al. (2003)). They found that the delays in construction projects in Malaysia were caused by a serious problem between the contractors, consultants, project owners, as well as external factors. The consequence was bad management that led to the delay of material delivery to the site. From the contractor's viewpoint, project delays were caused by a lack of skills, staff, and sub-contractors in the field. From the owner, delays were caused by the project's financial problems. While from the consultant, there was a lack of supervision and effectiveness, instructions were given late, the consultants had a lack of experience, and the consultants were weak in managerial skills. These all led to project delays. For the external factors, project delays were caused by a lack of materials, tools, and equipment.

According to an Economist article, 30% of residual waste materials was identified from a survey of 2,000 construction industries in the U.S.A. Meanwhile, a study by the US Bureau of Labor Statistics found that there was a decline in productivity since 1964. Therefore, to reduce inefficiency and residual waste material, the integrated project delivery (IPD) approach can be used to integrate the project output (AIA, 2007).

Traditional project delivery usually is figured in linear processes. Each process depends on the previous work because of their interdependence. In other words, the process is similar to a domino effect. For example, construction always starts with a design. If the domino does not fall, then the chain reaction does not occur. Even when the last domino is the construction, then a chain reaction between the design and construction will cause a gap in the acquisition process, such as advertising, bidding, selection, and contract. This gap occurs during the process, starting from the initial concept to the project completion, but the problem is different between the alignment and sustainability of the project completion among project delivery stakeholders.

Other issues are in the linear process of the traditional design-bid-build process, such as an indication of the identified conflict that causes project delays, and optimum solutions cannot be achieved. It is more difficult to complete the project, because none of them know the consequences. For example, there are compromises to be decided for an easier design, although in fact their decisions are contrary to the construction function. However, the completion of a project based on compromise will cumulatively affect the reduction of value.

Because of that, the architects (consultants) should try to estimate the impact of the proposed design as well as possible due to an understanding that a redesign will occur. However, in the IPD process, the architects are not required to predict the impact of a proposed design. Likewise, the contractors who are involved in the initial design concept, or even in an early stage, will have real-time feedback with the architects who have access.

In addition, the architects are notably weak in establishing the accuracy of a cost estimation. The decision is made at the beginning of the design phase; it is based on the best predictions of architects. After getting to this point, there will be no refund or reissue of a design effort and mitigated problems that are created by themselves. Meanwhile, the concept of the IPD process can keep maintaining the continuity and alignment of project goals.

Based on the background above, to improve the performance of a good integrated delivery process, this paper aims to simulate a system dynamics method for the role of project owners, contractors, and consultants in the design-bid-build process.

2. Literature Review

Integrated Project Delivery (IPD) is defined as an interrelated contract approach which is aligned with project objectivity and prime participant attractiveness (Matthew & Howell, 2005). This delivery method was introduced in the USA at architect, engineering, and construction (AEC) industries. A project delivery system is a detailed contractual structure about how a final project is designed, built, and delivered to the owner. The owners and stakeholders commonly look for the same project results, such as the highest quality, the lowest cost, and the completion of the project at the same time as required in the scheduled framework (Hassan, 2013).

The IPD system is a new contractual structure method that implies lean principles to improve productivity. IPD is a project delivery approach that integrates people, systems, business structures, and practices into a process which explores all of the experiences and talents from all of the participants collaboratively to optimize project productivity. The main focus is the principles in how to improve the owner’s value, reduce waste, and maximize efficiency through all of the planning phase, design phase, and construction phase. Similarly, IPD can be used to leverage knowledge and expertise contributions through new technological benefits earlier.

Table 1 shows the comparisons between a traditional project delivery system and an IPD project delivery system. It reveals the advantage of IPD in teamwork, process, risk management, awards, technology, and contractual agreement (American Institute of Architects).

Table 1: Comparisons between a Traditional Project Delivery and an Integrated Project Delivery (Hassan, 2013) (Kenig et al., 2010)

	Traditional Project Delivery	Integrated Project Delivery (IPD)
Team	Fragmented, created based on an as needed basis, hierarchical, controllable	Composed as part of integrated project main stakeholders, formed at the beginning of the process, open, collaborative
Process	Linier, different, desperate, stored up information, knowledge appropriate with need, knowledge reservoir and expertise	Concurrent, multi-level, early contribution in knowledge and expertise, accountability, truth and respect from stakeholders
Risk	Managed individually, maximum transferred	Managed collectively, appropriate with direction
Awards	Continue individually, minimum effort to maximum revenue, cost-based	Project success based on project success, value-based
Technology	Paper-use, two-dimension, analogy	Digitalization, virtual, Building Information Model (BIM); 3, 4 & 5-dimensional.
Agreement	Encourages unilateral efforts, transferred and allocated risks, no sharing	Encourages, supervises, promotes, and supports accountability and sharing of multi-lateral collaboration, risk sharing

A project team consists of the project main stakeholders as follows: owners, architects, engineers, general contractors, main sub-contractors, suppliers, and manufacturers. The objective of IPD is to create a talented experienced team that is guided by collaboration principles, trust, communication, accountability, decision making, and the use of the highest technology availability to achieve an optimum project as shown in Table 2.

Table 2: Integrated Project Delivery Principles (Hassan, 2013) (Kenig et al., 2010)

IPD Principles	Goals
Mutual respect and mutual trust	Team project commitment to collaborate and communicate the interested best projects
Mutual benefits and awards	Compensation based on the value added by team members
Innovation	Freely exchanged ideas by project teams to simulate innovation
Make a decision	Key decisions evaluated by the project team through the knowledge and expertise of all participants
The core participants in the initial engagement	Owners, planners, consultants, contractors, sub-contractors, suppliers, and manufacturers involved in the beginning from the project conceptual phase
The early goal definition	The purpose of the project developed early in the project's success, in response from the central
Intensive planning	Planning according to streamlining, design, and construction demands adds to the planning efforts, which will have a great impact on the efficiency during construction execution

