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## Effects of Payment Delays at Two Links in Payment Chains on the Progress of Construction Projects: System Dynamic Modeling and Simulation

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**Abstract:** Payment is the lifeblood of construction projects. However, steady fund flow is rare in construction projects. This paper focused on a quantitative evaluation of the impact of payment delays at the two links (i.e., from owner to general contractor and from general contractor to subcontractor) on the progress of a construction project. A hybrid research method combining the interpretative structural modeling (ISM) method and system dynamics was used to simulate the complex relationships between a payment delay and project progress. Four distinct payment policies are quantitatively simulated to reveal the impact of payment delays at the two links on the progress of a construction project. The results show that shortening the payment period at the two links in the payment chain will accelerate the flow of funds and relieve the burden on contractors in providing advance funds in terms of amount and duration, making them powerful measures to ensure smooth progress. The other three payment policies require that the subcontractor provide large sums of advance funds for lengthy periods to ensure smooth project delivery.

Keywords: payment delay; project progress; system dynamic; simulation; construction project

## 1. Introduction

Construction projects are characterized by large investment, lengthy transaction cycles, and high risk. These characteristics dictate that the conventional transaction mode of "payment upon delivery" or "payments made on time" does not suit construction projects. In the construction industry, most owners of construction projects use payment delay to contain the risks in the transaction process [1,2]. Specifically, the owner usually specifies a certain percentage of retainage and payment time frames in the contract so as to ensure that the contractor fulfils the contract dutifully, thus protecting its own interests [3–6]. Similarly, the general contractor of the construction project sets similar delayed payment terms in the contract with each subcontractor, which is conducive to easing the pressure on cash flow and strengthens control over subcontractors. However, wages for construction workers must be paid on time, regardless of whether subcontractors have received payment from the general contractor [7]. Besides, late payments have been perceived as a major issue by many subcontractors, but few owners or general contractors have been aware of this problem [8].

Although the timeliness of payment has been a common issue of the contracting and subcontracting practice in the construction industry [8], payment delay is a widely used means of credit-based transaction in supply chain management [9]. Its practice of payment delay is significantly different



from that in the construction industry. In most supply chains, payment delay starts from the end of the supply chain and propagates link-by-link to the top of the supply chain. However, the payment delay in the construction industry propagates from the top to the end of the supply chain. In the construction industry, owners at the top of the supply chain are mostly capital-intensive enterprises that can easily acquire funds and avoid risks, while most subcontractors at the end of the supply chain are labor-intensive firms with limited funds and risk resistance [10]. Therefore, if the payment delay terms of the project contract are set improperly and the contractor does not have a large fund reserve, the contractor may often encounter a fund shortage later in the construction period, which can easily lead to dried up cash flow and delayed wage payments [11–13]. Worse problems, such as contractual disputes and project delays, could occur if this shortage of circulating funds is not solved in a timely manner. Hence, delayed payment for construction work can easily lead into contractual disputes and even litigation, and the number of contractual disputes caused by payment delays in the construction sector has been recently increased [14,15]. Given that the issue of delayed payments taken as the internal risk initiated among owner and contractors [16,17], this paper explores the influence of delayed payments for contractors by owners and for subcontractors by general contractor in the construction projects.

Previous research has identified the severe delay causes related to construction projects including late payment [18] especially those delayed by the owners [19]. Delay of payments has appeared with critical impacts on the completion of projects in different countries/regions, such as the road projects in Palestine (ranking the 1st) [19], the highway construction projects in United Arab Emirates (UAE) (ranking the 9th out of 10) [20], some large construction projects in Saudi Arabia (ranking the 1st) [21], the construction industry of Malaysia (ranking the 4th) [22], the groundwater projects in Ghana (ranking the 1st) [23], and the building projects in Nigeria (ranking the 2nd) [24]. The progress payments is also a crux in the Chinese construction industry [25]. It is, therefore, reasonable to try to understand the influence of late progress payment for constrictors by owner, and thereby the delayed payment displays affect subcontractors. Despite delayed payment for construction work allows the owner to gain and maintain an advantageous position and power for contractors, excessive payment delays can adversely affect the progress of the project [26-28], and cause interruption in cash flow, which might lead to contractual disputes and project risks returned back to the owner. Hence, the delay in payments to contractors has been identified as one important project risks [16,20], and is vital for the timely implementation of construction works [29]. However, research on the influence of delays in construction projects mostly focused on the investigation of factors and statistical analysis, such as factor analysis [29,30], survey and case study [23,31]. Moreover, there were complex loop structure between the payment and project scheduling [32]. The complex relationships and feedback among the allocation of project funds, the contractor's cash flow, and project progress might not be reflected through the investigation and survey or qualitative description. Therefore, the modeling method, i.e., system dynamics, was used to model and simulate the payment mechanism—revealing how delayed payments affect project progress and the comparison of different payments in construction projects in this study.

The purpose of the current study was to assess and model the impact of different delayed payment conditions on the progress of construction projects. The two late payment chains—from owner to general contractor [16], and from general contractor to subcontractors (the subcontracting practice [8])—were integrated, modeled and simulated the effects and feedback on the progress of a construction project according to the distinct conditions of payment delays in this study. Firstly, this study provide a conceptual and casual integration of the two late progress payments, which were included in the literature of project risks [16,20,25,33]. Secondly, by linking the literature with factors affecting delays [22,29,30], this study provided hierarchical element structure and the influence mechanism explaining the affecting process for project progress. Thirdly, this study extended the progress payment literature [32,34,35] by specifying four conditions of late payments that are likely to occur in the construction industry, then to simulate and propose the optimal coping and regulating

strategies. Through this, we aim to guide the contractors and subcontractors carrying out financial risk assessments.

The rest of paper was structured as follows. Section 2 detailed the literature review and proposed the research question while Section 3 described the methodology. Section 4 established the influencing path using Interpretative Structural Modeling (ISM), and the causal loop diagrams and flow charts through System Dynamics (SD). Section 5 dealt with the model application and simulation. The simulated results, the theoretical and practical implications were discussed in Section 6 and conclusion and limitations described in Section 7 in the end.

## 2. Literature Review and Research Question

#### 2.1. Payment Issues in Construction Projects

Delay in construction projects has been a focus of project management research [30]. Some owners or general contractors may have the history of delayed payment in construction projects. Payment issues in construction projects include owner's delayed payments to contractors [16], the delayed payments for subcontractors by general contractors [8]. On the one hand, Faridi and EL-Sayegh [36] reported and investigated the causes of construction delays across UAE, as for the financial category, delays in contractor's progress payment by owner has been identified as the major one. El-Sayegh [16,20] also studied the significant risks in construction industry, revealing the owners' delay payments to contractors as the significant and internal risk in construction projects. Delays in payments to the contractor was evaluated as one of the important factors influencing the delays of construction works when involving contractors [29].

