Cost-Based Scheduling Method Using Object-Oriented Approach

Su-Ling Fan[1], Heap-Yih Chong[2], Tsung-Wei Hung[3] and Yen-Chih Wang[4]

ABSTRACT

Cost and schedule performances share common variables for effective project control. However, the real-world implementations of breakdown structures for cost and schedule are at different levels of detail, which makes the integration of cost and schedule information quite complex. Given the pressing need for an effective yet relatively easy-to-compile approach, this research proposes an innovative scheduling approach that enables contractors to develop a schedule based on the pay items in the contract during the tendering and construction phase. By using Microsoft Visual C#, a system with the proposed approach is implemented and, thus, pay items and schedule information are automatically integrated. A case study is investigated to demonstrate the merits of this system. The research shows a true synchronization between the cost and schedule functions. It provides useful insights into future project planning and scheduling in construction projects.

1. Introduction

The effective integration of cost and schedule control systems has become an issue of concern for researchers and practitioners in the construction industry [14]. Many researchers have emphasized the benefits of this integration, and several different methodologies combining cost and schedule control data have been developed [14, 17].

The interdependency between schedule and cost is obvious, as costs and schedules are closely interrelated in terms of their control process as they share common data, such as budgeted cost, resources, and quantities. However, in practice, they often remain two separate functions performed independently of each other and use two different structures: the work breakdown structure (WBS)

[1] Director of Research Development Center of Construction Law ; Assistant Professor of Dept. of Civil Engineering ,Tamkang University, No. 151, Ying-Chuan Road, Tamsui, Taipei County, Taiwan. E-mail: fansuling@hotmail.com

[2] Senior Lecturer, School of Built Environment, Curtin University, Australia.

[3] Master, Department of Civil Engineering, Tamkang University.

[4] Master, Department of Civil Engineering, Tamkang University.

[1,10,] and the cost breakdown structure (CBS) [5,8,19]. Much research has been proposed to integrate cost and schedule information [14, 17]; however, because CBS is usually generated by designers in the design phase as a form of the schedule of rates, and WBS is generated by contractors in the tendering phase of construction and a schedule is generated based on WBS to obtain meaningful information, the project scheduler needs to link schedule activities to the cost accounts, namely, pay items. However, because the breakdown structures as well as the level of detail used by each function are different, it creates fundamental difficulties in linking scheduling activities to cost accounts, which makes the integration of cost and time consumption impossible at times and, in some cases, a cost account is not related to any scheduling activities and a schedule activity is not related to any cost accounts.

Therefore, instead of attempting to link these cost and schedule information, as with the two different sets of data in the previous research, this research proposes an innovative scheduling approach that enables contractors to develop a schedule based on the pay items during the tendering and construction phases. With this proposed approach, the scheduling activities are integrated with the pay items automatically. As a result, this system with the proposed approach is implemented using Microsoft Visual C#, so that the contractor can develop a schedule in the construction planning stage based on pay items, in which pay items and schedule information are automatically integrated. The schedule generated by the system can be exported to MS-Project for future schedule updates, cost analysis, or Earned Valued Management after the progress of the project.

2. Literature Review

Projects have the basic objective of completing the project in minimum time and cost with no compromise in quality. All that stakeholders need to know is the project status at any given stage, which should provide an accurate view of the schedule and cost. A construction plan would have the total scope of the project defined in a required sequence along with both their time and cost data. The project is divided into high-level, manageable chunks of work called the Work Breakdown Structure (WBS) and the Cost Breakdown Structure (CBS) for tracking time and cost. These high-level elements are broken down into activity-level elements that have the job description, time information, and cost information pertaining to labor, materials, and equipment. The CBS follows a typical hierarchical structure for reporting all cost information by aggregating totals of costs that make up the activity-level elements to a summary-level account called the “Control Account.” The WBS follows a typical hierarchical structure, and effective schedule control is achieved by reporting at different levels as required by the stakeholders.

Cost and schedule controls are basic and important tools for managing projects. The cost and schedule performances share common variables, and if they share a common WBS [2] their effective integration is of primordial importance for project performance. However, the different levels of detail for the schedule and cost data have been the fundamental problem of the schedule-cost integration, which can be traced to the inherent constraints of time and cost information in the project [17]. For example, there will be variances of cost and duration in different progress or stages of a project [5]). Therefore, differences between the information hierarchy between low-level items of both cost and schedule make an effective level of integration extremely difficult. It would be ideal to control cost and schedule elements in a project with a common denominator.

The hierarchical structure of data elements in a costs database and the low-level WBS elements in a project schedule do not generally have a matching level.

The integrated structure requires that some fundamental questions be addressed regarding the project at an activity level, which provides critical information to stakeholders, namely: With the objective of generating a sound integrated plan, many efforts have been previously made to integrate cost and schedule data. However, a typical CBS cost baseline would not have information about the location of the activity, and a typical WBS would not have any information on the project organization structure. Proposed WBS-based models to overcome this problem are Telcholz’s model [18], Hendrickson’s model [11], and Eldin, N. N. [7], which integrate cost and schedule by linking a pay item to a schedule based on the assumption that CBS provides cost information and WBS provides schedule information, which provide both cost and schedule information. Hierarchical CBS and WBS models are effective at representing one-dimensional information flow but lack the flexibility in retrieving information from various viewpoints. Also, models based on hierarchy are lacking in various levels of detail, and they create too many Control Accounts (CA) that, in turn, create a complex data structure and data redundancies.

Kang and Paulson [15] proposed a standard classification-based model by combining the project-coding system with the construction information-classification system (CICS) into a notion system, which was a combination of four facets, namely, facility, space, element, and operation. Although this model offered greater flexibility compared to WBS-based models, its suitability for large projects came with severe limitations, mainly relying on a specific classification, a longer code system, and limited support functions. However, this model could be implemented on small civil projects with a small number of zonings and elements. Jung and Woo [14] proposed a flexible WBS-based system for cost and schedule integration. Instead of a fixed WBS numbering system, wherein different elements of the WBS have a rigid hierarchal structure, which makes data acquisition and integration extremely difficult and amassed data are mostly redundant, the flexible WBS allows for collating information on any level of the WBS hierarchy while keeping the interdependency among facets, which allows raw data to be used for other purposes. However, this cannot be a “global” approach, as a decision for the number of CAs in a project varies from project to project and is dependent on project delivery, contract type, and management policies of the organization.