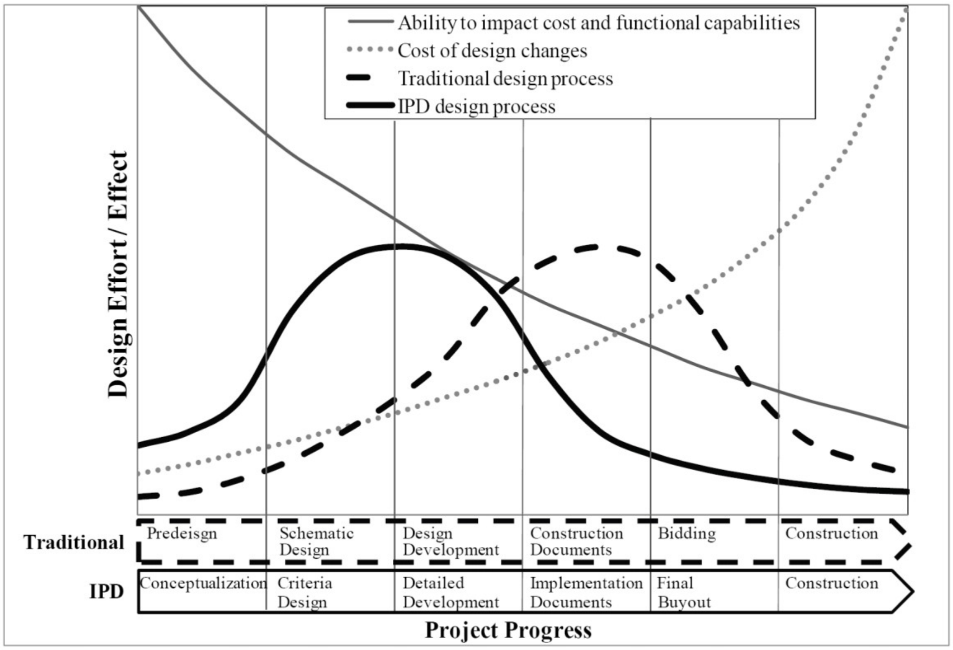
Communication	Open, honest, and direct communication among the project team, which can add to the team's performance and increase its productivity
Suitability of technology	Information technology integrated in an IPD project such as Building Information Modeling (BIM) to enable communication
Organization & leadership	Leadership roles clearly defined by the team members, most team members capable of special services appointed.

According to Lee (2013) and cited in AIA et al. (2010), recognizing a tiered approach of IPD is based on three levels of collaboration. These three levels represent a typical spectrum through project owner desires. The level of collaboration 1 (typical) involves collaboration that is not contractual. The level of collaboration 2 (enhanced) consists of some contractual terms of collaboration, while the level of collaboration 3 (requested) requests collaboration based on a multi-party contract. In this framework, levels 1 and 2 look at IPD as a philosophy while level 3 looks at IPD as a method of delivery.

Table 3: Level of Collaboration Comparison

	Level of collaboration 1 "Typical"	**Level of collaboration 2 "Enhanced"**	**Level of collaboration 3 "Requested"**
Level of collaboration	lower		higher
Philosophy and method of delivery	IPD as philosophy	IPD as philosophy	IPD as delivery method
Also known as …	N/A	IPD-ish; IPD lite; non multi-party; technology enhanced collaboration; hybrid IPD; integrated practice	Multi-party contracting; "pure" IPD; relational contracting; alliancing; lean project delivery system™
Delivery approach	CM at-risk or design-build	CM at-risk or design-build	Integrated project delivery

According to the AIA (2007), in an integrated project, it flows from a conceptual through implementation and closeout stages that differ significantly from a non-integrated project. Upstream decisions are moved as far as possible in a direction that is more cost effective and less with advocating a re-thinking of a typical project phase.

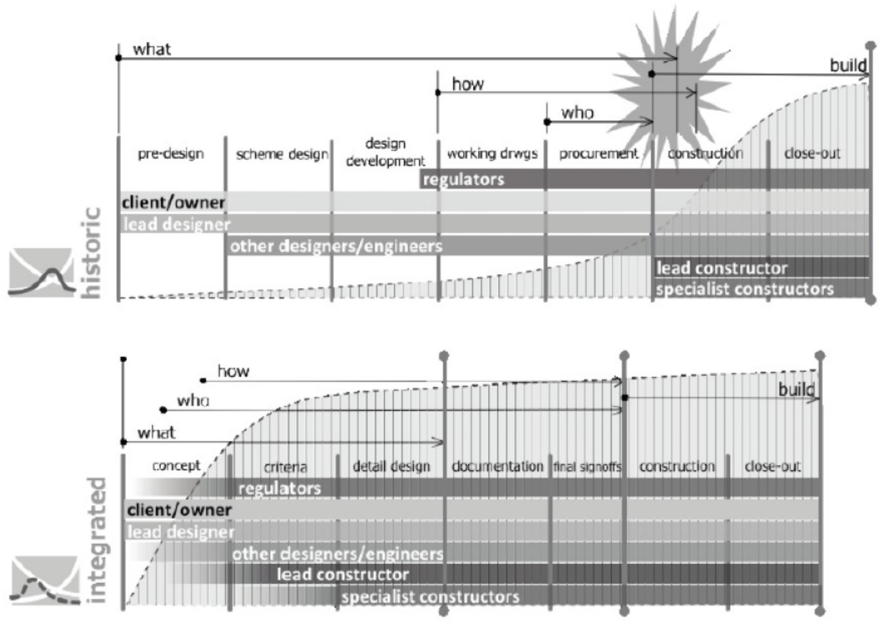


Source: Brennan, 2011

Figure 1: Comparison between Traditional and Integrated Project Delivery

In Figure 1, the MacLeamy's curve shows a reverse relationship between design cost changes and ability that affect the project results (cost and function) over the length of project delivery. The thin line represents the point of "good idea cut-off" along the project timeline. As the project progresses, the ability to implement a "good idea" to improve the design, correction error, or other increases the value created to become limited, while at the same time the cost of design changes is represented on the dotted line. The thick line represents design activities for the IPD process compared to design activities to the traditional project delivery method that is represented by thick dash lines. With the imposition of collaborative knowledge and the coordination of the IPD process that replaces the left curve in the IPD design, it keeps all the design activities on the "good idea cut-off" line and reduces the impact of increased costs and changes to the project delivery duration. Conceptually, the owner is able to reduce costs and increase the quality of a design if compared with traditional project delivery. The advantages of MacLeamy's curve are specifically for project owners who are complex and innovative with fast-track requirements, or for owners who have not clearly defined a program and/or its terms. With the introduction of a builder to the conceptual phase of an early design, the contractor can collaborate with the designer to adopt efficient methods (Brennan, 2011).

According to Mossman et al. (2010), as cited by Sun (2013), they stated that the IPD and the Lean Construction were assumed to be the same. It can be proven with comparisons between the lean construction and IPD being the same, as shown in Figure 2.



Source: Sun (2013)

Figure 2: Comparisons between Histories and *Integrated Project Delivery*

Figure 2 shows that there are two comparisons between the design-bid-build process (top) and the integrated delivery process (below). In the design-bid-build process, team members do not come until it is a substantially full design. The vertically sliced background represents the range of the whole team who can understand what the clients want and how the project will deliver it. In contrast, in an integrated design and delivery process, team members and teams immediately start. They build an understanding of what clients need, how clients are satisfied with the planners, and how they are able to develop effective cost production processes throughout the design.

3. **Methodology**

After the concept of an integrated project delivery is made based on literature, simulations are then conducted on the model. A quantitative method is used for the simulation based on System Dynamics (SD), because to analyze and design an IPD model of a complex high-rise building, it needs a powerful methodology and modeling techniques of a model simulation with computer aid. The model also needs to describe interdependence between variables, the mutual interactions between variables, the existence of information feedback between designs of building variables, and the existence of a causal loop in building an IPD model. An IPD dynamics model can help decision makers to understand the reasons of system behavior and know the probability that occurs in a building development in the future appropriate with the policy of high-rise building development.