On the other hand, Arditi and Chotibhongs [8] identified and investigated issues in subcontracting practice, proposed that the influences of delayed payments to many subcontractors received from their general contractors, has been the reason of friction for the two parties. Moreover, the delayed payment matter for the general contractor received from the owner (the upstream payment practice [37]), has the ripple effect on the timeliness of subcontractor payments. For example, subcontractors might be paid by the general contractors until the owners paid the progress payments and final payment (involving retainage) to the general contractors [38]. There was a time interval as the payment time delay between the billing date and the payment date for subcontractor payment [39].

## 2.2. Research Methodology for Delayed Payment in Construction Projects

The research design can be divided into three categories as for studying the causes of delays in construction, including empirical method (e.g., questionnaire, factor analysis or regression), qualitative method (e.g., literature review), and computational method (e.g., modeling or algorithm). For example, firstly, El-Sayegh [16,20,36] investigated the factors influencing delays in construction projects in UAE. Lo et al. [40] investigated and identified 30 causes of construction project delay in Hong Kong. El-Razek et al. [41] surveyed and identified main causes of delays in building projects in Egypt. Doloi et al. [30] recognized and examined the key delay factors using questionnaire, factor analysis, and regression analysis. Secondly, Ulusoy and Cebelli [32] used a double-loop genetic algorithm to solve the payment scheduling problem including the amount and timing of the payments. Vanhoucke et al. [34] studied progress payments in unconstrained project scheduling problem using the branch-and-bound algorithm. Kwon et al. [11] considered the model of project management and contractors and compared the results of both a delayed payment condition and a no-delayed-payment condition through game theory and computational formula.

Based on the above literature review, most previous studies focused on the recognition and identification of the key causes from the perspectives of different parties during construction project delivery. However, it is crucial to identify the associations between different factors of delay [30]. Moreover, there were complex relationships and feedback between a payment delay and project cash flow, and between cash flow and project progress. Work is yet to be done in identifying the relationship

linking the two delayed payments chains together—from owner to general contractor and from general contractor to subcontractor. Hence, this study simulated and analyzed the type of payment problem in which a payment delay occurs at two delayed payment chains in a construction project using system dynamics. Then the impact of four payment delay modes will be analyzed separately, and the influence of degree of trust between the participating parties on cash flow and project progress was taken into consideration.

## 3. Research Methodology

For this research, mixed research methods were used combining the ISM method, SD, and case analysis. The analytic strategy framework has been shown in Figure 1.



Figure 1. Research methodology.

Step 1: System analysis. The main task of system analysis is to define and clarify the system problems. The key system elements are identified using literature review and field survey. These two methods are combined to collect the relevant data on the system problem from the theoretical and practical perspectives, then propose the basic assumptions of the model and delineate the system boundaries [42,43].

Step 2: Structure analysis. Structure analysis focuses on the relationships among the elements identified above, including the feedback loop and unidirectional relationship. Specifically, feedback among various elements (i.e., causal loop diagram) are identified using the system dynamics method. System dynamics is an effective tool to capture the feedback processes and flows, also including causal mapping and simulation modeling to assess the consequences of the designed policies and structures [44]. The one-way impact between elements rather than the feedback loops are identified using the ISM method. ISM is applied to develop a multilevel hierarchical structure model through analyzing and calculating the relationship matrix of system elements [45–47]. These two tools are beneficial for modeling the interactions and links between the various system elements. Finally, the feedback mechanism between the system variables is determined and developed using both methods and combining with the feedback loop and one-way relationship results.

Step 3: Simulation model establishment. To develop and establish the simulation model, a stock-flow diagram of the system is drawn and shown based on the causal diagram, and the equations

describing the relations between the variables are derived. The stocks and flows could describe the accumulation and dispersal of resources, which are crucial for the dynamics of complex systems [44]. Specifically, the rectangles represent the stocks, such as populations or cash, and the "pipe" connecting two stocks represents the flow, such as the cash moves from owner to contractor. Besides, the equations are set up before model simulation.

Step 4: Model effectiveness testing. Combined with the real case in construction projects, the parameters and initial conditions are estimated from the sources of real data [44]. Then the established system dynamics model is tested and fine-tuned based on a real project with the aim of optimizing the parameters in the equations. The model validation focuses on the technical and computing aspect of the simulated model [48]. All the parameters and variables are programmed and tested using Vensim software to examine the dimensional consistency, structural and variable verification following on the procedure of Forrester and Senge [49].

Step 5: Model application. Perform quantitative analysis on practical problems for the example project using the constructed model. Through the developed model, the effects of four different payment policies for ensuring working capital of contractors are examined to quantitatively assess and compare the improvement policies using the case data.

# 4. Constructing a System Dynamics Model for Analyzing the Effect of Two-Link Payment Delays on the Progress of a Construction Project

## 4.1. Basic Assumptions of the Model

Different construction projects vary greatly, e.g., in operation, organizational structure, and payment terms; the way in which two-link payment delays affect the progress of a construction project is very complicated. In view of this complexity, we must make the following assumptions:

**Assumption 1.** The model proposed in this paper only considers the construction phase of the project. Only three participating parties (one owner, one general contractor, and one subcontractor) will be considered in the model, and the payment delays at both links in the payment chain will be considered. In real construction projects, the general contractor always perform and subcontract the construction works to various specialty subcontractors [8,38]. Although there are different specialized subcontractors, the general contractor has the same contractual agreements with them in general. Moreover, it's better to consider the constructing and subcontractor issues in the construction practice from the viewpoints of all the relevant parties (i.e., the owner, general contractor and subcontractor) [8]. Hence, to simplify, simulate, and operate the developed model, the relationships among three parties—i.e., owner, general contractor, and subcontractor—were analyzed and modeled in this study.

**Assumption 2.** Payment for construction work consists of prepayment, interim payment monthly, and retainage to be paid upon the completion of the project. For each payment term, only three parameters were considered in this study: prepayment, percentage of each interim payment, and length of payment delay. It is further assumed that the percentage of each interim payment and length of payment delay are fixed during the project.

**Assumption 3.** All resources invested in the construction project are measured monetarily. The sources of funds for the project include the project fund paid to the general contractor by the owner, start-up funds provided by the general contractor and the subcontractor, and the advance funds paid to the subcontractor by the general contractor. It is assumed that the contractor and subcontractor will not appropriate project funds throughout the project. The owner has sufficient funds, thus they can pay the general contractor at the end of each phase according to the payment terms, while both the general contractor and subcontractor may experience sporadic fund shortages.

**Assumption 4.** During the project, the general contractor and subcontractor can provide a fixed amount of advance funds to cover expenses from construction activities, and a fixed degree of trust exists between the general contractor and the owner, as well as between the subcontractor and the general contractor.

**Assumption 5.** The subcontractor cannot delay payments for construction costs, e.g., such as wages, machine rent fees, and material costs. The owner and the general contractor cannot pay wages and cover other construction costs directly (i.e., skipping the subcontractor). Construction will halt immediately once the subcontractor fails to make payment (i.e., the subcontractor's investment in the project in each phase determines the output within the same phase).