One of the most accepted models to date is the Work Packing Model [17], which aims to overcome the limitations of the CBS and WBS structures by (1) eliminating CBS, (2) adding cost data to WBS, (3) linking WBS to OBS at the lowest level and formulating the CA as a common denominator for cost, schedule, and performance management. However, this can cause critical issues in data acquisition for project controls by developing too many CAs, which can be difficult in tracking and monitoring cost and schedule performance. Hence, the overhead expenditure required a critical factor toward its practical impact.

In conclusion, the previous studies have used different models to overcome the specific cost-schedule integration dilemma for different industries and scenarios. However, this is still an ongoing problem that we have not been able to formulate into a generic model that can be used across all types of industries and scenarios.

3. Methodology

The structure of the paper begins with the proposed model. The research methodology seeks what knowledge is required for integrating cost and time, and how it can be acquired to address the project planning. It adopted an epistemological assumption, where the model is produced and verified using deductive reasoning [3]. Subsequently, the model has been validated and tested in a practical case study.

The structure of the paper is organized as follows:

1. The proposed model is developed based on an object-oriented approach to discuss how a schedule can be generated from the Pay Items.
2. A cost-based scheduling method is used and developed as a system using Microsoft-Visual C#.
3. Subsequently, the functions of the system are examined using a case study to demonstrate its feasibility and benefits.

4. Proposed Model

With an object-oriented approach, the proposed model with a schedule from the pay item is analyzed.

4.1 Class Diagram

There are many Work Items, Pay Items, Areas, crews, and activities in a project. Each activity consists of the Work Item to be performed and the area where it is being performed. The class diagram of the proposed object-oriented model is illustrated in Figure 1. The asterisk (*) denotes "many."

The following seven classes are introduced:

1. Project Class: This class is about how a project progresses. In a project, there are many Pay Items, Work Items, Areas, and crews. This research defines an activity as the Work Item that is performed in one specific area and how it will differ from other Work Items in other Areas. The proposed model conceives that in each project there will be many Areas, Pay Items, activities, Work Items, and crews. Although these Areas, Pay Items, activities, and Work Items are specific to one project, the crews can be used in different projects. Therefore, a Project Class has one-to-many relationships with Area Class, Pay Item class, Activity Class, and Work Item class, and it has a many-to-many relationship with Crew Class.

2. QCell Class: This class is meant to keep the quantity of Pay Items to the related Work Items in one particular Area to be performed. Therefore, it has a many-to-one relationship to these three classes: Pay Item class, Work Item class, and Area Class. It also has a many-to-one relationship to the Activity Class.

3. Pay Item Class: This class refers to the item that composes the cost of the project. For each Pay Item, there might be different Work Items involved, and for each Work Item there might be different Pay Items involved, therefore, this class has a many-to-many relationship to the Work Item class. Similarly, for each Pay Item, there might be different Areas, activities, and crews involved, and for each area, activity, or crew there might be different Pay Items involved. Hence, this class also has a many-to-many relationship to the Area, Activity, and Crew Classes.

4. Area Class: This class discusses where the work is to take place. As mentioned above, the Area Class has a many-to-many relationship with the Pay Item class. This system assumes that for each Area there might be more than one activity to be performed, but for each activity

there should be one Work Item performed in only one Area. Therefore, this class has been designed as a one-to-many relationship with the Activity Class.

5. WorkItem class: This class is about the work being performed; it has a many-to-many relationship with the PayItem Class. This system also assumes that for each Work Item in a different area it becomes another activity, therefore, it will consist of more than one activity; but for each activity, there should be only one Work Item performed in one Area. Hence, this class also has been designed as a one-to-many relationship with the Activity Class.

6. Crew Class: This class is about the crew who perform the Work Items. Each crew might perform different activities and, for each activity, more than one crew might be needed. Therefore, this class has a many-to-many relationship with the Activity Class.

7. Activity Class: This class is about the detailed activity in the schedule, which categorizes under a Work Item at one particular working area (Area). It has a many-to-many relationship with the Crew Class, PayItem Class; a many-to-one relationship to the Area Class, WorkItem Class, and Project Class; and a one-to-many relationship to the QCell Class.

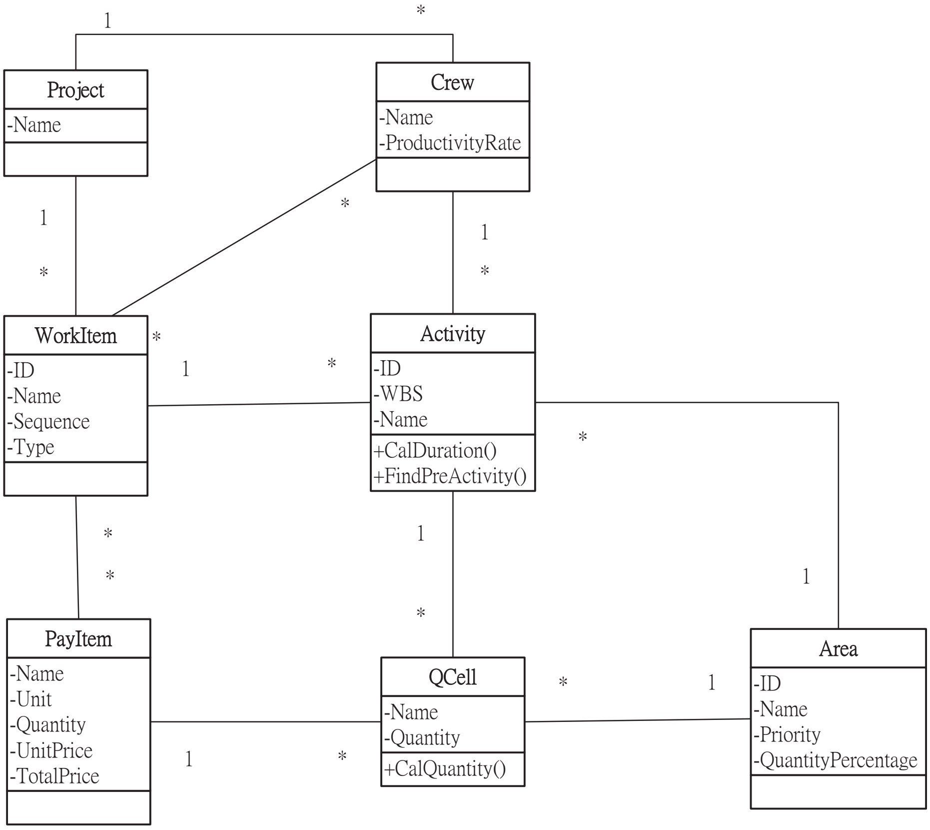


Figure 1: Class diagram for the proposed model.

