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Dynamic Model-Based Risk Manageability in the Modular Construction of High-Rise Residential Buildings to Improve Project time Performance

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Abstract Modular construction has been applied in low-rise buildings over the past three decades, but its application in high-rise buildings is still less than 1% worldwide. Thus, the need for high-rise residential buildings applying modular construction in Indonesia becomes very important. The unavailability of design guidelines disrupts the life cycle of modular construction projects**.** This study aims to analyze the factors which affect the risk manageability of on-time performance in modular construction residential high-rise building projects, then analyze risk manageability modeling using dynamic systems for on-time performance, then analyze the results of the simulations and modeling scenarios of risk manageability using dynamic systems to improve time performance. The research variables were obtained based on the results of a literature study seeking the opinions of experts qualified in this field. The methods used were cause flow diagram models which were then developed into stock-flow diagrams with input formulation and validation, thereafter simulations and scenarios were carried out and reviewed for time overrun. The research results showed 15 factors of risk manageability that affect on-time performance in the modular construction of residential high-rise buildings. Without any mitigation of the risks, the highest time overrun of 12.79 days was incurred due to drawing approval, then design standardization of 12.79 days, and supply chain 12.78 days. The results of scenario #3 showed an optimistic alternative with a 53.55% improvement whereby project delays decreased from 126 days/25.25% to 59.17 days/11.8%, delivering a time overrun of <20% which could be implemented in the construction process.

Keywords Modular Construction, Residential High-Rise Building, Risk Manageability, Time Performance

1. Introduction

The world's cities have experienced faster growth in the number of people compared to the number of homes over the past five years so a portion of the population has exceeded the housing availability. It is estimated that by 2030 nearly 60% of the world's population will be urbanized, by 2050 it is estimated that over 80% of the world's population will live in cities when the world's population reaches 9 billion [1]. To achieve the goal of housing availability, the Special Capital Region of Jakarta (DKI) Jakarta encourages the implementation of the "Compact City" concept and the construction of residential high-rise buildings through the 2012 Regional Spatial Plan [2]. Jakarta's very high population density of 14,464 people per km², above the metro area standard of 4,383 people per km², means that the population has exceeded the number of available Occupancies [3]. Residential high-rise building construction is a growing business in Indonesia [4], where sales increased by 20.15% Y-o-Y in the first half of 2018-International Construction Costs published in the International Construction Cost (ICC) Comparison 2020 as the impact of the COVID-19 pandemic continues. Many previous studies have discussed the critical success factors of modular high-rise building construction but no research discusses time performance for modular construction in residential high-rise buildings using dynamic system methods-based risk manageability. This research is very much needed at this time as modular construction is considered able to answer the problems of increasing costs due to high labor costs and the construction process [5]. Although modular construction has been widely applied in low-rise buildings over the last three decades, its application in high-rise buildings is still limited (less than 1%) globally [6]. Thus, the need for residential high-rise buildings with modular construction in Indonesia becomes very important. In previous studies, many have investigated the time, cost, and quality performance of projects using the VE, ABC, BIM 5D, and LCCA methods in the bridge, dam, railroad, and highway projects. For the time method in previous research, many use the CPM, PERT, M-PERT, and BIM 4D time methods. However, no research measures project time performance using the dynamic system method in high-rise building projects, so this research is renewable research. The dependency between parties in modular construction is more than in conventional construction. The unavailability of design guidelines will hinder the implementation of Modular construction [7]. The current application of modular construction for high-rise buildings is very limited due to the lack of robust structural systems and joining techniques to ensure the structural integrity and overall stability and robustness of fully modular buildings [7]. Not all of the resources needed to implement a modular system are available. These resources consist of limited land at the project site, the skill of workers, available equipment, and existing technology. There is a high risk of project time overrun due to the implementation of the modular system which requires the interaction of various activities. Therefore, it is necessary to research the risk manageability of modular construction in High-Rise buildings. On-site work has a direct effect on the efficiency of module installation, careful coordination is essential, especially in terms of pre-manufactured components and accuracy on site[8]. The structural behavior of modular assembly differs from column/frame structures due to the many interconnections between the modules. This study aims to develop scenarios to improve project time performance based on risk manageability by modeling and simulating project time performance. 41 Indicators were taken from the literature for evaluation. Risk manageability and control need to be applied so that project targets are within the established corridor. The definition of risk manageability states the ability to reduce the possibility of the risk and any negative impact [9]. Manageability is defined as the difficulty level of the risk owner to manage the event or impact of risk [10]. The advantage of a dynamic system is a feedback structure that is interconnected and leads to balance [11]. The analysis performed on systems that have a feedback relationship cannot be done partially. Model validation is the main consideration in assessing whether the model created represents the actual situation. Model testing can be done by testing the structure and behavior of the model.