According to Radzicki and Taylor (1997), SD is a powerful methodology with modeling simulation techniques that use computer assistance for constructing, understanding, and discussing problems for complex issues or themes. According to the System Dynamics Society (2014), SD is one approach that uses a computer to analyze and help design policies. Applying it in SD issues can result in a dynamic ecological, economic, managerial, or complex social system; literally any dynamical system is characterized by interdependence, mutual interactions, information feedback, and circular causality.

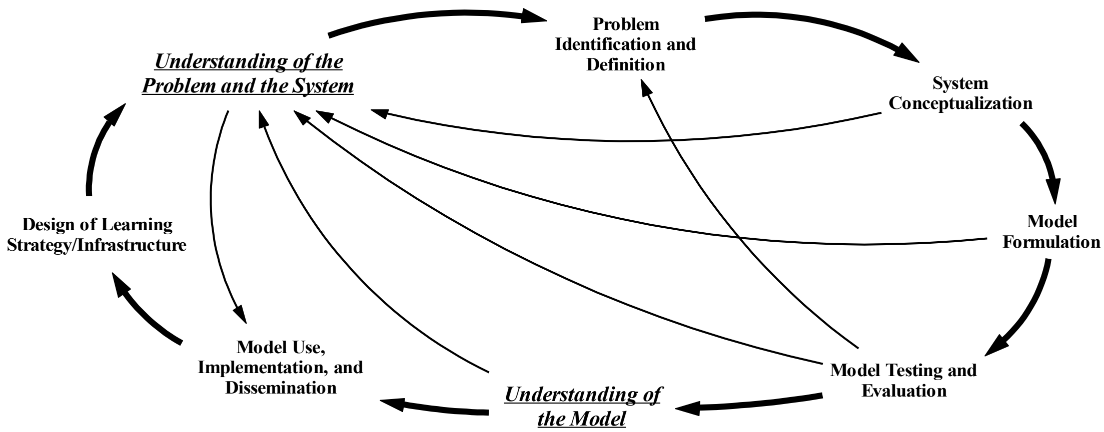
According to the CD4 System Dynamics Group, based on the principles of SD, dynamic models are based on viewpoints of business systems that have feedback, as shown in a closed boundary. For example, it embodies all the relevant main variables that have a relationship with the problems that will be investigated. In a dynamic model, the main key is able to represent it as a level variable and rate variable in the form of inflow and outflow.

The SD modeling process, as shown in Table 3, describes the comparisons of a framework that are used based on the literature, such as there is a seven-stage framework as modified from Richardson and Pugh (1981, pp. 16-17), as cited by Martinez-Moyano and Richardson (2013).

Table 3: The Process of System Dynamics Approach Modeling – the Stages of a System Dynamics Modeling Process

Randers (1980, p. 119)	**Richardson and Pugh (1981, p. 16)**	**Sterman (2000, p. 86)**	**Martinez-Moyano and Richardson (2013, p. 108)**
Conceptualization	Identification and Define Problems	Problem Articulation	Problems Identification and Definition
	System Conceptualization	Formulation of the Dynamics Hypotheses	System Conceptualization
Formulation	Model Formulation	Formulation of the Simulation Model	Model Formulation
Testing	Analysis of Model Behavior	Testing	Model Testing and Evaluation
	Evaluasi Model	Design and Policy Evaluation	
Implementation	Policy Analysis		Model Use, Implementation, and Dissemination
	Use or Model Implementation		
			Design of Learning Strategy / Infrastructure

According to Martinez-Moyano and Richardson (2013), the SD modeling approach in Figure 3 consists of two characteristics: (1) the modeling of SD is described as circulation, an iterative process; and (2) the modeling of SD explicitly represents a key product from an integral part of a process (in Figure 3, it is shown with italics and underlined). That means that there is an understanding of the model as well as an understanding of the problem and system. In a typical SD study, "The model is an understanding until to the end, and ends on the understanding" ((Richardson & Pugh, 1981, p. 16). Every SD modeling effort should have purposes as goals to better understand the problems and systems contained therein.



Source: Martinez-Moyano and Richardson (2013)

Figure 3: Process of System Dynamics Modeling (adopted from Martinez-Moyano and Richardson, 2013, Fg. 2, p. 108)

Thus, the methodology of a system dynamics modeling for a high-rise building is divided into three stages, namely: (1) the input of SD modeling; (2) the process of SD modeling; and (3) the output of SD modeling. The input of SD modeling consists of identification stages and problem definition until it gets to the IPD variables, then the system conceptualization that is obtained from interviews / focus groups, and then finding the IPD model. The System Dynamics modeling process is a model formulation, testing and model evaluation, use, implementation, model dissemination, and design and infrastructure / learning strategy design. The output of system dynamics modeling is IPD system dynamics modeling.

4. Integrated Project Delivery System Dynamics

To get the IPD SD modeling, in accordance with SD modeling, the first step done is to understand the problem and the system, then identify and define problems, make the conceptualization of the system, devise the model formulation, test and evaluate the models, examine the models of understanding, do implementation and dissemination, and later design the learning strategies / infrastructure. In this chapter, sub-sections will be performed in the following stages.

4.1 Understanding of the Problem and the System

As has been outlined in the introduction sub-section, an issue raised in this research is the existence of a gap between project deliveries with the design process, especially in the IPD construction. In traditional projects, it is revealed that the biggest design mistakes are in the construction document phase, but with IPD, design error results can be known from the design criteria and detailed development, as depicted in Figure 1 and Figure 2.

4.2 Problem Identification and Definition

With the gap between the traditional delivery project and IPD, then the dynamics hypothesis is if an IPD method is used, then the building construction design will be detected more quickly at the time of development. This is illustrated in Figure 4.

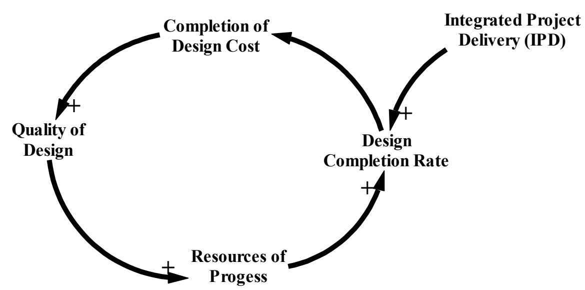


Figure 4: Hypothesis Dynamics

4.3 System Conceptualization

This is the basic dynamics hypothesis. The IPD based on design-bid-build is described in Figure 5.