4.2. Attributes and Methods

1. Project Class: The attribute of the Project Class is Name, which refers to the project name.

2. QCell Class: Table 1 shows the attributes of the QCell Class. The Name of QCell is the combination of the name of its related PayItem and area. The method of the QCell Class is CalQuantity, which is to calculate the quantity of the QCell. The quantity of QCell is either input directly by the user or equals to the quantity of its related Pay Item and its related quantity percentage.

Table 1 Attributes of QCell Class

Attributes	Data Structure	Example
Name	String	“Rebar-Area A”

Quantity	Double	124.31

3. PayItem Class: Table 2 shows the attributes of the Pay ItemClass and the related units of measurements.

Table 2 Attributes of PayItem Class

Attributes	**Data Structure**	**Example**
Name	String	Rebar
Unit Price	Double	30,290
Quantity	Double	191.25
Unit	String	Tons
Total Price	Double	5,792,963

4. Area Class: Table 3 shows the attributes of the Area Class. The priority of the area denotes the preferences or the concerns of the sequence of the works in that area and how they will be performed rather than the works in other Areas. The lower the priority number, the higher the priority. For example, if the priority of Area A is 1 and the priority of Area B is 2 then, if given only one crew, the crew will perform work in Area A first then Area B; however, if given two crews, work in both Areas will be performed.

Table 3 Attributes of Area Class

Attributes	**Data Structure**	**Example**
Name	String	Area A of 1F

Priority	Double	1

5. WorkItem Class: Table 4 shows the attributes of the WorkItem Class. The sequence of the Work Item denotes the sequence of the work to be performed because of technical reasons. The lower the sequence number, the earlier the work should be performed. The type “soft” refers to the Work Item that can be worked in other Areas once its technical predecessor (or the second predecessor) has been finished. The type “fixed” means that all the Work Items with this designation should be finished in the same area before proceeding to the next Area. For example, a “concrete” Work Item should be performed after the “tie rebar” Work Item; therefore, if the sequence number of the “tie rebar” is 1, then the sequence number of “concrete” will be 2. Both “Rebar Tie-Up” and “Concrete Pouring” on the next floor won’t proceed until the Concrete Pouring is finished; therefore, the type of both is “fixed.” However, with Work Items like “Painting,” the type shall be “soft” because to start 2F of Painting doesn’t require all Work Items of 1F to be finished.

Table 4 Attributes of WorkItem Class

Attributes	Data Structure	Example
Name	String	Rebar Tie-Up
Sequence	Double	3
Type	String	Fixed

6. Crew Class:

Table 5 shows the attributes of the Crew Class. The Productivity Rate explains the productivity rate of the crew in terms of the quantity can be done in one unit of the duration.

Table 5 Attributes of Crew Class

Attributes	Data Structure	Example
Name	String	Rebar Tie-Up
Productivity Rate	Double	8 (T/Day)

7. Activity Class:

Table 6 shows the attributes of the Activity Class. The name of an activity is the combination of the name of its related area and the name of its related Work Item.

Table 6 Attributes of Activity Class

Attributes	Data Structure	Example
Name	String	Area B of 1F Rebar Tie-Up
Duration	Double	10 days
Predecessor	Double	Area B of 1F Rebar Tie-Up
Quantity	Double	124.31 (T)
Pay Item Name	String	Rebar
Quantity Percentage	Double	65%

Activity Class serves two functions. The details are as follows:

(1) CalDuration Method: The CalDuration method calculates the duration of the activity, which is the quantity of its related QCell divided by the productivity rate of the crew of this activity.

(2) FindPreActivity Method: The FindPreActivity Method determines the predecessors of the activity. This system assumes that for each activity there are two predecessors. Termed the Area Predecessor, the first predecessor is assumed to be a resource reason. The second, owing to technical reasons, is termed the Technical Predecessor.

The activity of a soft Work Item type refers to the Work Item that can be worked in other Areas once its technical predecessor has been finished. The Area Predecessor searches for the activities using the same crew. Among all items, the Area has a higher priority (in this system the lower the number, the higher the priority), but the closest one is its predecessor. If there is no activity that uses the same crew in an area that is of a higher priority, then the activity of the same crew in the Work Item is the predecessor.