2. Methods

The questionnaire consists of questions about factors that affect time performance in the case study of the modular construction project of a residential high-rise building. The object was TAMANSARI URBANO Bekasi apartment. That's where 41 variables were adopted from the results of the literature study and the expert's experience. Primary data collection carried out in this study was done in several stages; the first stage was the construction validation stage as follows: before the questionnaires were distributed to respondents, expert/supervisor validation was first carried out so that the distributed questionnaires could be understood by the respondents and the data obtained is in line with the expected research objectives. At this stage, reductions or additions to existing sub-variables were also carried out based on the perceptions of these experts. The selected experts were at least 3 practitioners competent in the field of Modular Construction High Rise Buildings and risk management with 5-10 years of experience. The second stage was the Pilot Survey: at this stage, the construction validation questionnaire was distributed to 5 prospective respondents to determine the respondent's level of understanding of the questions or statements in the questionnaire and the level of difficulty of the respondents in answering the questionnaire. At this stage, improvements were made to the editorial questions or statements in the questionnaire so that they were easier to be understood by prospective respondents. The third stage of data collection was done by distributing questionnaires to the sample respondents. Sampling was carried out among the project Respondents consisting of 100 individuals who were involved in similar projects and included: Owners, planning consultants, Project Coordinators, Project Managers, Quantity Surveyor Managers, Quantity Surveyors, and Site Engineering Managers with more than 5 years of experience and having a Bachelor degree education. In the fourth stage, expert validation was again performed on the results of the data analysis obtained from the fourth stage. This was intended to ensure the results of the analysis that had been carried out. After the complete data had been collected, then tabulation was made based on the Likert scale in the questionnaire. The simulation process uses the SPSS application for testing Validity, Reliability, Normality, Kolmogorov-Smirnov, Durbin-Watson, Linear Regression with T-test, and F-test so that the equation of the effect of the independent variable on the dependent variable can be identified. 100 questionnaires were sent to the respondents, including project managers, designers, directors, site managers, and site operations managers. Returns from the respondents were 65%, with 35% of non-returns. According to the calculation of minimum respondents, from a total of 41 respondents, the minimum number of respondents required was 37 respondents, and the number of respondents who returned the questionnaire was 65 respondents which met the requirements to analyze the data [12]. The data tabulation and data input were carried out on SPSS, and then the data was tested for reliability and checked for the Cronbach alpha value > 0.6, if the value met the requirements, then the validity test continued. If it did not meet the requirements, then new data was added. As an invalidity test, a check was carried out, namely r count > r table if it met the requirements then normality and linearity tests were carried out, namely descriptive statistics and KOLMOGROV SMIRNOV (KS), if the K-S data was normal > 0.05, then we continued to with the linear regression analysis but if it did not meet the requirements then it was returned for the input of new data. The linear regression analysis tests consisted of the Durbin Watson autocorrelation test, multicollinearity test, namely tolerance & FIV, then linear regression, ANOVA and sig, T-Test and F Test, then checks on the sig Count < 0.05, r count > t table and f count > f table. If the results met the requirements, then we continued with the ranking of the influential sub-factors and then proceeded with a case study. The following flow chart of the research methodology carried out in the research can be seen in Figure 1.