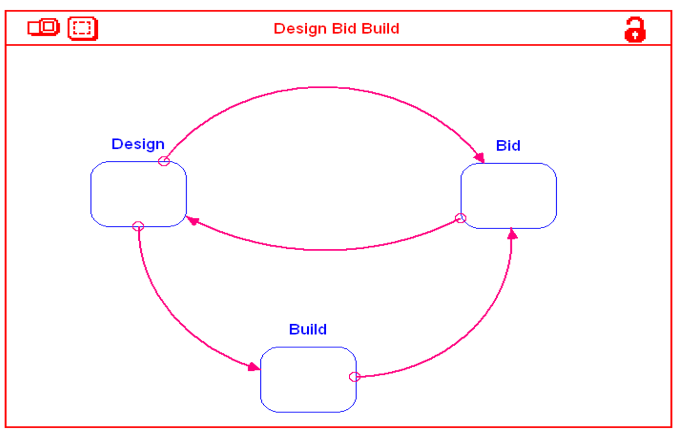


Figure 5: Causal Loop Diagram

4.4 Model Formulation

The model formulation of this paper is described in Figure 6.

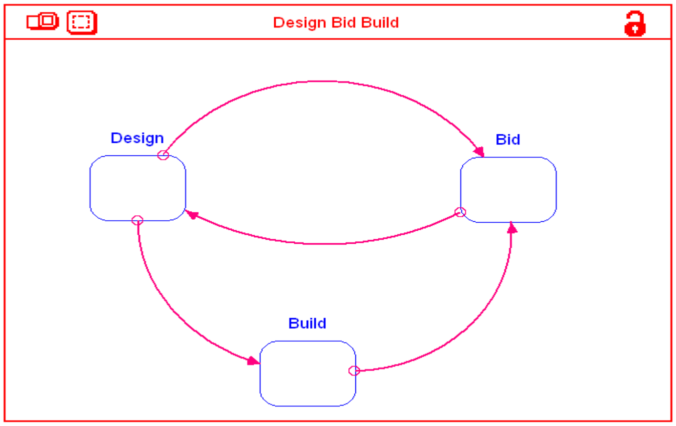


Figure 6: Model Formulation

4.1.1 Process of Design Dynamics

The design dynamics process can be seen in Figure 7.

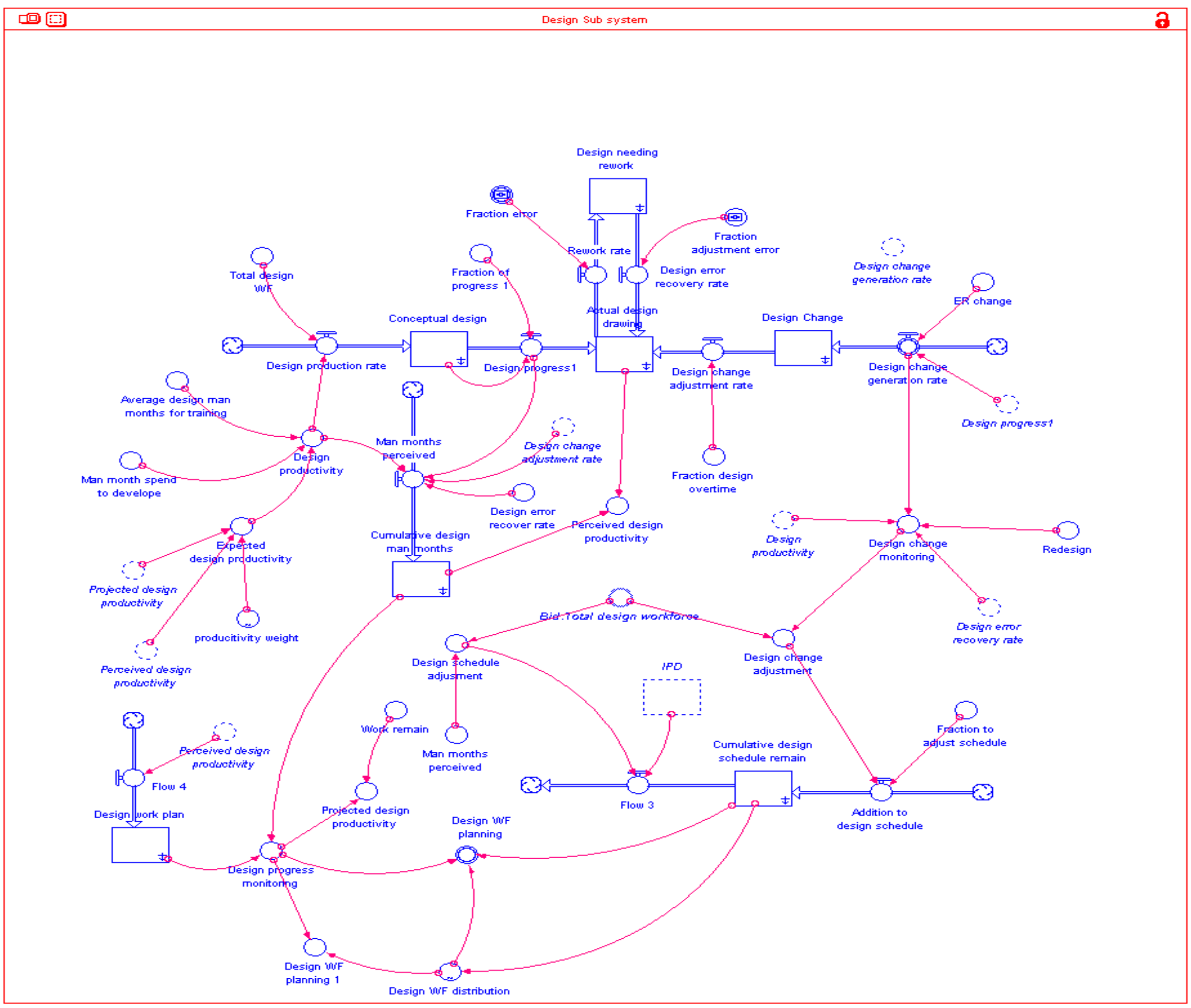


Figure 7: Design Dynamics Process

In the design dynamics process, the critical element is the product design. The product design, which is measured with the working drawing terminology, is assumed to change at a rate that depends on the total design workforce and design productivity. The design production is divided into the conceptual design and details. Details are added with more details, which leads to a completed design after considering errors and making adjustments. The monitoring design process is done by calculating the 'man-months effort remaining' to complete the work, in which there are differences from the 'design work plan' to 'cumulative design man-months'. A measurement of man-months remaining is used to plan the workforce for the design, in order to keep the design process on time.

In this design dynamics process, the effects of the IP dynamics model can influence the remaining cumulative design schedule.

4.1.2 Process of Bidding Dynamics

The Process of Bidding Dynamics can be seen in Figures 8, 9, 10, and 11. The Bidding Dynamics Process includes manpower, materials, and equipment. An important element of manpower in D/B construction is to compare the design and workers that are involved in construction. They need skills, especially related with new manpower and experiences. New manpower is transformed into experienced manpower after training, with an average of 3 months to design and 1 month to build. New manpower and experienced manpower represents the total manpower, which is adjusted as manpower planning.