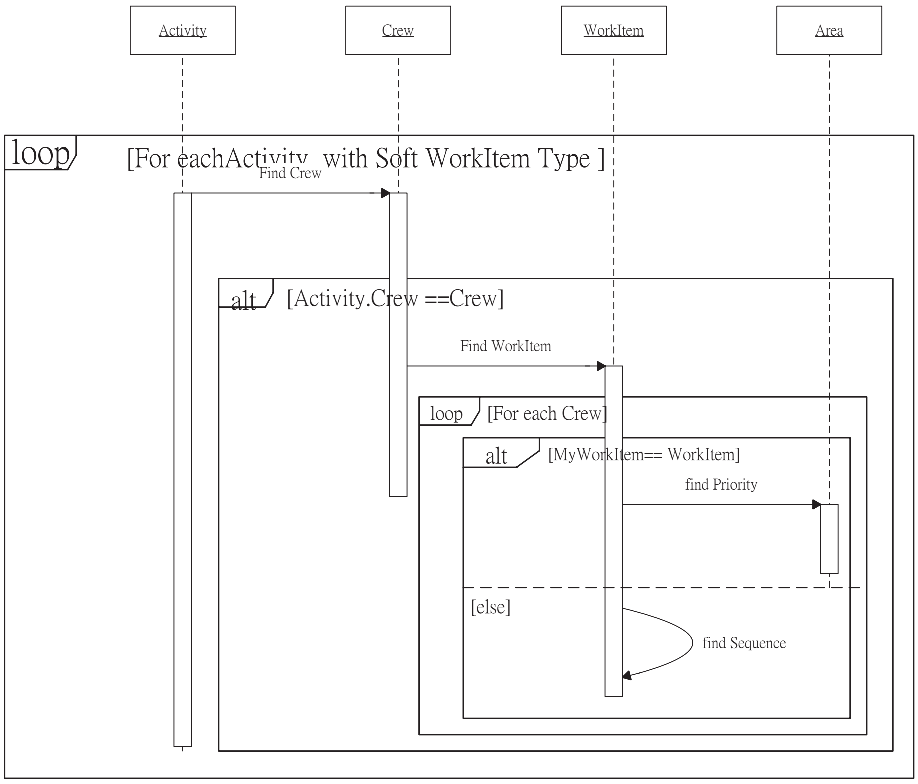


Figure. 2: Area Predecessor with Fixed Work Item Type

However, if the type of the related Work Item of the activity is fixed, meaning that all the Work Items with lower sequences should be finished in the same area, then the Area Predecessor of the activity will be the last Work Item with fixed type in the Area with a lower but closer priority; there is no Area predecessor for this activity if one is not found.

Figure 3 illustrates the method to find the second predecessor. Alternatively, this system calls it a Technical Predecessor, which is to find the activities to be done within the same area; however, because of technical reasons, one activity must be done before another activity, such as “Rebar Tie-Up” must be done before “Concrete Pouring,” for example. In an activity in this same area, the related Work Item should be sequenced first, which means there’s a search for activities in the same area with the sequence of its related Work Item lower than but closest to the sequence of the related Work Item.

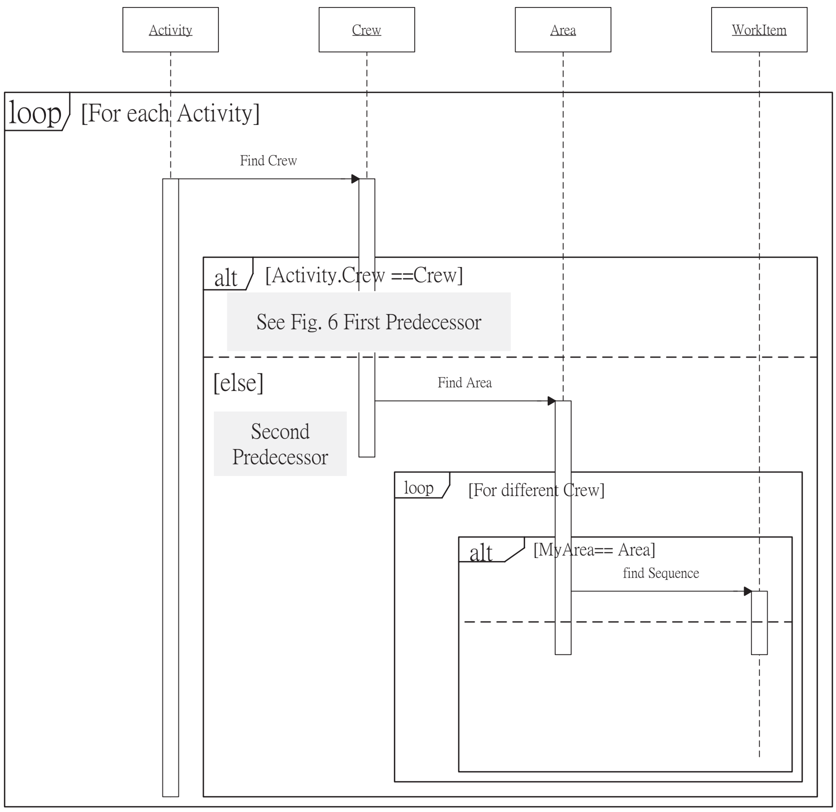


Figure. 3: Technical Predecessor

5. System Implementation

The proposed model is implemented using Microsoft Visual C#. There are 8 tabs of the system.

Table 7 shows the different approach in the proposed system than in the current process.

247 **Table 7: Comparisons of the Proposed Model to the Current and Previous Research**

Current Practice and Previous Research [Del Pico 2013]	Proposed Model	Comparison
Schedule Generation		
1. Defining Activities: (1) Define Works to be done based on the drawings and specifications of the project.	**1. Defining Activities:** (1) Import the Pay Items as in Fig. 5, then define Works to be done (named Work Items in the research) based on cost accounts in the schedule of rates of the contract (termed as Pay Items in the research) in the PayItem tab in Figure 7.	Work Items are defined separately, which make the breakdown structure and level of details of Work Items very different to the Pay Items.
(2) Defining Areas to perform the work based on the drawings and specifications of the project.	(2) Defining Areas to perform the work based the drawings and specifications of the project as in the Area Tab in Figure 6.	Same.
(3) Defining activities based	(3) Activities are defined	In a similar process, however, one

on the works to be done and the area to perform the work manually.	based on the work to be done and the area to perform the work automatically in the "Name" column of the Activity Tab in Figure 11.	is done automatically by the system, whereas one is done manually. For example, in step 1, if one of the Work Items defined is "Rebar Tie-Up," and in step 2 the area to perform the work is BF, 1F, 2F, 3F, and 4F, then activities "Rebar Tie-Up in BF," "Rebar Tie-Up in 1F," "Rebar Tie-Up in 2F," "Rebar Tie-Up in 3F," and "Rebar Tie-Up in 4F" are defined manually in the current process, whereas they are generated automatically after defining areas and Work Items.
2. Defining Durations: The durations of activities are calculated based on the quantity of work to be done and the productivity of the crews performing the work manually.	**3. Defining Durations:** By inputting the quantity of work to be done in each Area in the Quantity Tab in Figure 9, the productivity of the crews performing the work in the Crew Tab in Figure 8, the Crew to perform the work in each Area in the ChooseCrew Tab in	In the same process of calculation, however, it is done by the system, whereas in the current process the calculation is done manually. For example, if the quantity of the "Rebar Tie-Up in 1F" is 10 tons and the productivity of the crew performing the "Rebar Tie-Up in 1F" is 1 ton per day, the calculation of duration = quantity/productivity rate is done manually in the current