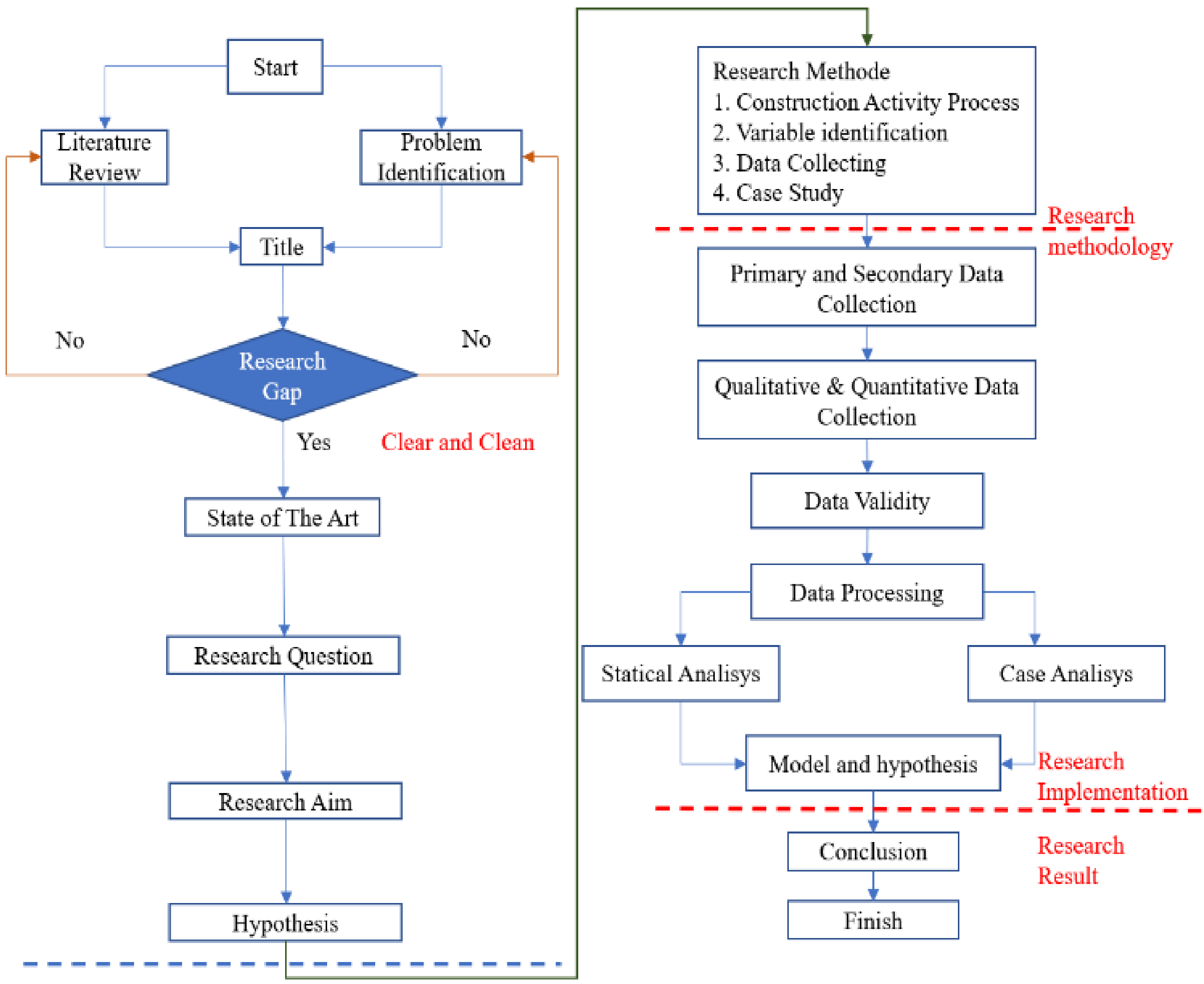

Figure 1. Flowchart of research methodology

Table 1. Data of Case Study

Data	Explanation
System	Concrete PPVC Prefabricated Prefinished Volumetric Construction
Module Weight	20-35 Tones
Residential Type	Apartment, 27 Conventional 1-4 Floors, 5-27 PPVC Concrete Floors
Large	9460 m^2
Project Investment Value	IDR 705 billion
Number of Modules	1200 unit

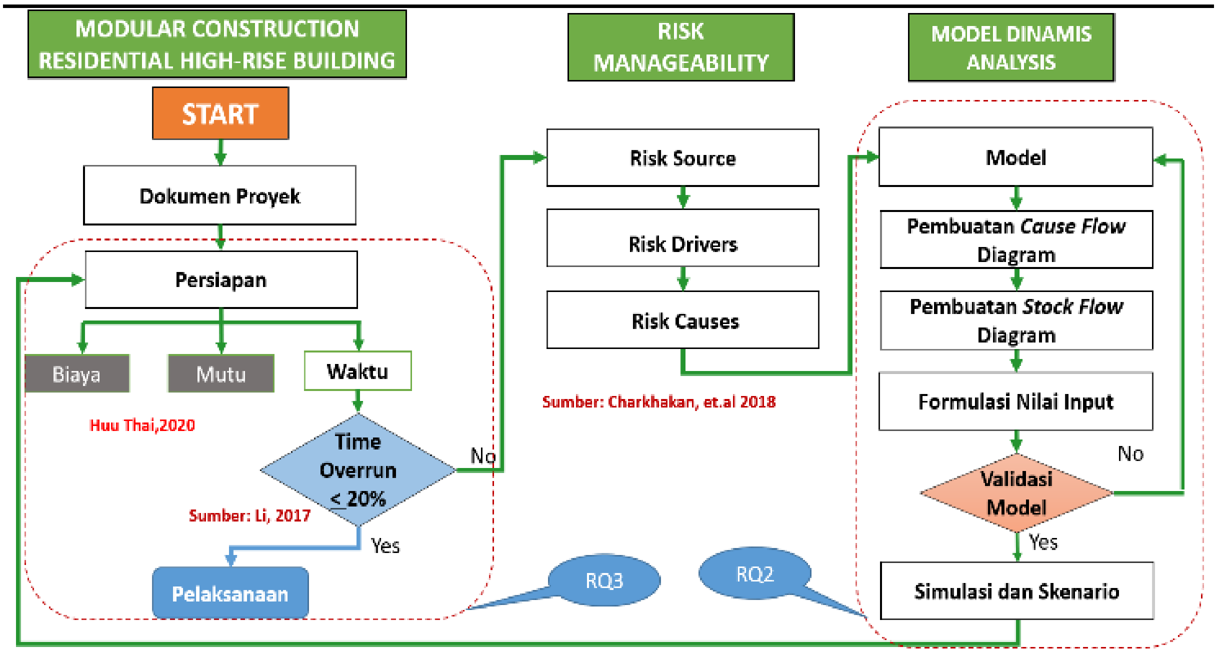

Figure 2. Implementation diagram

We continued the analysis of the project documents by analyzing the project schedule. The allowed time overrun on the project was <20%. For this object, the time overrun was > 20%, then analysis was carried out on risk manageability [13]. There are three stages of risk manageability analysis, namely risk source analysis, risk drivers, and risk causes [9], which can be seen in figure 2. From the results of the risk manageability analysis, a dynamic model analysis was carried out. In understanding a problem that involves a complex and dynamic system, a solution method is needed that can answer the question of how the behavior pattern of the system emerges from its structure.