The material management sub-system starts from the goods ordered stage, storage, inspection, and then it is taken to the field to be used or discarded as waste. The kind of material that is kept in storage depends on the material usage requested and the requested inventory rate. Material adjustments are made based on design information, financial information, and material adjustments in the field. Sometimes, material requests are delayed. The delay in material is caused by long production, transportation, and inspections. The material is classified into productive material and waste material. The effectiveness of material usage depends on how to control the unproductive material. The material used is assumed to be based on the average desired material usage. Then it is based on the construction work rate and ratio of material usage. Afterwards, it is based on the construction work and ratio of material usage per construction unit.

In this bidding dynamics process, the influence of the IPD dynamics model can influence the experience design workforce, experience construction workforce, material in the field, and equipment in the field.

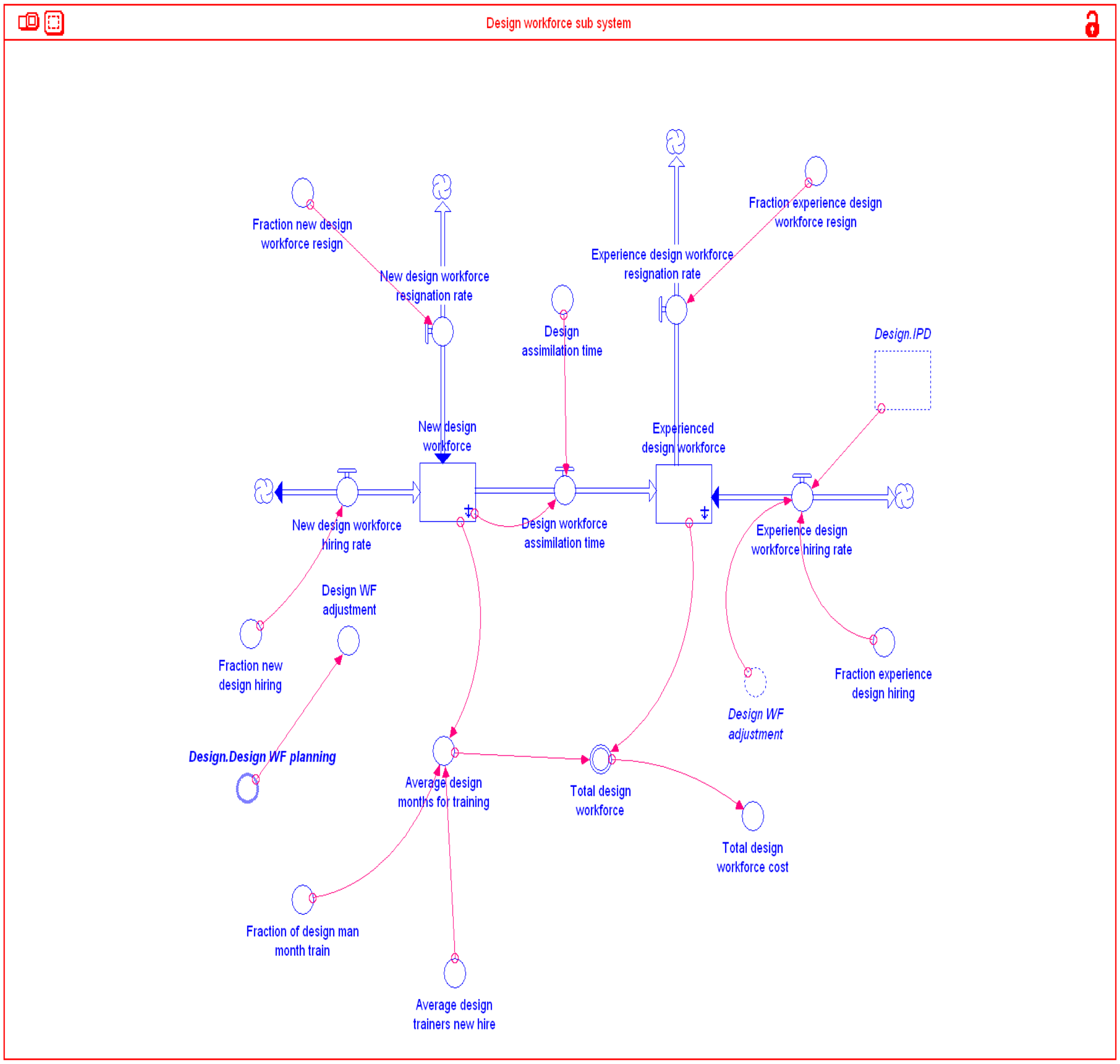


Figure 8: Bidding Dynamics Process

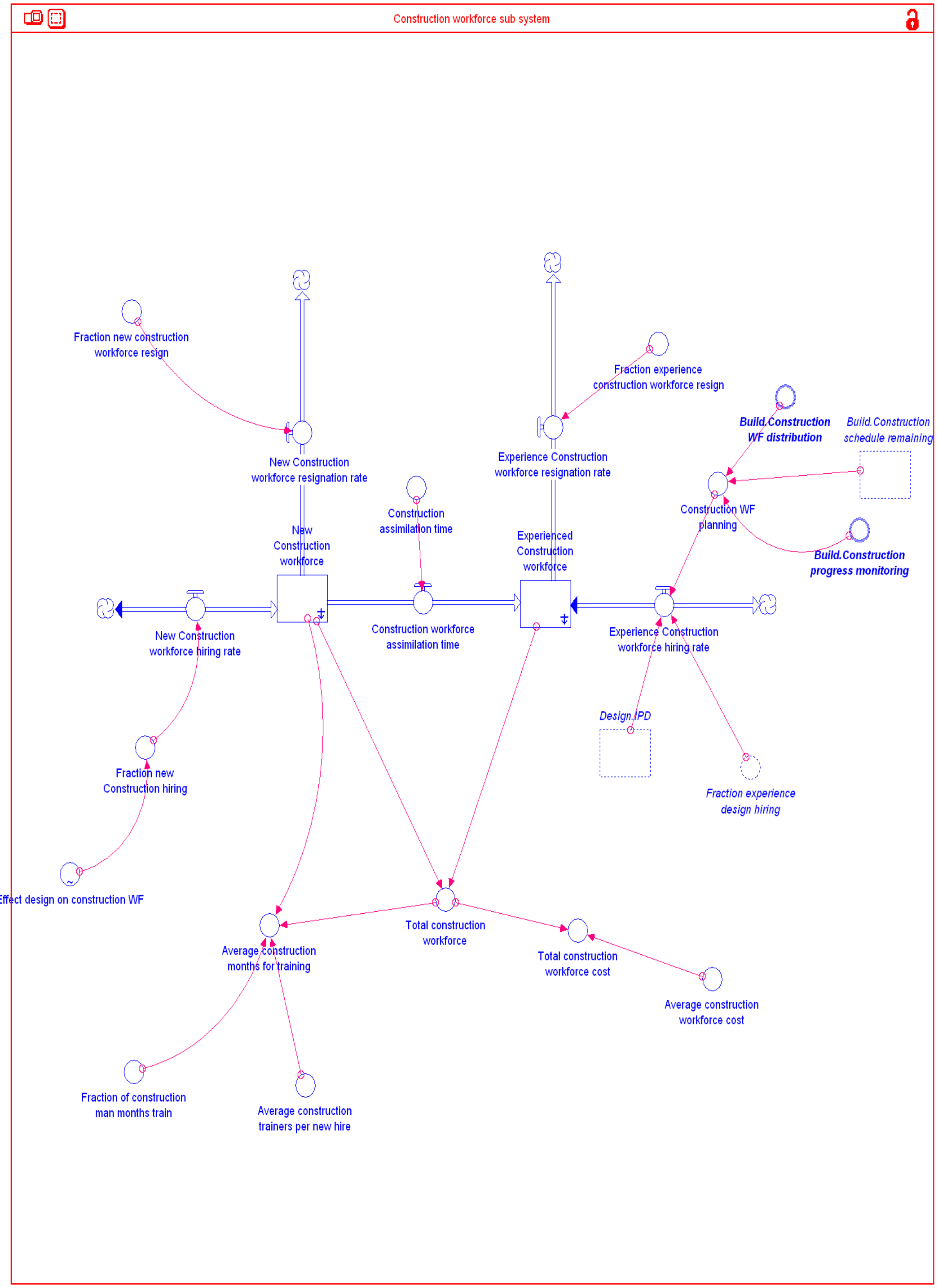


Figure 9: Bidding Dynamics Process (1)

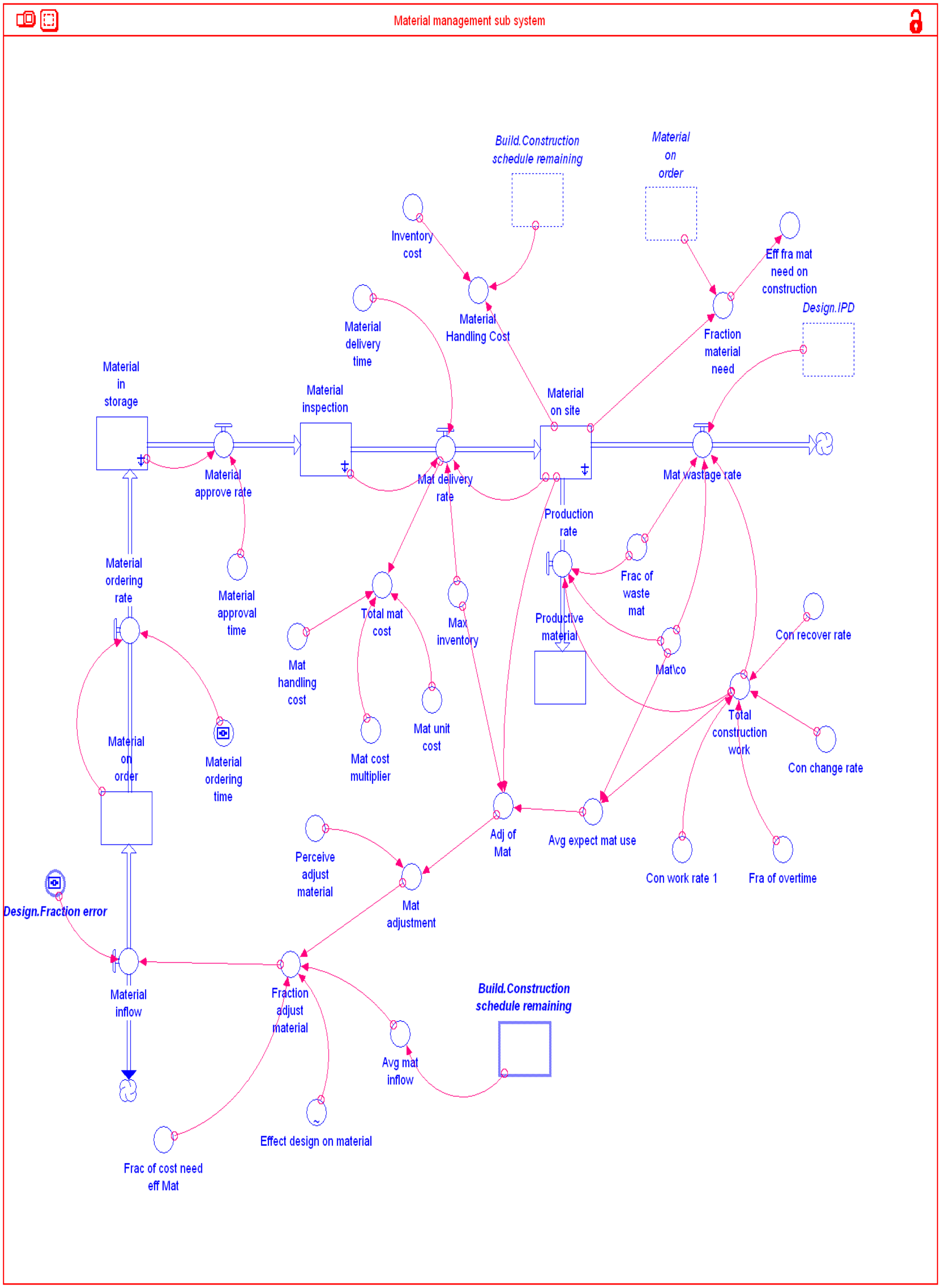


Figure 10: Bidding Dynamics Process (2)