**Assumption 6.** There are no uncertainties, e.g., related to weather or the site itself, during construction. In other words, labor productivity remains unchanged, and the monetary value of the work completed by the subcontractor during each month is proportional to its investment in the project (the ratio of the two is defined as labor productivity).

**Assumption 7.** The general contractor and subcontractor set reasonable unit prices in the contract, and there are reasonable profit margins for the general contractor and subcontractor. The interim payment received by the general contractor in each phase is roughly equal to the general contractor's expenditures in the same phase.

## 4.2. Analysis of the Model Structure

## 4.2.1. Information Feedback Loops

To ensure that construction can be completed smoothly in each phase, the subcontractor must have sufficient funds and invest enough resources. In other words, subcontractors can invest sufficient resources such that the required construction work in each phase is satisfied. According to the previous assumptions, the sources of the subcontractor's funds during construction include: the start-up fund supplied by the subcontractor, the advance fund paid by the general contractor to the subcontractor, monthly progress payments to the subcontractor from the general contractor, the advance fund provided by the subcontractor during construction, and the retainage to be paid by the general contractor to the subcontractor upon the completion of the project. The degree of fund sufficiency will affect the willingness of the subcontractor to invest in construction work, and the subcontractor's investment will affect the construction output during the current month, thus construction output will affect the owner's progress payment to the general contractor and that paid to the subcontractor by the general contractor. The causal relationship is depicted in Figure 2.



**Figure 2.** The general causal diagram. Note. +: The positive (+) signs at the arrowheads indicate that the effect is positively related to the cause at the arrow tail. -: The negative (-) signs at the arrowheads indicate that the effect is negatively related to the cause at the arrow tail.

When the actual progress of the project lags schedule, the owner will take certain punitive measures to force the contractor to increase investment and adjust the construction plan. When the general contractor is unable to pay the progress payment to the subcontractor on time due to shortage of circulating funds, the general contractor will decide how much self-raised advance funds it can provide based on various considerations, including cost of default, expected return, potential risks, and its ability to provide advance funds. Similarly, when the subcontractor's circulating funds cannot meet the needs of construction, the subcontractor will also weigh the expected return against the potential risks of the project before deciding whether to provide a certain amount of self-raised advance funds based on its own ability to provide them. When a project delay occurs, the causal relationship between the general contractor's advance funds and those of the subcontractor is shown in Figure 3.



**Figure 3.** The causal influencing of fund flow on contractor's behavior. Note. +: The positive (+) signs at the arrowheads indicate that the effect is positively related to the cause at the arrow tail. -: The negative (-) signs at the arrowheads indicate that the effect is negatively related to the cause at the arrow tail.

Figures 2 and 3 show a total of 9 causal feedback loops in the system, four of which are negative feedback (B1–B4) and five are positive feedback (R1–R5). Positive feedback means that an increase (or decrease) in any initial parameter in the loop will strengthen the effect of this increase (or decrease) under the action of a series of parameters in the loop. In negative feedback, an increase (or decrease) in any initial parameter will cause a decrease (or increase) in this parameter under the action of a series of parameters in the feedback loops are shown in Figures 2 and 3 as follows.

(1) Positive feedback loop R1: the subcontractor's production investment carries a greater guarantee if they have a larger fund surplus, and more work will be completed during a given month if the subcontractor invests more funds in production. The subcontractor receives larger progress payments they complete more work during a given month, which increases the subcontractor's fund surplus.

(2) Positive feedback loop R2: If the subcontractor's fund surplus is larger, then their production investment carries a greater guarantee. Greater investment from the subcontractor causes more work to be completed during a given month, causing the owner to provide a larger progress payment to the general contractor, thus increasing their surplus funds and allowing sufficient funds to provide a progress payment to the subcontractor. The progress payment the subcontractor receives in turn will have a positive effect on the subcontractor's reserve fund.

(3) Positive feedback loop R3: a shortage in the subcontractor's funds will reduce the subcontractor's production investment, thus reducing the amount of work completed in the month and decreasing their expected cumulative profit. This smaller expected cumulative profit increases the financial risk related to providing advance funds, which will have negative effect on the willingness of the subcontractor to provide advance funds. The fund shortfall will be greater when the subcontractor is less willing to provide advance funds.

(4) Positive feedback loop R4: a larger progress payment to the subcontractor from the general contractor increases the subcontractor's fund surplus. Thus, the subcontractor will invest more in production, and more work will be completed during a given the month. The general contractor's cumulative expected profit will be greater if the subcontractor completes more work during a given month, which increases the general contractor's expected cumulative profit and reduce their risk of providing advance funds. This will have a positive effect on the willingness of general contractor to provide advance funds. The subcontractor will have a greater guarantee of payment from the general contractor provides more advanced funds.

(5) Positive feedback loop R5: the subcontractor's production fund will not have a shortage if they have sufficient fund surplus. Therefore, the subcontractor can guarantee its production input, which will increase the amount of work completed during a given month and will increase the general contractor's cumulative expected profit. The general contractor will be at lower risk of providing advance funds if their expected cumulative profit is larger, which will have a positive effect on the willingness of general contractor to provide advance funds. The subcontractor will have a greater guarantee of receiving a progress payment from the general contractor, which then increases the subcontractor's fund surplus.

(6) Negative feedback loops B1 and B2: these represent the direct inverse relationship between the fund surpluses of the general contractor and subcontractor and the production input. Negative feedback loops B3 and B4: these represent the direct reverse relationship between the willingness of the general contractor and subcontractor to provide advance funds and the risk of default. The risk of default is higher when the general contractor (or subcontractor) provides more advance funds. The increased of the risk of default will reduce the willingness of the general contractor (or subcontractor) provides more advance funds.

## 4.2.2. Study on Information Transmission Path

For elements that do not include a feedback loop, ISM was used to investigate information transfer between elements. Based on the system elements determined from the system analysis, an ISM panel consisting of 12 experts with more than 6 years of experience in managing construction projects was formed to judge the relationship between various elements. After processing the relevant data following the standard steps in ISM, the ISM panel determined two information transmission paths as, shown in Figures 4 and 5.

Figures 4 and 5 illustrate the information transmission mechanism between factors affecting the willingness of the general contractor to provide advance funds and the willingness of the subcontractor, respectively. These mechanisms are similar for the general contractor and subcontractor. The following is a description of the information transmission mechanism between factors affecting the willingness to provide advance funds, where Figure 4 is used as an example. The subcontractor's comprehensive unit price and total engineering volume have a positive effect on its expected total profit, while the subcontractor's cost coefficient will reduce the subcontractor's expected total profit. The subcontractor's payment credibility and payment period. If the general contractor has high payment credibility and short payment period, the subcontractor can expect a higher total profit. The subcontractor's residual willingness to provide advance funds is largely determined by the subcontractor's expected total profit and the cumulative advance funds. The subcontractor's residual willingness to provide advance funds is lower if they have more cumulative advance funds. The subcontractor's residual ability to provide advance funds is

determined by its initial ability to provide advance funds and the cumulative advance funds. The subcontractor's residual ability to provide advance fund is lower when they hold more accumulated advance funds. The subcontractor's residual willingness and residual ability to jointly provide advance funds determine the maximum amount of advance funds that will be provided by the subcontractor at present.