An understanding of the system can be obtained by looking at the interrelated relationships between the components of the system as a whole. Many variables affect the risk manageability of modular residential high-rise building construction, so it requires an analysis that must be carried out with a comprehensive approach. The use of the system dynamics model in the analysis process to formulate a risk manageability analysis policy is carried out applying considerations that the system dynamics model is: a. able to simulate various interventions and can generate system behavior due to these interventions; b. allows simulating an intervention whose effects can differ dramatically in the short, medium, and long term (dynamic complexity); c. a behavior that has been experienced and observed (historically), or a behavior that has never been observed (experienced but never observed, or has never been experienced but is most likely to occur); d. able to explain why a certain behavior can occur; and e. does not base the model on historical data alone but can be developed based on the suitability of the model's structure in the real world, so it is suitable for use in a study that suffers from a problem of "weak data validity". Modeling using POWER SIM STUDIO 10, the researcher's started with creating cause flow diagrams, then stock-flow diagrams, formulating input values, model validation then simulations and scenarios. The model validation consisted of 2 test criteria, namely the average comparison test and the amplitude variation comparison test. For the average comparison test, namely E1 =|S-A|/A, where the model was considered valid if E1 <5%, then the second validation using the amplitude variation comparison test, namely E2 = |Ss – Sa|/Sa, where the model was considered valid if E2< 30%. If the validation met the requirements of the 2 criteria, then the time overrun analysis continued on each of the sub-factors that were reviewed over some days. From the reviewed sub-factors, it was found that those sub-factors which contribute to a larger time overrun are therefore necessary to carry out scenarios for improvement. In the first scenario, an intervention was carried out on the drawing approval factor and the coordination of design drawings by increasing the number of experts. The second scenario involves supply chain intervention and delayed supplier payments by increasing the number of experts and the number of material suppliers. In the third scenario, an intervention was added to the large crane sub-factor from the second scenario by increasing the number of large cranes. In the fourth scenario, the intervention was added to the quality standard and certification sub-factor by increasing the number of QC supervisors in scenario three. In the fifth scenario, an intervention was added to the sub-factor drawing approval by increasing the number of BIM training for engineers in scenario four, therefore from the results of the five scenarios, pessimistic, moderate, and optimistic scenarios were analyzed, and from the results of the optimistic scenario, an increase in project performance can be seen, improving the time overrun to become <20%. Then we continued with the next stage, the project implementation stage.

3. Results and Discussion

3.1. Variables Data

In this study, there were 41 variables adapted from the results of the literature study and expert experience, which can be seen in Table 2.

Table 2. Table of Variables from the literature study and expert experience

Variable	Source
Cost savings	[14]
Economic analysis	[15]
larger cranes	[14]
Experience of contractors, designers, and manufacturers	[15] [16]
Modular Acceptance	[17]
Engineering specifications	[17]
Poor client understanding	[15]
Effective collaboration and communication	[18] [19] [17]
Transportation delay	[14]
Material cost	[20]
Labor costs	[20]
Client payment	[21]
Quality standard/certification	[22]
Material availability	[23]
Owner Expectations	[23] [22]
Project manager experience	[24]
Effective scheduling	[24]
Accurate material estimation	[20]
Drawing Approval	[25][26][15]
Design standard	[27]
Supply Chain	[9]
Design Change	[9]
Construction process requirements	[9]
Local Regulations	[27]
Design drawing coordination	[9]
Scope of Work	[28][29]
Delay Payment Supplier	[28][30]
Revenue cash flows	[31]
Project Income	[31]
Net Present Value	[31]
Adequacy of supervision	[32]
Overtime fatigue	[32]
Moral	[32]
Work Intensity	[33]
Overtime	[33]
Workforce	[33]
Activity Definition	[34]
Organizational Planning	[34]
Development Schedule	[34]
Cost Budgeting	[35]
Quality Planning	[35]

3.2. Most Influencing Factors

SPSS analysis of the factors that affect time performance in the case study of a modular construction project for the residential high-rise building at TAMAN SARI URBANO Bekasi apartment was carried out. It was found that the reliability test for the Cronbach alpha value of all data on the independent variables X1 (Modular construction), X2 (Residential High-Rise Building), X3 (Risk Manageability), and X4 (Model dynamic analysis) was > 0.6. Then the validity test was performed to check, namely: r count > r table, that all independent variables X1, X2, X3, and X4 met the requirements where the value of r count is > 0.2058. The calculated data showed that the overall order of influencing factors on-time performance in Modular construction is as follows, as seen in Table 3.

Table 3. Table of 15 Potential Success Factors

Factors	Scale
Drawing Approval	5,45
Supply Chain	5,12
Design Standard	5.02
Design Change	4.57
Local Regulations	4.53
Supplier Delay Payment	4.50
Design Drawing Coordination	4.47
Revenue Cash Flow	4.45
Project Income	4.44
Net Present Value	4.42
Adequacy of Supervision	4.38
Overtime fatigue	4.37
Client Payment	4.36
Experience with contractors, designers, and manufactures	4.36
Effective Scheduling	4.36

3.3. Risk Manageability

Based on the actual duration of this project, the researchers concluded that project delays were influenced by several sensitive variables and that the researchers needed to analyze risk manageability and apply a dynamic thinking approach using dynamic modeling. Table 4 shows the analysis of risk manageability in the internal context.

Table 4. Risk manageability analysis in case studies for Internal Context

Macro Factor	Technical		
Risk Group	Technical project		
Risk Type	Technical Design and Drawing Productivity during construction		
Risk Source	Drawing Approval	Design Standard	Supply Chain
Risk Drivers	Design Change	Construction process requirements	Local Regulation
Cause Risk	Drawing and design coordination	Scope of work	Delayed payment supplier

3.4. System Dynamics

System dynamics simulation is a continuous simulation developed by Jay Forrester of MIT in the 1960s. It focuses on the structure and behavior of a system consisting of interactions between variables and feedback loops [36]. System dynamics is an approach to study the dynamics of the behavior of a system, at the beginning of its development system dynamics was used to analyze and design policies and to assist decision making.