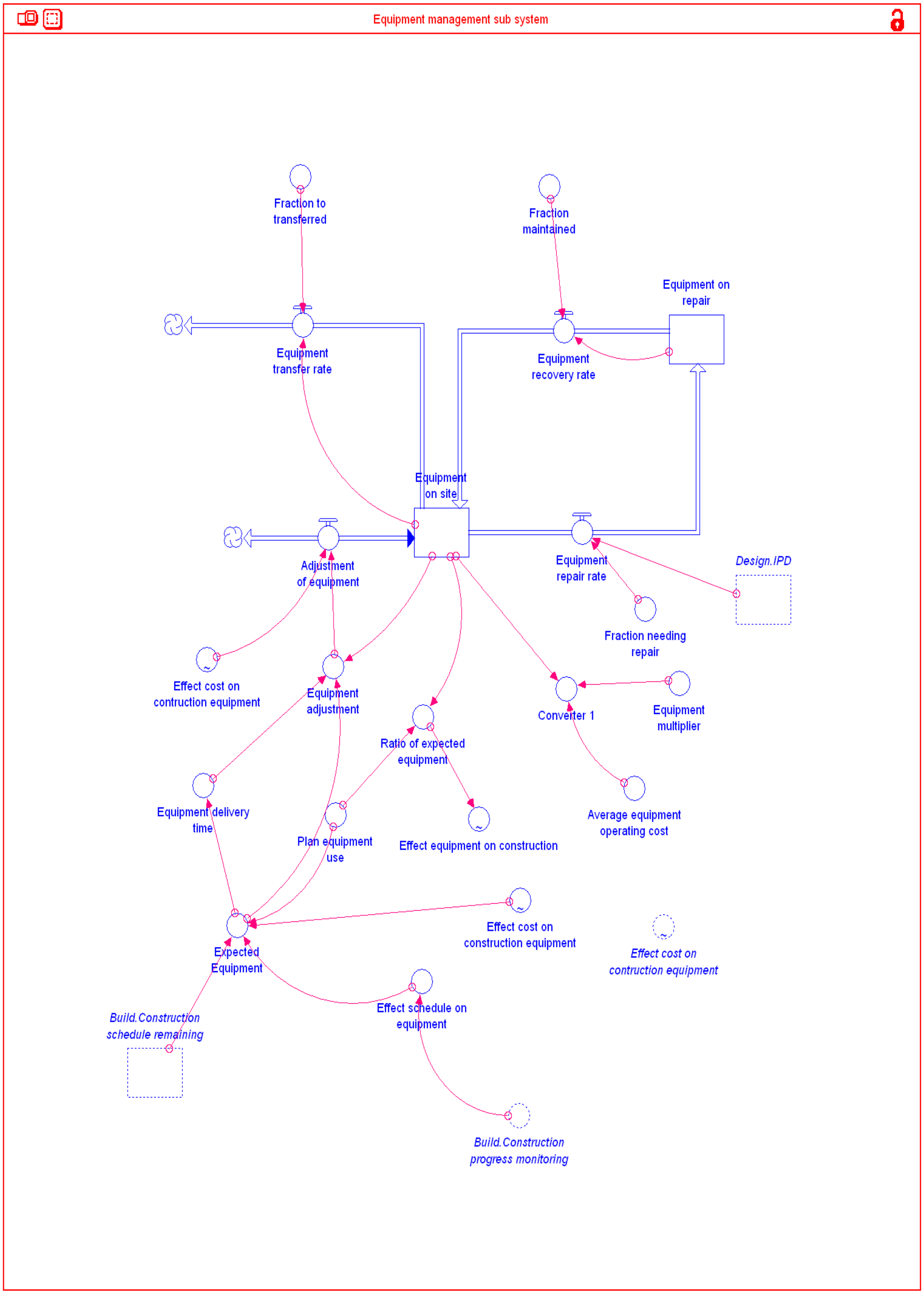

Equipment management sub system
Fraction to transferred
Fraction maintained
Equipment on repair
Equipment transfer rate
Equipment recovery rate
Equipment on site
Adjustment of equipment
Equipment repair rate
Design.IPD
Fraction needing repair
Effect cost on contruction equipment
Equipment adjustment
Converter 1
Equipment multiplier
Ratio of expected equipment
Equipment delivery time
Plan equipment use
Effect equipment on construction
Average equipment operating cost
Effect cost on construction equipment
Effect cost on contruction equipment
Expected Equipment
Effect schedule on equipment
Build.Construction schedule remaining
Build.Construction progress monitoring

Figure 11: Bidding Dynamics Process (3)

4.1.3 Process of Building Dynamics

The building dynamics modeling is illustrated in Figure 11. The building dynamics process for a D/B construction project, which is an advanced process from the design, bidding, and building, starts with the design information, financial information of the bid, material, and equipment in the field. Contractors start planning manpower based on schedule constraints. Construction manpower has to be planned in order to be suitable with the amount of needed manpower every month according to the construction monitoring process that is presented with the man-months remaining until the project is finished, the construction schedule remaining, and the construction manpower distribution.

The construction monitoring process is a variable that controls the project progress until it is complete, as seen in the overall schedule. The total man-months cumulatively spent at a project are the 'cumulative construction man-months'. The cumulative man-months are based on the construction man-months rate. The construction man-months rate is calculated as man-months per month, the amount of 'weight on construction progress', and 'construction change rate'.

The construction progress weight is the distribution from all of the construction work into 3 parts: prepared works including sub-structure activities (foundation, dried, cut/fill), main activities including super-structure (flooring, columns, walls), and finishing activities including utilities (entrances, paving blocks, fences, car ports, septic tanks). The scope of work compares the whole construction progress from sub-structures to utilities. The construction progress in the sub-structure is calculated as the total construction manpower times the construction productivity and fraction of construction.