**Figure 4.** Factors affecting the willingness of the subcontractor to provide advance funds. Note. +: The positive (+) signs at the arrowheads indicate that the element is positively related to the element at the arrow tail. -: The negative (-) signs at the arrowheads indicate that the element is negatively related to the element at the arrow tail.



**Figure 5.** Factors affecting the willingness of the general contractor to provide advance funds. Note. +: The positive (+) signs at the arrowheads indicate that the element is positively related to the element at the arrow tail. -: The negative (-) signs at the arrowheads indicate that the element is negatively related to the element at the arrow tail.

#### 4.3. Constructing the System Dynamics Model

Based on a comprehensive analysis of the causal relationships in the process of two-link payment delays affecting the progress of a construction project illustrated in Figures 2–5, we can construct a dynamic evaluation model according to system dynamics, as shown in Figure 6. The model contains a total of 66 variables, including 8 flow bit variables, 9 flow rate variables, and 49 parametric variables. For convenience of reading the model, the variables are abbreviated, as shown in Appendix A (Table A1). The model has 40 equations, including the main flow rate equations and auxiliary variable equations. Refer to Appendix B for details.



Figure 6. Stock-and-flow diagram.

## 5. Model Application: Case Study

## 5.1. Case Selection

The above system model was construed based on the relationship between funds and the progress of the project. To facilitate quantitative investigation, it is necessary to quantify all parameters in the model and quantify the relationships between the parameters based on a real construction project. This study is based on a highway project under construction in Yunnan Province, China. The project in question is a highway PPP (Public-Private Partnership) project led by a state-owned construction enterprise group. For this study, a contracted section of the project was selected as a case study. With a length of 2.3 km, the selected contracted section was completed in 24 months and cost 100 million yuan.

Construction of the PPP project was awarded to one single general contractor. There were three layers in the organizational structure of the project: a project investment company, general contractor, and subcontractors. Among them, the project investment company and the general contractor were affiliates of the same construction enterprise group. The researchers obtained the main parameters of the project through random interviews and surveys. After the data were collected, the parameters in the model were quantified in three ways according to the type of parameter. The first type refers to data type parameters obtained through surveys, including "payment period", "payment percentage", and "start-up capital". These parameters could be used directly in the model. The second type was the parameters that must be normalized, including "general contractor comprehensive unit price", "subcontractor comprehensive unit price", "general contractor cost coefficient", and "planned engineering amount". These parameters were normalized in this study. The "general contractor comprehensive unit price" was defined as 1, and the "subcontractor comprehensive unit price" to the "general contractor comprehensive unit price" to the "general contractor comprehensive unit price" to the ratio

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unit price". The "general contractor cost coefficient" was converted to a positive number less than 1, i.e., equal to the ratio of the "general contractor cost" to the "general contractor comprehensive unit price". Finally, the "subcontractor cost coefficient" was converted to a positive number less than the "subcontractor comprehensive unit price", i.e., equal to the ratio of the construction cost to the "subcontractor comprehensive unit price". The work to be completed during each month was calculated according to the "planned completion quantity" and converted to the "construction output value" as a function of time.

The key parameters of the project include: 80% of interim payments were paid to the general contractor by the owner, the owner prepayment was 5 million yuan (RMB, similarly hereinafter), the interim payment period was 4 months, 5 million yuan of project start-up capital was provided by the general contractor, the "general contractor comprehensive unit price" is 1, and the "general contractor cost coefficient" was 0.1. The percentage of interim payments to be paid to the subcontractor by the general contractor was 85%, the general contractor's prepayment was 0 yuan, the interim payment period was 4 months, the subcontractor provided 5 million yuan of project start-up capital, the "subcontractor comprehensive unit price" was 0.8, and the "subcontractor cost coefficient" was 0.65.

## 5.2. Model Validation

After all the equations and parameters of the model are in place, the model must be validated to ensure it is an accurate abstraction of the real-world system. The model is considered valid if it passes a mechanical error test, dimensional consistency test, and extreme condition test as suggest by Forrester and Senge [49] and Richardson and Pugh [50]. In this study, Vensim software was used to build the model and test its validity. The used tests and procedures were represented in Table 1 followed by Shin et al. [48] and Han et al. [51].

Test	Purpose	Results/Criteria
Mechanical error	Test of the parameter values	Each parameter was programmed to have a limited range by setting the minimum and maximum.
Dimensional consistency	Test of model structure	Variables are programmed to have the consistent unit, and the dimension of all variables were logically tested.
Extreme condition	Test consistency of the model with reality	Extreme condition test was conducted to determine whether the developed model behaved in a realistic manner under extreme values.
Behavior reproduction	Test of model behavior/effectiveness	The test used to assess the model's ability to reproduce the behavior of interest combined with the values from real case.

Table 1.	Applied	validation	tests ir	this	study
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Through adjusting and debug parameters or values, the proposed model passed the mechanical error test, dimensional consistency test, and extreme condition test. Next, the actual payment terms, construction schedule, and related parameters of the case project were input into the model to simulate the relationship between payment delay and construction progress to test the effectiveness of the developed total model. The simulation results are shown in Figures 7 and 8. In Figure 7, the curve of the planned construction progress or the planned target quantity current month is abbreviated to PTQCM, the curve of the current accounts total payment of the general contractor is abbreviated to CATPG, and the curve of project delay is abbreviated to CPD1. The simulation results show that under the given payment terms, the project started to lag schedule beginning in the third month, and the

delay increased continuously until the 11th month. The delay started to decrease in the 12th month. As shown in Figure 8, the curve of the current fund gap of the subcontractor is abbreviated to EFDP, the profit/loss status of the general contractor in the current phase is abbreviated to PLFG, and the profit/loss status of the subcontractor in the current phase is abbreviated to PLFS. The simulation results show that the general contractor always had a fund surplus, while the subcontractor started to experience a fund shortage in the 2nd month. The subcontractor had to provide advance funds at all times (the sum was close to 5 million yuan at its peak), and this fund shortage resulted in a project delay.



Figure 7. Simulation result of construction progress.



Figure 8. Simulation result of cash flow.