3.4.1. Causal Loop Diagram (CLD)

There are 4 significant variables in the loop diagram that affect the time performance of modular construction including poor client understanding, transportation delays, effective collaboration, and communication, and development schedule, the greater the delay in transportation the greater the time required, and the more collaboration and communication involved then the more time it will take. A greater degree of poor client understanding will result in a long time being required, thereafter if all the signs are positive; the large loop will have a positive loop.

From the CLD that was formulated, it can be seen that each variable is interrelated; the CLD explains the factors that affect the performance of modular residential high-rise building construction time which are interrelated. From the results of the CLD, an SFD can be formed which will later become a model as the basis for designing scenarios.

3.2.2. Stock Flow Diagram (SFD)

Variable system dynamics can be classified into three parts stock or level, second flow or rate, and thirdly auxiliary, which can be seen in Figures 4,5, and 6. Total time overrun was described as stock or level, because there was an accumulation of time overrun from time to time. Those which can incur time overrun are quality planning, cost budgeting, activity definition, organization planning, and development schedule so if the value is in the form of an accumulation over time, it is defined using a level, if the variable adds value to a level, then it is defined as a variable flow. In this study, the flow of time delay in the modular construction so that it added to the total time overrun is referred to as the modular construction time delay rate. The time interval was from October 2017 to May 2019.

3.4.2. Simulation

Validation was carried out using 2 test criteria, namely the average comparison test and the amplitude variation comparison test. The average comparison test where $E = |S - A|/A = (41{,}76 - 42{,}61)/42{,}61 = 1{,}99\%$ with E1 as the average comparison (Mean Comparison), S as the average value of the simulation results, A as the average value of the data. The model was considered valid where E1 = 5%.

The other was the amplitude variation comparison test where: E2 =|Ss-Sa|/Sa = (34.81−37.58)/ (37.58) = 0.07%, with E2 for a ratio of amplitude variations, Ss for model standard deviation, Sa for data standard deviation. The model was considered valid where E2 ≤ 30%. Based on the results of the 2 tests, the base model was declared valid as it was found that: E1 <5% = (1.99% < 5%) and E2 ≤ 30% = (0.07% ≤ 30%), so all the factors, which together influence the residential high rise building project, were able to represent the actual system in its effect on improving project time performance. In Figure 3, From reviewed sub-factors, it can be seen that the drawing approval sub-factor, design standardization factor, and supply chain factor have contributed to the largest time overruns, so scenarios needed to be designed for improvement.

3.4.3. Scenarios

The scenario model aims to develop various alternative possibilities in the future [37] by identifying the drivers that cause a change in other situations. The stages of Scenario Development were to formulate the problem and time frame, identify the main stakeholders, then build a CLD to show the linkages between causal relationships, identify the main uncertainties, then create a forced scenario by placing all the positive outcomes of the main uncertainties in one scenario, and finally examine the correlation between the items of this artificial scenario.

The following are some of the scenarios formulated for improvement applied in this study, which can be seen in Table 5:

Table 5. Scenarios

Scenario	Explanation
Pessimistic Scenario (Figure 1)	Increase the number of experts
Moderate Scenario (Figure 2)	1. Increase the number of experts 2. increase the number of material suppliers 3. increase the number of large cranes
Optimistic scenario (Figure 3)	1. Increase the number of experts 2. increase the number of material suppliers 3. increase the number of large cranes 4. Increase the Number of QC supervisors 5. Increase the number of BIM training for engineers