	Figure 9, the durations of the activities are calculated automatically in the "Duration" column of the Activity Tab in Figure 11.	process, but it's automatically calculated by the system.
3. Defining Logics: Logics between activities are defined based on technical reasons, site layout concerns, and crew allocations.	**3. Defining Logics:** After the technical reasons (defined by the sequence of Work Items in the system in the WorkItem tab in Figure 7), site layout concerns (defined by the priority number of Areas in the Area Tab in Figure 6) and crews allocation (defined by the matrix of Crews to Areas in the system in the ChooseCrew Tab in Figure 10), the system automatically defines the logics in the "Predecessors" column of the Activity Tab in	Logics are automatically defined after the factors influencing logics, namely, technical reasons, site layout concerns, and crew allocation, are defined.

	Figure 11.	
4. Cost-Time Integration Linking the schedule activities to the Pay Items and define the related percentages.	4. Cost-Time Integration Linking of the schedule activities to the Pay Items and the related percentages are done automatically in “PayItemName” column of the Activity Tab in Figure 11.	The time-consuming or even infeasible linking of the schedule activities to the Pay Items and the related percentages are done automatically.
Schedule Update		
Schedules are updated according to the actual progress of the project and the EVM (Earn value management) are performed.	The schedule generated by the system is exported to the MS-project for the use of scheduling updates and EVM.	Same

1. Project Tab

Figure 4 illustrates the Project Tab, which the user may insert the name of the project.

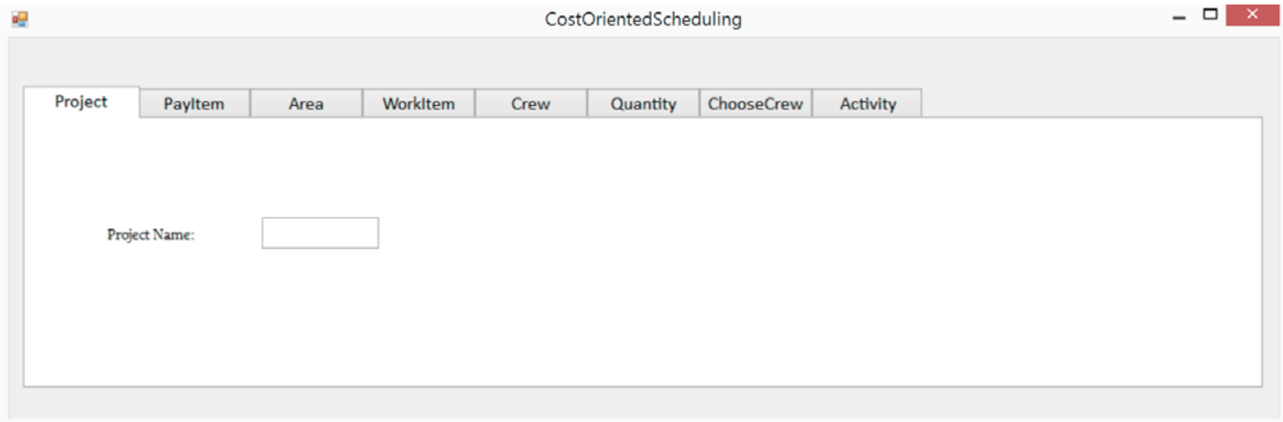


Figure 4: Project Tab

2. PayItem tab

Figure 5 illustrates the PayItem tab, which allows the user to either insert the Pay Items in the schedule of rates of the contract by filling in the Name, Unit, Quantity, Unit Price, and Total Price data, or to import these data from an Excel file.

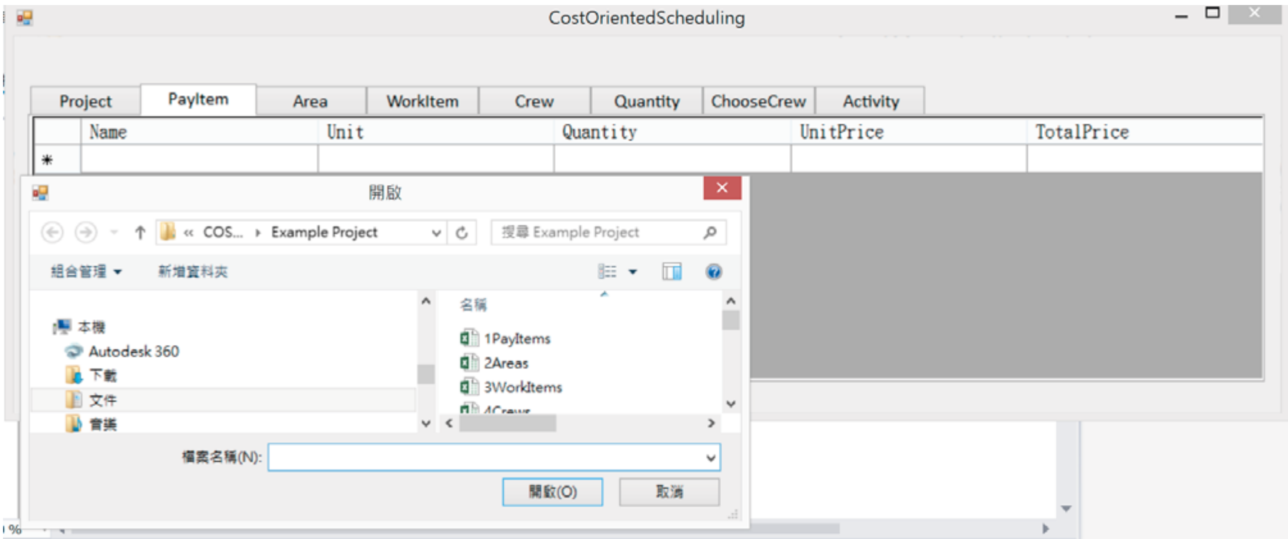


Figure 5: PayItem tab

3. Area Tab

Figure 6 illustrates the Area Tab, in which the user may insert the Name and the Priority of the Area, or import these data from an Excel file. The priority of the Area refers to the technical sequence of the Area to be performed.