In this project, one cycle of interim payment paid to the general contractor by the owner was very long (4 months). To alleviate the pressure on funds, the general contractor also increased the cycle of interim payments paid to the subcontractor. Moreover, the general contractor did not provide advance funds to the subcontractor. Thus, capital pressure on the whole project was transferred to the subcontractor, forcing the subcontractor to provide self-raised advance funds and suffer fund shortages for a lengthy period. Some other factors also aggravated the fund shortage. Information asymmetry between the general contractor and subcontractor exists, plus the parent company (a state-owned enterprise) imposed strict fund controls on the project department of the general contractor, and the general contractor enjoyed a fund surplus while the subcontractor suffered a fund shortage. This indicates that two-link payment delays led to project delays and reduced the efficiency of capital use. The results from the above simulation and analysis are highly consistent with the actual situation of the project, indicating that the model established in this study was valid.

#### 5.3. Simulation and Analysis of Project Payment Policy

The payment policy usually involves comprehensive application of parameters, e.g., comprehensive unit price, prepayment, payment period, and payment percentage. It is assumed in this study that the comprehensive unit price is fixed. The fund shortage suffered by the subcontractor was the direct cause of the continuous project delay. There are two measures to adjust the payment policy and ensure healthy cash flow for the subcontractor: (1) accelerate the process of fund disbursement and shorten the payment period, and (2) increase prepayment to the subcontractor or the percentage of interim payments. The following is a description of an experiment simulating the effects of the four payment policies.

## 1. Policy 1: Shorten the payment period at both links in the payment chain.

The system dynamics model was used to simulate project implementation under the condition of a shortened payment period at both links (i.e., from owner to general contractor and from general contractor to subcontractor) in the payment chain. The simulation results show that the project could proceed on schedule after the payment period was shortened from 4 months to 1 month at both payment links and the owner's prepayment to the general contractor was reduced from 5 million yuan to 0 yuan. As indicated by curve CPD1 in Figure 9, the progress of the project overall was in line with the schedule, with only short delays in the 5th, 6th, and 7th months. The curve EFDP in Figure 10 indicates that the subcontractor had sufficient funds in most months, with only small fund shortfalls in the 4th, 5th, and 6th months. Curve PLFG indicates that the general contractor basically did not need to provide advance funds for the project and had small fund surplus throughout the construction period. The curve PLFS indicates that the subcontractor relied on self-raised advance funds to sustain construction from the 2nd to the 10th month, with the advance fund peaking at 1.92 million yuan in the 7th month. The amount of advance funds decreased gradually after the 7th month, and the subcontractor had a fund surplus during from the 11th to the 24th month, indicating that the subcontractor's circulating fund was replenished effectively. Under this payment policy, the owner and the general contractor do not need to provide prepayment for the project, the general contractor does not need to provide advance funds, and the subcontractor only needs to provide a small amount of advance funds for short periods. This payment policy is more acceptable for all the three parties since the level of risk of fund shortage is low.



Figure 9. The construction progress under Policy 1.



Figure 10. The cash flow under Policy 1.

#### 2. Policy 2: Only the payment period from the general contractor to subcontractor is shortened.

The system dynamics model was used to simulate the project under the condition of a shortened payment period at the "general contractor  $\rightarrow$  subcontractor" payment link. The simulation results show that the owner's prepayment to the general contractor remained at 5 million yuan after the payment period was shortened from 4 months to 1 month, and the project could proceed in an acceptable manner. As indicated by curve CPD1 in Figure 11, the overall progress of the project was in line with the schedule, with only short delays in the 5th, 6th, 7th, 10th, and 12th months. Curve EFDP in Figure 12 indicates that the subcontractor had small fund shortfalls in the 4th, 5th, 6th, 9th, and 11th months, and funds were sufficient throughout the remainder of the construction period. Curve PLFG indicates that the general contractor provided advance funds from the 6th to the 15th month (the advance funds peaked at 2.4 million yuan in the 8th month) and saw a fund surplus beginning in the 16th month. Curve PLFS indicates that the subcontractor relied on self-raised advance funds to sustain construction activities from the 2nd to the 21st month, with the advance fund peaking at 3.59 million yuan during the 11th month. The amount of advance funds decreased gradually since then, and the subcontractor started to have a fund surplus from the 22nd month. Under this payment policy, the owner must provide prepayment, but the progress payment was relatively small in the early phase. The general contractor must provide a small amount of advance funds to pay the interim payment. The subcontractor must provide a large amount of advance funds for lengthy periods. The financial risk is low for the owner and general contractor, but it is relatively high for the subcontractor. Under this payment mode, the subcontractor is likely to use delay as a self-protection measure, taking advantage of flaws in the contract and its advantage in knowing more details of the required construction work.



Figure 11. The construction progress under Policy 2.



Figure 12. The cash flow under Policy 2.

## 3. Policy 3: Increase the advance fund provided to the subcontractor by the general contractor.

The system dynamics model was used to simulate the project under the condition of increased advance funds provided to the subcontractor by the general contractor. The simulation results show that after the prepayment reached 5 million yuan, the project could proceed in an acceptable manner. As indicated by curve CPD1 in Figure 13, the overall progress of the project was in line with the schedule, with delays from the 7th to the 13th months. The maximum monetary value of delayed work was 2.4 million yuan. The progress caught up with the schedule in the 14th month and stayed on schedule thereafter. Curve EFDP in Figure 14 indicates that the subcontractor had a fund shortage from the 5th to the 12th months (the maximum fund shortfall was 1.28 million yuan) and had sufficient funds throughout the remainder of the construction period. Curve PLFG indicates that the general contractor provided a small amount of advance funds from the 2nd to the 10th months (the advance fund peaked at 0.5 million yuan in the 5th month) and had a fund surplus beginning in the 11th month. Curve PLFS indicates that the subcontractor relied on self-raised advance funds to sustain construction activities from the 5th to the 22nd month, with the advance fund peaking at 4.01 million yuan in 10th month. The amount of advance funds decreased gradually thereafter, and the subcontractor started to have a fund surplus beginning in the 24th month. Under this payment policy, both the owner and general contractor must provide prepayment, and the general contractor must only pay a small amount of advance funds. The subcontractor has a relatively large sum of funds during the early phase of the project and only needs to provide relatively large sums of advance funds for lengthy periods in the middle phase of the project. Under this payment mode, the level of financial risk is low for the owner and the subcontractor but relatively high for the general contractor.



Figure 13. The construction progress under Policy 3.



Figure 14. The cash flow under Policy 3.