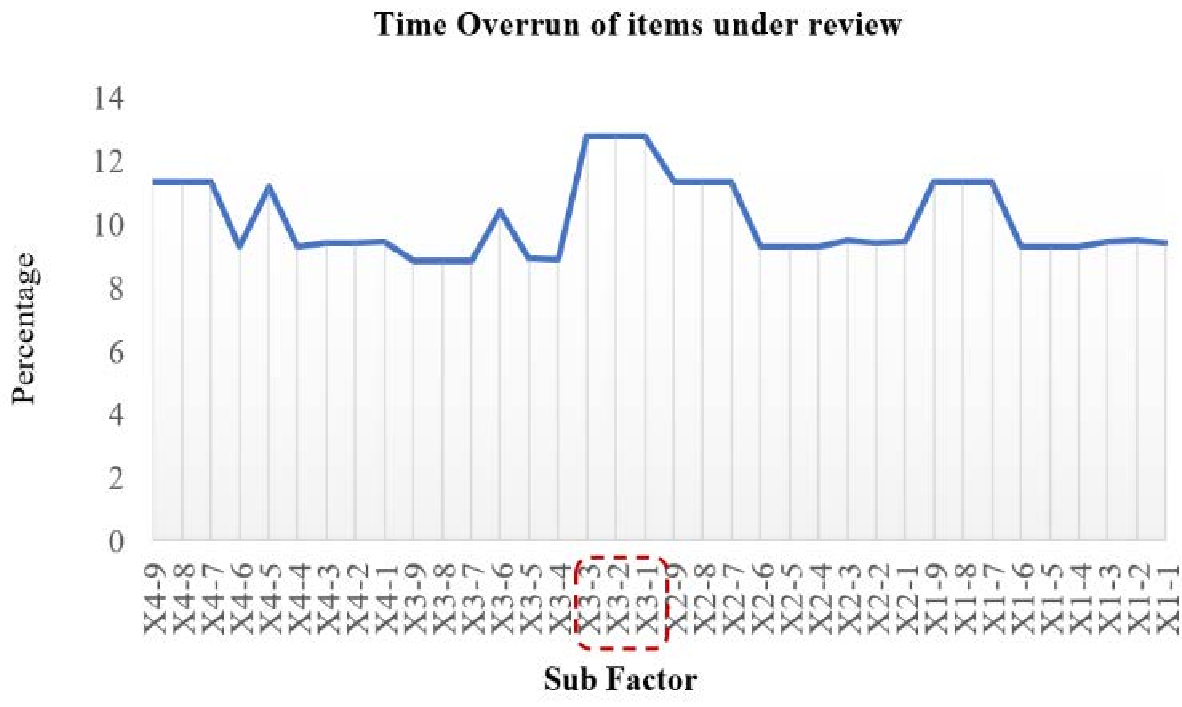

Figure 3. Time overrun of items under review

The Residential High-Rise building project in the case study of the Bekasi urban apartment using the modular construction method, after the various simulations and scenarios had been applied, found that the project delay of 126 days could be minimized by delivering the following scenario results as can be seen at table 6. After studying the simulations and scenarios, the optimistic scenario delivered a decrease in project delay from 126 days to 59 days, or in other words, a time overrun of < 20 % or 11,8%, and therefore the implementation phase could be continued.

Table 6. Scenario Results

Scenario	Results	Total Time overrun (days)
Pessimistic Scenario	10.03%	113
Moderate Scenario	27.73%	92
Optimistic scenario	53.55%	59

3.4.4. Comparison with Previous Research

Previous research [38] showed that among the design risk factors, the most dominant factors can be categorized into six groups: the risk of an inappropriate design team, the risk of the lack of designer responsibility, the risk of the lack of designer experience, the risk of inaccuracies or delays in third party information, the risk of inappropriate design schemes, and the risk of design changes and employer review. This study supports previous research whereby in this study, among the 15 most influential factors are the drawing approval factor, and the risk driver in modular residential high-rise building construction is design changes. These study results can serve as a checklist for contractors when analyzing project design risk factors. This research contributes to the body of knowledge related to risk manageability in modular constructions and enriches research on risk analysis and management.

4. Conclusions

The results of this study show that in answer to the research objectives, the 15 factors which affect the Risk Manageability of on-time performance in the Modular Construction of Residential High-Rise Building projects include: Drawing Approval, Supply Chain, Design Standard, Design Change, and Local Regulations; Supplier Payment Delays, Design Drawing Coordination, Cash Flow Revenues, Project Income, Net Present Value, Adequacy of Supervision, Overtime fatigue, Client payment, Experience of contractors, designers, and Manufactures, and Effective Scheduling.

The results of simulations and scenario modeling of Risk Manageability applying the Dynamic System on the Modular Construction of Residential High-Rise Building Projects without any mitigation of the risks showed a time overrun of 12.79 days with the highest simulation result being drawing approval during the construction period, then design standardization of 12.79 days, and supply chain delays of 12.78 days. The results of scenario #3 showed an optimistic alternative with a 53.55% percentage improvement such that project delays decreased from 126 days / 25.25% to 59.17 days / 11.8%, namely a time overrun of <20%. Therefore, from the Research Results the Hypothesis "Modeling Risk Manageability Using Dynamic Systems in the Modular Construction of Residential High-Rise Building Projects Can Improve Time Performance" has been proven and can be implemented.