The quantity percentage refers to the percentage of the quantity of a Pay Item in the Area to the total quantity of that Pay Item in which it assumes that for each Area the percentage is the same for each Pay Item. If it's not the case, the user then leaves the QuantityPercentage column blank and inputs the exact quantity later in the Quantity Tab.

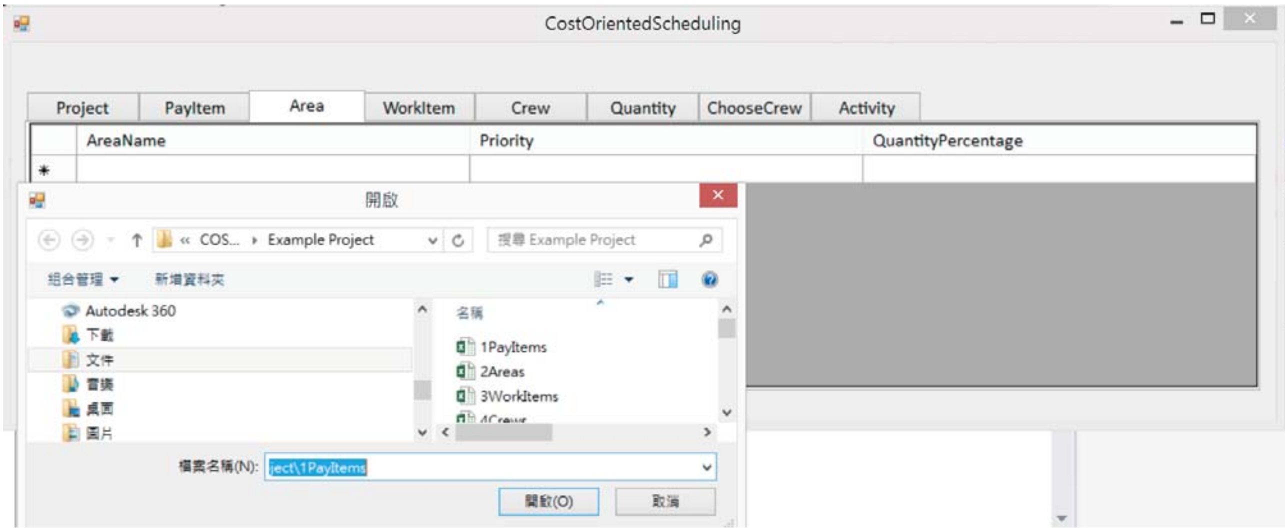


Figure 6: AreaTab

4. WorkItem tab

Figure 7 illustrates the WorkItem tab, in which the user may insert the Name, Sequence, Type of the Work Item according to the Pay Items imported from PayItem tab, or import these data from an Excel file.

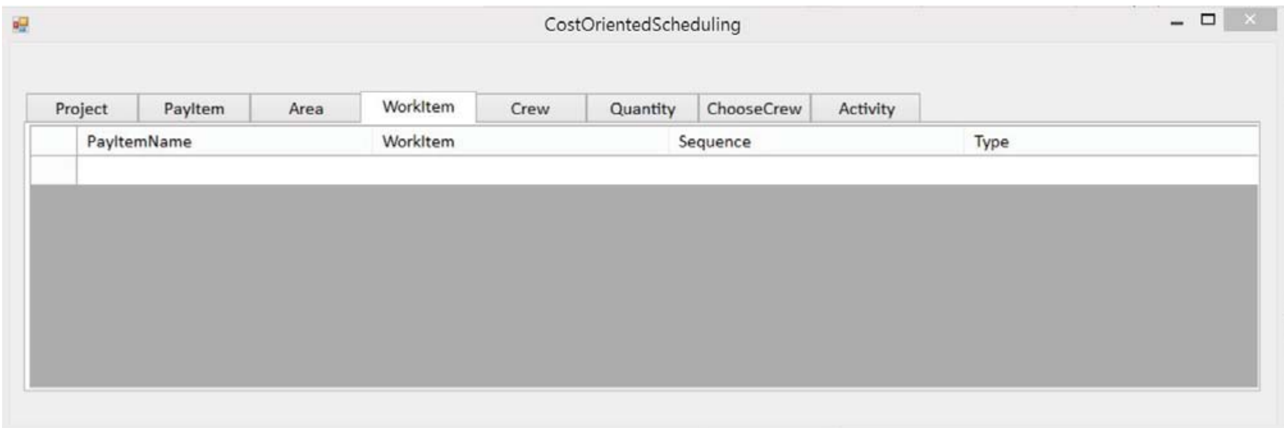


Figure 7: WorkItem tab

5. Crew Tab

Figure 8 illustrates the Crew Tab, in which the user can insert the name and productivity rate of the crews according to the Work Items imported from WorkItem tab or import these data from an Excel file.