4. Policy 4: Increase the percentage of interim payments to be paid to the subcontractor by the general contractor.

The system dynamics model was used to simulate the project under the condition of increased percentage of interim payments to be paid to the subcontractor by the general contractor. The simulation results show that the project could proceed in an acceptable manner after the percentage of interim payments to be paid to the subcontractor by the general contractor reached 90%. As indicated by curve CPD1 in Figure 15, the overall progress of the project was in line with the schedule. The project experienced delays from the 4th to the 9th months, with the monetary value of delayed work peaking at 2.5 million yuan. Progress caught up with the schedule in the 10th month and stayed on schedule thereafter. Curve EFDP in Figure 16 indicates that the subcontractor experienced a fund shortage from the 3rd to the 8th months (the maximum fund shortfall was 1.64 million yuan in the 4th month) and had sufficient funds throughout the remainder of construction. Curve PLFG indicates that the general contractor often had a fund surplus and started to provide small sums of advance funds beginning in the 18th month (the advance fund peaked at 0.79 million yuan). Curve PLFS indicates that the subcontractor relied on self-raised advance funds to sustain construction activities from the 2nd to the 19th month, with the advance fund peaking at 7.49 million yuan in the 10th month. The amount of advance funds decreased gradually thereafter, and the subcontractor started to have a fund surplus from the 20th month. Under this payment policy, the owner must provide prepayment for the project, the general contractor has a fund surplus in the early phase of the project and a fund deficit in the later phase, and the subcontractor must provide very large sums of advance funds for lengthy periods in the middle phase of the project. Under this payment mode, the level of financial risk is relatively high for all three parties, increasing project delays and contractual disputes during project delivery.



Figure 15. The construction progress under Policy 4.



Figure 16. The cash flow under Policy 4.

#### 6. Discussion of Simulation Results

## 6.1. Reasonable Payment Policy

A reasonable payment policy involves the payment cycle from the owner to the general contractor and/or from the general contractor and the subcontractor, the advance payment and the interim payment proportion received by the subcontractor. First of all, profit is the driving force for the contractors to continuously invest in construction work [23,52], and a reasonable comprehensive unit price or quotation is the basis for smooth execution of any construction project [53]. However, subcontractors or general contractors often paid late [20,38], and some subcontractors or general contractors tend to increase the quotations to boost the project cost as well as their expected profit [8]. It can be improved if owners pay general contractors on time and in turn general contractors pay subcontractors on time to shorten the payment cycle. Therefore, an appropriate payment cycle can ensure that contractors have the motivation and sufficient funds to continuously invest in construction work minimizing the risks of all parties involved and helping achieve effective cooperation. It can also make sure that contractors can gain a certain amount of profit as a reward for dutifully executing the contract.

Secondly, the advance payment amount and the interim payment proposition are associated with the surplus funds and advance funds of general contractors or subcontractors. It is important to control the amount of surplus funds in the hands of the general contractor and subcontractor. However, the owner can gain more bargaining power if the contractor must provide self-raised advance funds in the early project phase, and the extensive delay will provide a ground for disputes and claims [54]. Therefore, the payment policy should facilitate the contractor for having surplus funds in the middle or late stage instead of the early phase of a project. If the subcontractor will have a fund surplus in the middle or later phase of the project through the appropriate advance payment or interim payment from general contractor, and the fund surplus should increase over time and the subcontractor will be motivated to continuously invest in production. Besides, the amount of advance funds should also be contained within a reasonable range. The willingness of the contractor to provide advance funds is affected by various factors, such as its ability to provide advance funds and the risks involved. As a result, a reasonable payment policy should be able to ensure that the amount of advance funds the contractor requires and the duration of providing such funds are within reasonable ranges. When the contractor perceives the financial risk of providing advance funds to outweigh the expected profit, it is likely to mitigate risk by reducing the production input, which often leads to project delays and contract disputes [38,55,56].

## 6.2. Comparison of Different Payment Policies

From the above simulated results, the summarized results are shown in Table 2.

Payment Policies	The Early Phase	The Interim Phase	The Later Stage	
Policy 1: The payment periods from owner to general contractor and from general contractor to subcontractor are both shorten.	The general contractor and subcontractor must input a few advance funds within an acceptable range.	Both the general contractor and subcontractor will have surplus funds.	The amount of surplus funds will increase continuously.	
Policy 2: The payment cycle from general contractor to subcontractor is shorten.	• The general contractor will have a large amount of surplus funds.	The general contractor will have a large amount • The general contractor must provide advance funds.		
	• The subcontractor must provide a large sum of advance funds for the project throughout the entire project.			
Policy 3: Increasing the prepayment to the subcontractor by the general contractor.		• The general contractor only needs to provide a small amount of advance funds.		
	• The subcontractor will have a relatively large sum of surplus funds.	<ul> <li>The subcontractor needs to provide a large sum advance funds.</li> </ul>		
Policy 4: Increasing the percentage of interim payment to the subcontractor by the general contractor.			• The general contractor only provides a small amount of advance funds.	
	The subcontractor need pr     the project.	ovide a mass of advance fur	nds throughout most phases of	

Table 2.	The com	parison c	of different	payment	policies.

The simulation results show that after the payment periods of both links in the payment chain are shortened simultaneously (Policy 1), capital flow within the project can be guaranteed without requiring prepayment from the owner. Under this payment policy, the contractors will not encounter major fund shortages. The general contractor and the subcontractor must provide advance funds in the early phase of the project. For both the general contractor and subcontractor, the amount of the advance funds is small compared with the contract value and the expected profit, and the duration of providing advance funds is also within an acceptable range. In the middle and later phases of the project, both the general contractor and subcontractor will have surplus funds, and the amount of surplus funds will increase continuously as the project progresses. This situation will motivate contractors to continuously invest in production, ensuring smooth implementation of the project.

When only the period of payment to be paid to the subcontractor by the general contractor (Policy 2), the general contractor will have a large amount of fund surplus during the early phase of the project and will need to provide advance funds in the middle phase of the project. The subcontractor must provide a large sum of advance funds for the project throughout the entire project. The supply of production funds and smooth implementation of the project can be effectively guaranteed only if the general contractor does not appropriate funds and the subcontractor keeps providing advance funds. In this project, the general contractor and the owner belong to the same construction enterprise group, and there is no risk of the general contractor appropriating funds. If the subcontractor lacks faith in the general contractor, it usually avoids providing a large sum of advance funds for a lengthy period to minimize its own risk. This passiveness may result in insufficient investment in the project, which in turn slows progress.

If the prepayment to be paid to the subcontractor by the general contractor is increased (Policy 3), the general contractor only needs to provide a small amount of advance funds in the middle phase of the project. The subcontractor will have a relatively large sum of surplus funds in the early phase of the project and will need to provide a large sum of advance funds for a lengthy period in the middle and later phases of the project. The supply of production funds and smooth implementation of the project can be effectively guaranteed only if the subcontractor does not appropriate funds in the early phase and keeps providing large sums of advance funds in the middle and later phases of the subcontractor to provide advance funds is directly affected by the subcontractor's ability to provide advance funds and the subcontractor's faith in the general contractor, the subcontractor is likely to appropriate funds and avoid providing a large sum of advance funds for a lengthy period. As a result, the progress of the project may be hindered by insufficient investment in production.

If the percentage of interim payments to be paid to the subcontractor by the general contractor increases (Policy 4), the general contractor must only provide a small amount of advance funds during the final phase of the project. The subcontractor must provide advance funds throughout most of the project, and the peak amount of the advance funds is very large. The amount of advance funds will start to decrease in the middle phase of the project, and a large sum of surplus funds will accumulate during the final phase of the project. Under this payment policy, the faith of the subcontractor in the general contractor will also have a decisive impact on the willingness of the subcontractor to provide advance funds, which will in turn affect the progress of the project.