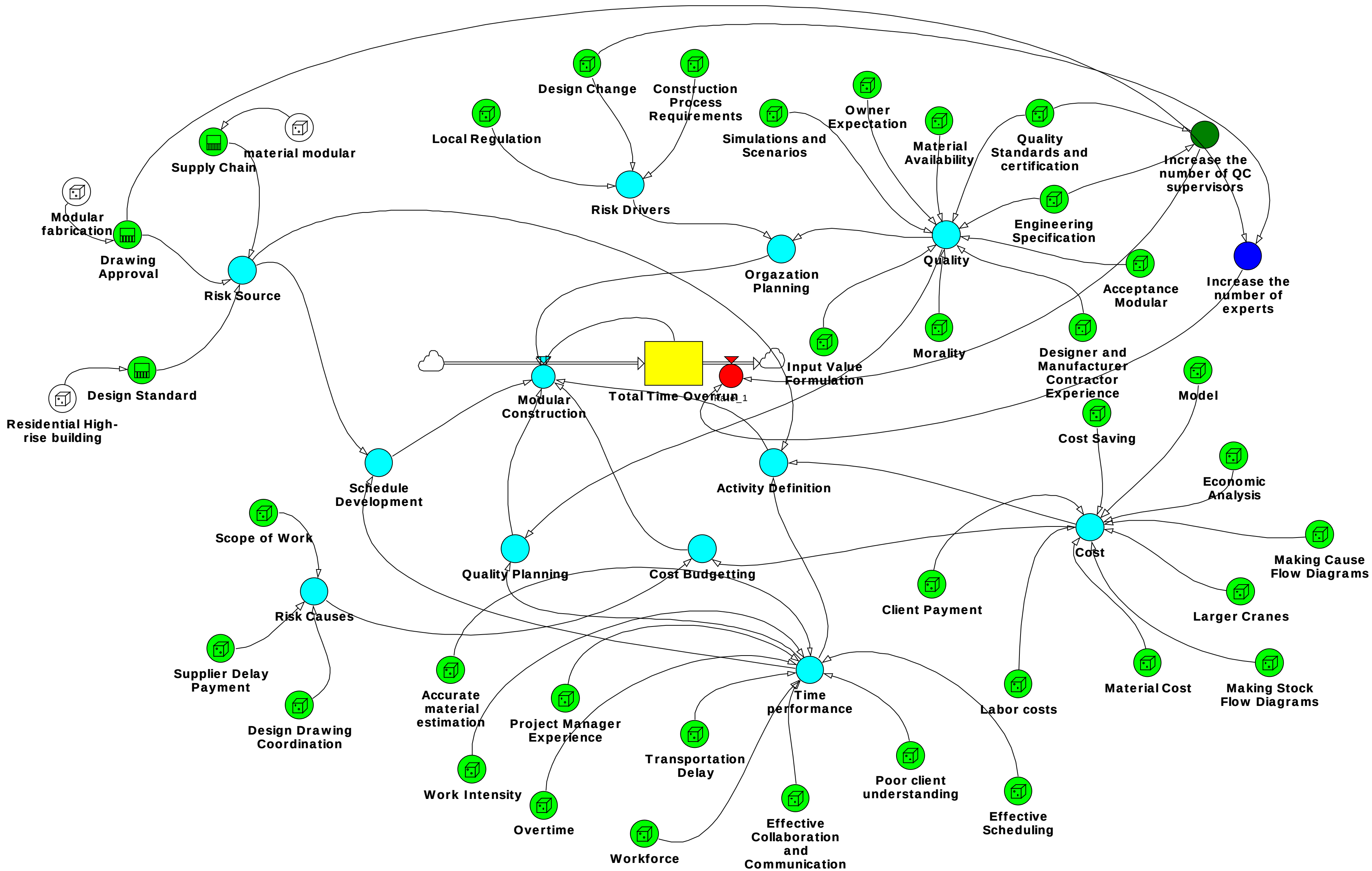

Figure 4. Stock flow diagram for pessimistic scenario

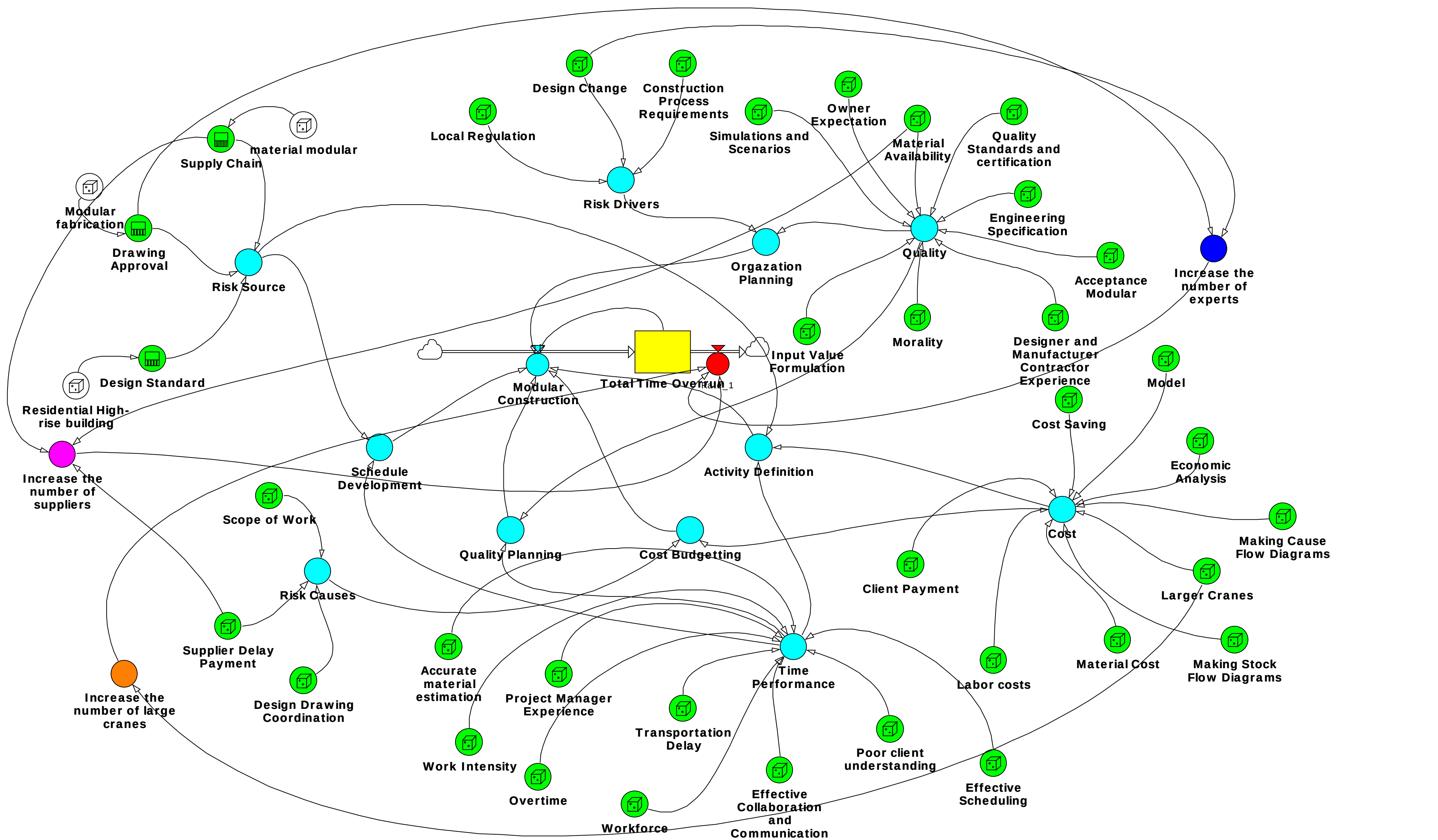

Figure 5. Stock flow diagram for Moderate scenario

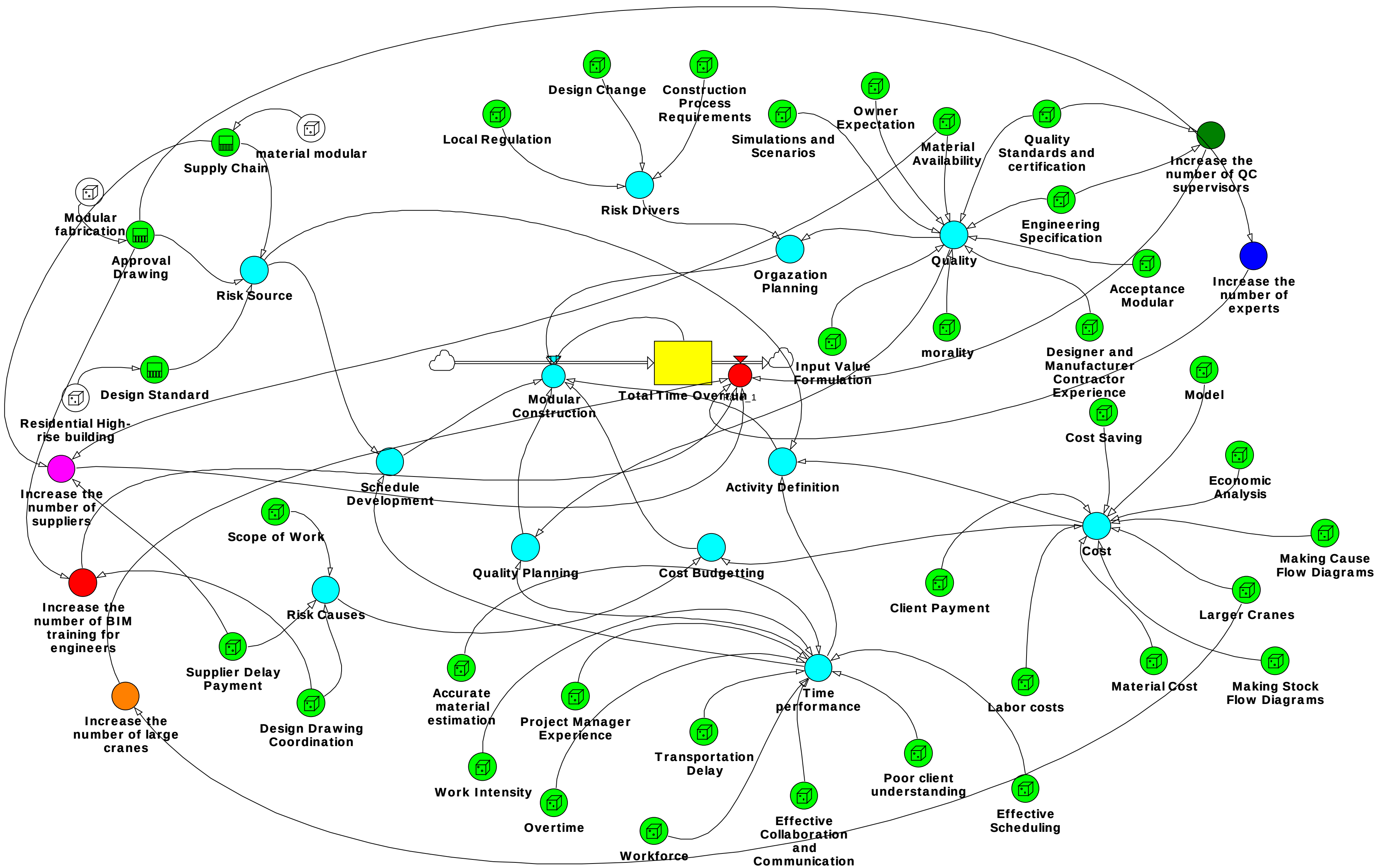

Figure 6. Stock flow diagram for Optimistic scenario

The results of this study are expected to be used as an operational basis for construction companies to take corrective actions in terms of time performance.

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