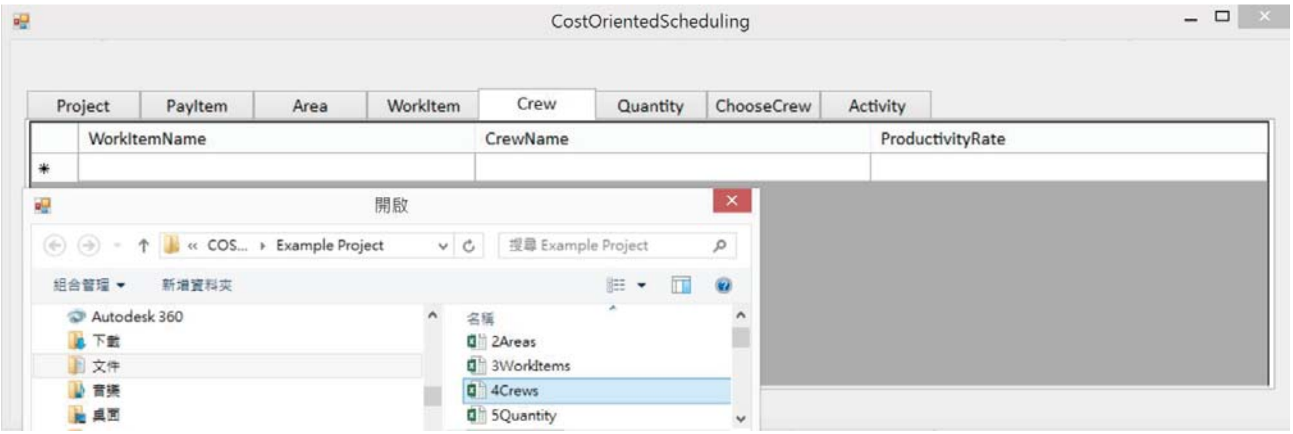


Figure 8: Crew Tab

6. Quantity Tab

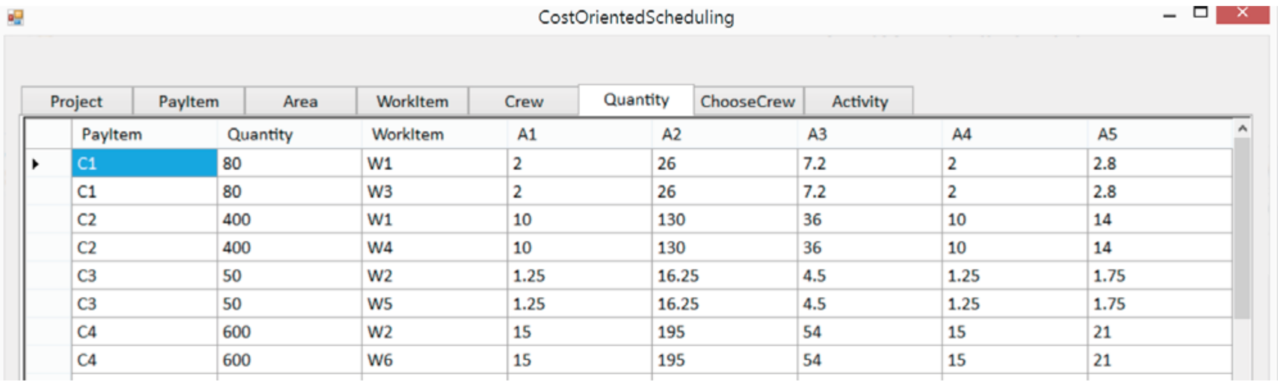
Figure 9 illustrates the Quantity Tab, which in the columns "Pay Item" and "Quantity" display the names and quantities of the Pay Items. They are imported from the Excel file in the PayItem tab, and the "Work Item" column displays the Work Item that is linked to the Pay Item by the WorkItem tab. The title of the following columns displays the Areas in that project that is imported from the Area Tab. By this table, a matrix of different Work Items to different Areas is shown, and the user can fill in the cell of matrix to show the quantity of each Work Item in a different area; the summation should equal the quantity of that Pay Item in different Work Items. The default value of the quantity of each Work Item in each area is assumed as the equation below, and the user may revise the default value if necessary.

$$Q_{ij} = \Sigma (Q_{pi} / N_w * P_j)$$

Q_{ij} : Quantity of Work Item-i at Area-j

Q_{pi}: Quantity of the related Pay Item of Work Item-i

P_j : Quantity Percentage of Area-j

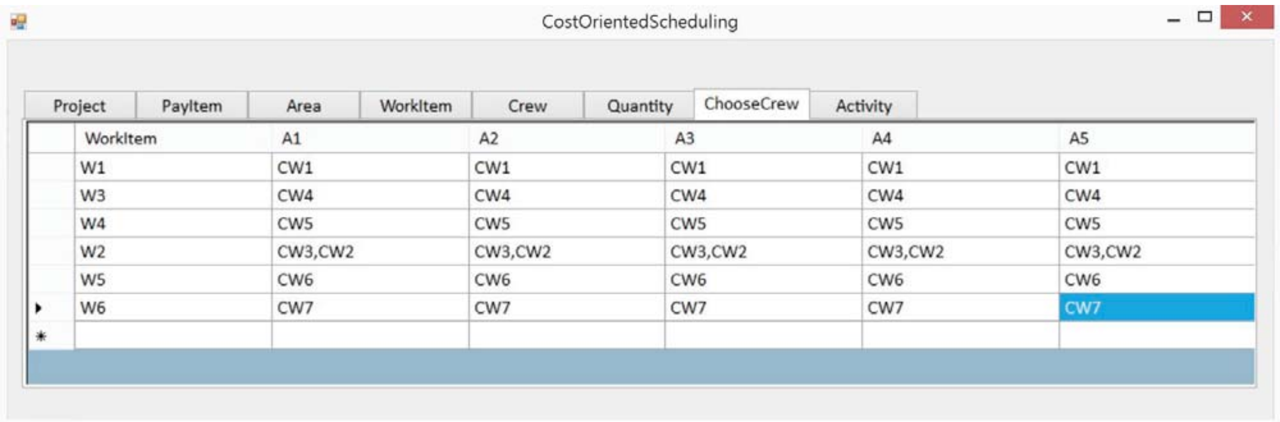


PayItem	Quantity	WorkItem	A1	A2	A3	A4	A5
C1	80	W1	2	26	7.2	2	2.8
C1	80	W3	2	26	7.2	2	2.8
C2	400	W1	10	130	36	10	14
C2	400	W4	10	130	36	10	14
C3	50	W2	1.25	16.25	4.5	1.25	1.75
C3	50	W5	1.25	16.25	4.5	1.25	1.75
C4	600	W2	15	195	54	15	21
C4	600	W6	15	195	54	15	21

Figure 9: Quantity Tab

7. ChooseCrewTab

Figure 10 illustrates ChooseCrewCrew Tab, which the column "Pay Item" and the column "WorkItem" display the names of the Pay Items and the related Work Items, the user can assign which crew shall perform the Work Item in different Areas. As in Figure 8, if there is more than one crew for the Work Item, more than one crew will be shown in the default value such like in Figure10, Work Item "W2" has two crews, namely, "CW3" and "CW2" , therefore "CW3, CW2" is shown in the table, and the user needs to delete the extra crews for the Area. It is explained in more detail in the example project in the next section.