## 7. Conclusions, Implications, and Limitations

#### 7.1. Conclusions

Previous studies have revealed the impacts of different payment delay terms on cash flow stability and pointed out that payment delay in construction projects is a key factor resulting in overall project delays. However, few researchers have conducted quantitative analysis of the complex relationship between payment delay and construction progress. Setting reasonable payment terms in construction project management is still a thorny issue waiting for a satisfactory solution. In this study, the system dynamics method was used to quantitatively analyze the complex relationship between different payment delay terms and project progress.

This study considered payment delays at the two links (from owner to general contractor and from general contractor to subcontractor) in the payment chain. The payment delay parameters used in the study included prepayment, percentage of interim payment, payment delay period, start-up fund, etc. The system dynamics model, on other hand, took into consideration of some other factors, e.g., the abilities of the general contractor and subcontractor to provide self-raised advance funds, and the degrees of trust between the parties involved. A causal loop diagram describing the relationships between the key elements and a system stock-flow diagram were drawn, and the parameters of the model set based on a real construction project. After testing the model validity, simulations were conducted to analyze the effects of four payment policies. The simulation results indicated that shortening the payment period at the two links in the payment chain will accelerate the flow of funds and relieve the burden on contractors in providing advance funds in terms of amount and duration, making them powerful measures to ensure smooth progress. The other three payment policies require that the subcontractor provide large sums of advance funds for lengthy periods to ensure the project is delivered smoothly.

#### 7.2. Theoretical and Practical Implications

The theoretical contribution of this research can be summarized as follows. First of all, previous studies have pointed out that payment delay is a key factor leading to overall project delay [19,21] and

other project risks [16,20,25,33]. This study as a result provided a conceptual and casual integration of the two delayed progress payments using the causal loop diagrams through the dynamics method. Secondly, this study provided hierarchical element structure (e.g., unidirectional hierarchical structure) and the influence mechanism (e.g., stock-flow diagram) explaining the affecting process for project progress and advance funds amount through linking various literature of delay causes [22,29,30]. Specifically, in this study, the methods of ISM and SD model were used and combined to delineate and analyze the complex relationship between two-link payment delays and project progress. Thirdly, this study extended the progress payment literature [32,34,35] by specifying and simulating four conditions of late payments which are likely to occur during construction project delivery. The system dynamics model and equations were developed to simulate and analyze the effect of various payment policies on progress of the project, and the established system dynamics model can be used as a simulation platform to study various problems under different payment terms, e.g., fund management efficiency and the financial risk borne by contractors when providing advance funds.

The practical implication for contractors is to reduce the financial and payment risks through focusing on the contractual payment policies. Before entering into the agreement, greater attention should be paid to the payment policy including the payment cycle, payment proportion, and the advance fund amount. As for general contractors and subcontractors, researchers and practitioners have recommended that they should refuse to cooperate with the parties with the history of delayed paying and negotiate the terms of payment of the agreement [8]. In particular, if owners pay general contractors promptly, the timeliness of payments to subcontractors by general contractors can be also improved [8,37]. Besides, the other implication for contractors is about the project funding. In the Chinese construction industry, it is normal that there is not sufficient funds to develop projects at the start [25]. The general contractors and subcontractors must provide a certain amount of advance funds as the funding source before the construction phase. Considering the initiate input is necessary, contractors can envisage a contingency fund at the start and negotiate with owners to secure the cash flow, gradually withdraw the funds to control cost and profit as the project is proceeded.

## 7.3. Limitations and Future Research Directions

Although this study has made significant contributions, it has two limitations. The first lies in the assumptions in the system dynamics model, namely that the cost of the contractor is known. With the cost of the contractor known, the owner can set a reasonable percentage of interim payments based on the contract price and the contractor cost in order to gain an advantageous position in the contract management process. In practice, the contractor cost is usually a business secret that is difficult to obtain. Therefore, as the complexity of problems in payment management faced by the owner are greatly simplified in the model used in this study, the model cannot be used to with high-fidelity payment management simulations under the condition of information asymmetry. Second, the system dynamics model developed in this study only considers the scenario in which only a single subcontractor is involved. In reality, various subcontractors are usually involved in real construction projects, and subcontractors have different prices and costs. Therefore, the model proposed in this study requires further development and improvement before it can be used to simulate the effect of payment policy in projects with multiple subcontractors.

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## Appendix A

## Table A1. Descriptions of the variables used in the model.

Acronym	Descriptions	Variable Type	Acronym	Descriptions	Variable Type
FBG	Fund balance of the general contractor	Stock	RDVS	Redeem discounted value of the subcontractor's profit	Auxiliary
FBS	Fund balance of the subcontractor	Stock	RRFO	Redemption risk factor of the owner	Constant
ACAG	Accumulated cash advance of the general contractor	Stock	RRFG	Redemption risk factor of the general contractor	Constant
ACAS	Accumulated cash advance of the subcontractor	Stock	UPC	Unbalanced price coefficient	Auxiliary
AAEG	Accumulated accrued expenses for the general contractor	Stock	PRW	Planned remaining work	Auxiliary
AAES	Accumulated accrued expenses for the subcontractor	Stock	PTQNM	Planned target quantity neat month	Auxiliary
AICS	Accumulated input costs of the subcontractor	Stock	EPS	Expected payment to the subcontractor	Auxiliary
UW	Unfinished work	Stock	EFGP	Expected financial gap for production next month	Auxiliary
MPRG	Medium-term payment ratio to the general contractor	Auxiliary	EFPP	Expected financial gap for progress payment	Auxiliary
PCG	Payment cycle to the general contractor	Auxiliary	CAFOS	Cash discount factor of the owner's settlement	Constant
MPRS	Medium-term payment ratio to the subcontractor	Auxiliary	CDFGS	Cash discount factor of the general contractor's settlement	Constant
PCS	Payment cycle to the subcontractor	Auxiliary	CMAVG	Current maximum advance value of the general contractor	Auxiliary
CUPG	Comprehensive unit price of the general contractor	Auxiliary	CMAVS	Current maximum advance value of the subcontractor	Auxiliary
CUPS	Comprehensive unit price of the subcontractor	Auxiliary	PFD	Penalty factor of delay	Constant
CACG	Capital advance capacity of the general contractor	Auxiliary	CPA	Current penalty amount	Auxiliary
CACS	Capital advance capacity of the subcontractor	Auxiliary	SRP	Share ratio of penalty	Constant
RCACG	Residual capital advance capacity of the general contractor	Auxiliary	CCUPG	Current comprehensive unit price of the general contractor	Auxiliary
RCACS	Residual capital advance capacity of the subcontractor	Auxiliary	ICIG	Initial capital investment of the general contractor	Constant
CRG	Cost ratio of the general contractor	Constant	ICIS	Initial capital investment of the subcontractor	Constant
CRS	Cost ratio of the subcontractor	Constant	PPO	Prepayments of the owner	Constant
PCOS	Price coefficient of the subcontractor	Constant	PPG	Prepayments of the general contractor	Constant
WAFG	Willingness to advance funds of the general contractor	Constant	CCAG	Current cash advance of the general contractor	Flow
WAFS	Willingness to advance funds of the subcontractor	Constant	CCAS	Current cash advance of the subcontractor	Flow
CEPG	Cumulative expected profit of the general contractor	Auxiliary	CPPO	Current progress Payment of the owner	Flow
CEPS	Cumulative expected profit of the subcontractor	Constant	CAPPG	Current accounts progress payment of the general contractor	Auxiliary
RDVG	Redeem discounted value of the general contractor's profit	Auxiliary	CRIPG	Current real progress payment of the general contractor	Flow
CCEG	Current cost expenditure of the general contractor	Flow	CPD	Current progress delay	Constant
ACEG	Accumulated cost expenditure of the general contractor	Stock	APTQ	Adjusted planned target quantity	Constant
CCIS	Current construction investment of the subcontractor	Flow	ATQ	Adjusted target quantity	Auxiliary
CATPO	Current accounts total payment of the owner	Flow	CATPG	Current accounts total payment of the general contractor	Flow
CACEQ	Current Actual completion of engineering quantity	Flow	FSINM	Fund should be invested next month	Auxiliary
PTQCM	Planned target quantity current month	Auxiliary	FSICM	Fund should be invested current month	Auxiliary
APTQ	Adjusted planned target quantity	Auxiliary	SAF	Schedule adjustment factor	Constant