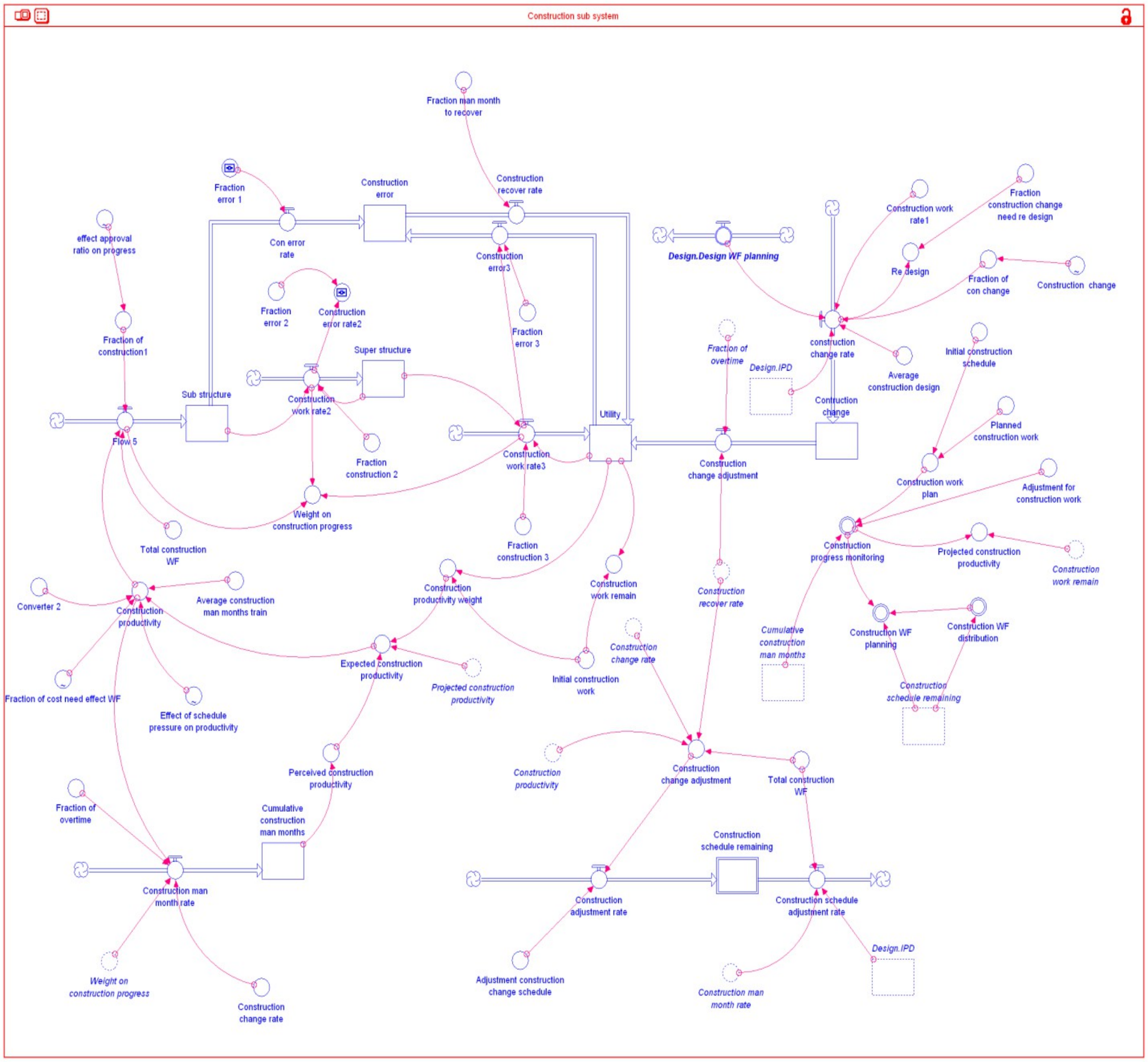


Figure 11: Building Dynamics Process

In this building dynamics process, the IPD dynamics modeling can influence construction changes and construction schedule adjustment rates.

5. **Results of IPD System Dynamics**

The results of the IPD system dynamics are illustrated in Figure 12 and Table 4.

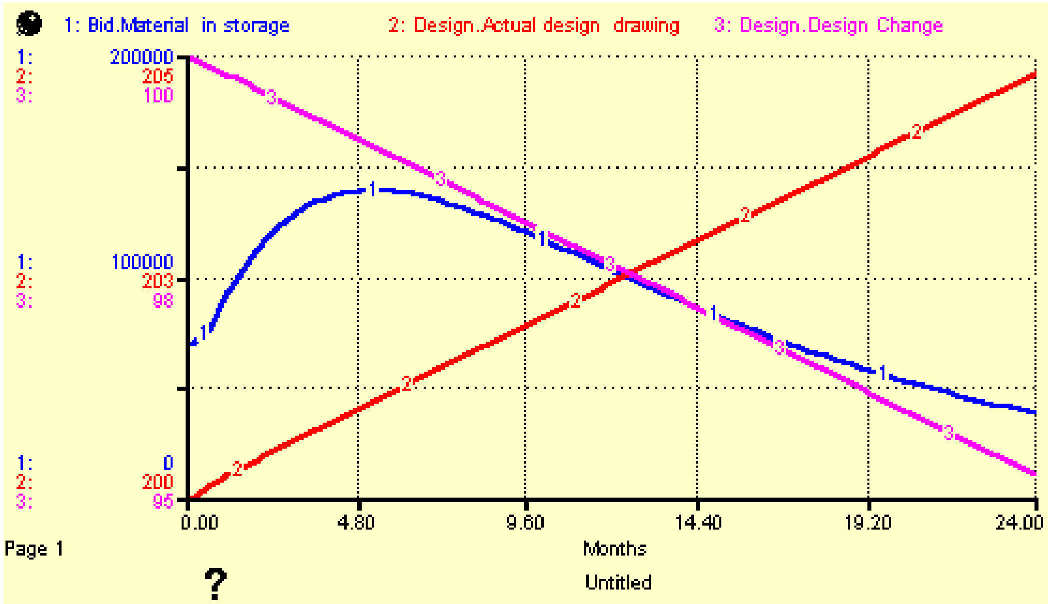


Figure 12: Results of the IPD System Dynamics Modeling Based on the Design-Bid-Build Process

Figure 12 shows that the IPD modeling and material in storage can be more efficient with a design change over time with the design change and bidding material will be decreased and the amount of actual drawing will be increased. The value can be seen in Table 4.

Table 4: Results of IPD Modeling in a Design-Bid-Build Based System Dynamics

4:48 AM 12/11/2014 Table 4 (Untitled Table)

Months	Bid.Material in storage	Design.Actual design drawing	Design.Design Change
.00	70,000.00	200.00	100.00
1.00	92,630.76	200.25	99.82
2.00	115,905.92	200.46	99.62
3.00	130,026.56	200.67	99.42
4.00	137,411.29	200.87	99.23
5.00	139,899.24	201.07	99.03
6.00	138,884.42	201.27	98.83
7.00	135,419.29	201.47	98.63
8.00	130,294.65	201.66	98.43
9.00	124,101.06	201.86	98.23
10.00	117,276.20	202.06	98.03
11.00	110,141.22	202.26	97.83
12.00	102,928.78	202.46	97.64
13.00	95,804.48	202.66	97.44
14.00	88,883.39	202.85	97.24
15.00	82,242.62	203.05	97.04
16.00	75,931.02	203.25	96.84
17.00	69,976.51	203.45	96.64
18.00	64,391.73	203.65	96.44
19.00	59,178.25	203.84	96.24
20.00	54,329.86	204.04	96.04
21.00	49,834.93	204.24	95.84
22.00	45,678.26	204.43	95.64
23.00	41,842.45	204.63	95.44
Final	38,308.86	204.83	95.24

Untitled Table: (1)

Table 4 reveals that *design change* will decrease over time, from the initial month (0 month), with as many as 100 drawings, and in the 24th month design changes will be 95.24 drawings. In other words, *actual design drawing* will increase. In the initial month (0 month), there are 200 drawings. The result of the 24th month shows that the actual designs will increase to be 204.83 drawings. Likewise, for the storage material in the initial month (0 month), there are 70,000, and in the 24th month it will decrease to be 38,309. It will happen because an integrated project delivery method is used, so there will be more material in the initial month, but overtime until the 24th month, the material in storage will decrease.

6. Conclusion

The comparisons between traditional project delivery and integrated project delivery are significant. Based on the simulation that uses a system dynamics method, this paper found that in the initial month (0 month) there are as many as 100 drawings and in the 24th month design changes will be 95.24 drawings. In other words, the *actual design drawing* will increase. In the initial month (0 month), there are 200 drawings. By the 24th month, the actual design will increase to 204.83 drawings. Likewise, for the storage material in the initial month (0 month), there are 70,000, and in the 24th month it will decrease to be 38,309. It will occur because an integrated project delivery method is used, so there will be more material in the initial month, but by over time until the 24th month, the material in storage will decrease.

So, using system dynamics modeling is very useful to find comparisons. Also, it helps decision makers to devise a policy about what material can be stored in the design phase.

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