## Appendix B

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Equations of the model
                    AAPG(t) = AAPG(t - 1) + CAFG \times dt
                    AAPG(0) = 0
                    FBG(t) = FBG(t - 1) + (CAFG+CIPO - CCEG - CRIPG) \times dt
                    FBG(0) = PPO + ICIG - PPG
                    ACEG(t) = ACEG(t - 1) + CCEG \times dt
                    ACEG(0) = 0
                    FBS(t) = FBS(t - 1) + (CAFS + CRIPG - CCIS) \times dt
                    FBS(0) = PPG + ICIS
                    AICS(t) = AICS(t - 1) + CCIS \times dt
                    AICS(0) = 0
                    AAPS(t) = AAPs(t - 1) + CAFS \times dt
                    AAPS(0) = 0
                    AAES(t) = AAES(t - 1) + CATPG \times dt
                    AAES(0) = 0
                    AAEG(t) = AAEG(t - 1) + CATPO \times dt
                    AAEG(0) = 0
                    UW(t) = UW(t - 1) - CACEQ \times dt
                    UW(0) = 10000
                    RCACG = IF THEN ELSE ((CACG(t) - AAPG(t)) \ge 0, (CACG(t) - AAPG(t)), 0)
                    CMAVG = IF THEN ELSE ((RCACG(t) \geq WAFG(t)), WAFG(t), RCACG(t))
                    CACG = constant
                    PPO = constant
                    WAFG = IF THEN ELSE ((RDVG(t) - AAPG(t)) \ge 0, (RDVG(t) - AAPG(t)), 0)
                    CAFOS = constant
                    RRFO = constant
                    RDVG(t) = RRFO \times CAFOS \times CEPG(t)
                    CUPG = constant
                    PCG = constant
                    MPRG = constant
                    CCUPG(t) = CUPG \times UPC(t)
                    CATPO(t) = CACEQ(t) \times CCUPG(t) + CPA(t)
                    CUPS(t) = PCOS \times CCUPG(t)
                    UPC(t) = ([(0,0) - (24,2)], (0,1), (1,1), (2,1.5), (3,1.5), (4,1.5), (5,1.5), (6,1.5), (7,0.8), (8,0.8), (9,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), (10,0.8), 
(11,0.8), (12,0.8), (13,0.8), (14,0.8), (15,0.8), (16,0.8), (17,0.8), (18,0.8), (19,0.8), (20,0.8), (21,1), (22,1), (23,1), (24,1))
                    PTQCM(t) = ([(0,0) - (24,1000)], (0,0), (1,200), (2,400), (3,500), (4,500), (5,600), (6,600), (7,600), (8,600), (1,200), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,400), (2,40)
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(21,200),(22,200),(23,200),(24,100))
                    APTQ(t) = PTQNM(t) + CLQ(t)
                    ATQ(t) = PTQCM(t) + CLQ(t)
                    CLQ(t) = UW(t) - PRW(t)
                    CIPO(t) = DELAY1(CATPO(t)*MPRG, PCG)
                    CAIPG(t) = IF THEN ELSE((FBG(t) \ge CATPG(t)), CATPG(t), FBG(t))
                    CRIPG(t) = DELAY1(MPRS(t) \times CAIPG(t), PCS(t))
                    CAFG(t) = IF THEN ELSE((EFDIP(t) \ge CMAVG(t)), CMAVG(t), EFDIP(t))
                    CCEG(t) = CATPO(t) \times CRG
                    CRG = constant
                    CEPG(t) = AAEG(t) - AAES(t)
                    PCOS = constant
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EPS(t) = APTQ(t) \times CUPS(t) \times MPRS
MPRS = constant
CCEG(t) = CATPO(t) \times CRG
ICIG = constant
PPG = constant
ICIS = constant
CAFS(t) = IF THEN ELSE((EFDP(t) \ge CMAVS(t)), CMAVS(t), EFDP(t))
CCIS(t) = IF THEN ELSE((FBS(t) \ge FSICM(t)), FSICM(t), FBS(t))
CACS = constant
RCACS(t) = IF THEN ELSE((CACS(t) \ge AAPS(t)), (CACS(t) - AAPS(t)), 0)
CMAVS(t) = IF THEN ELSE((RCACS(t) \ge WAFS(t)), WAFS(t), RCACS(t))
WAFS(t) = IF THEN ELSE((RDVS(t) \geq AAPS(t)), (RDVS(t) - AAPS(t)), 0)
EFDP(t) = IF THEN ELSE((FBS(t) \ge FSINM(t)), 0, (FSINM(t) - FBS(t)))
CEPS(t) = AAES(t) - AICS(t)
RDVS(t) = CEPS(t) \times CDFGS \times RRFG
CDFGS = constant
RRFG = constant
FSINM(t) = APTQ(t) \times CRS
FSICM(t) = ATQ(t) \times CRS
CRS = constant
PRW(t) = ([(0,0)-(24,12000)], (0,10000), (1,9800), (2,9400), (3,8900), (4,8400), (5,7800), (6,7200), (7,6600), (6,7200), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,6600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600), (7,600)
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(8,6000), (9,5400), (10,4900), (11,4400), (12,3900), (13,3500), (14,3100), (15,2700), (16,2300), (17,1900), (18,1500), (19,1100), (20,700), (21,500))

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