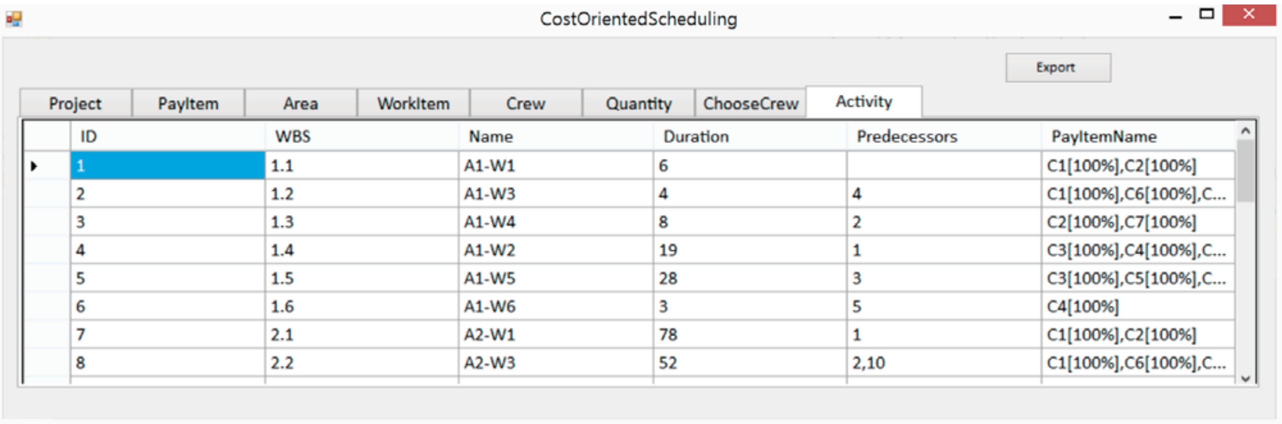


WorkItem	A1	A2	A3	A4	A5
W1	CW1	CW1	CW1	CW1	CW1
W3	CW4	CW4	CW4	CW4	CW4
W4	CW5	CW5	CW5	CW5	CW5
W2	CW3,CW2	CW3,CW2	CW3,CW2	CW3,CW2	CW3,CW2
W5	CW6	CW6	CW6	CW6	CW6
W6	CW7	CW7	CW7	CW7	CW7

Figure 10: ChooseCrew Tab

8. Activity Tab

Figure 11 illustrates the Activity Tab, in which the name, duration, Predecessor, related Pay Items, and the percentages are generated automatically. It can be exported to Excel and imported to MS-Project.



ID	WBS	Name	Duration	Predecessors	PayItemName
1	1.1	A1-W1	6		C1[100%],C2[100%]
2	1.2	A1-W3	4	4	C1[100%],C6[100%],C...
3	1.3	A1-W4	8	2	C2[100%],C7[100%]
4	1.4	A1-W2	19	1	C3[100%],C4[100%],C...
5	1.5	A1-W5	28	3	C3[100%],C5[100%],C...
6	1.6	A1-W6	3	5	C4[100%]
7	2.1	A2-W1	78	1	C1[100%],C2[100%]
8	2.2	A2-W3	52	2,10	C1[100%],C6[100%],C...

Figure 11: Activity Tab

6. Case Study

To demonstrate the merits of this proposed approach, an actual building project, which amounted to approximately 100,000,000 NTD with 821 Pay Items, were selected to perform in 5 Areas. However, there are too many items that cover Pay Items, Work Items, or other activities that make it difficult to demonstrate.

Therefore, the authors designed a simple example to demonstrate the process and function of the proposed system. Figure 12 shows the relationship of Pay Items, Work Items, Crews, and Areas of the example project. The process of developing the schedule with this system is explained in detail as follows.

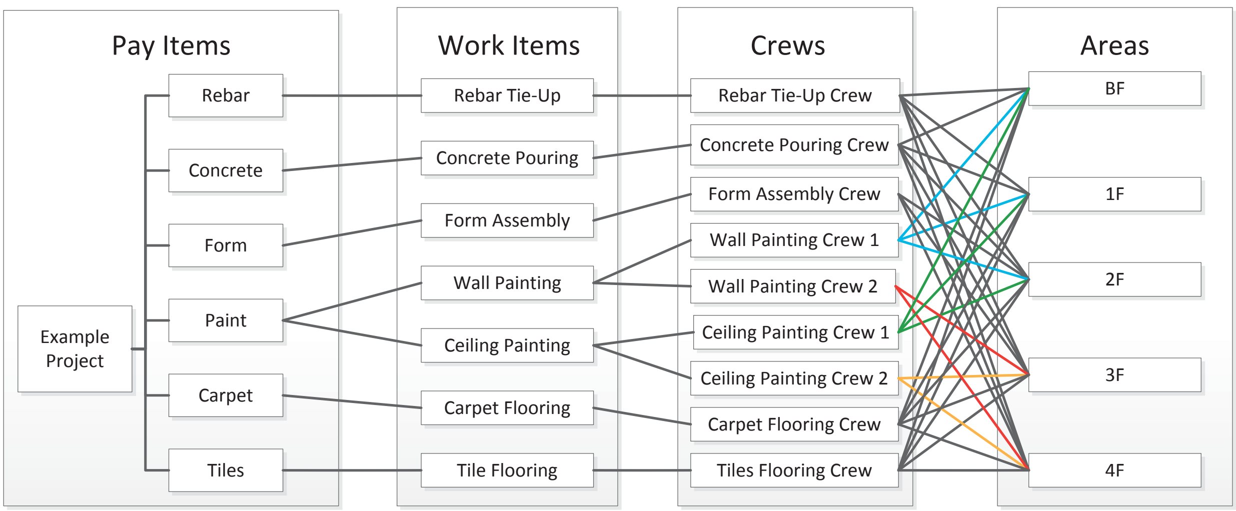


Figure 12: Relationship of Pay Items, Work Items, Crews, and Areas of the example project

6.1 Basic Data

The user inserted the basic data from the first 5 tabs, namely, the Project Tab, PayItem Tab, Area Tab , WorkItem Tab, and Crew Tab.

An example on the name of the project in the Project Tab was illustrated in Figure 13.

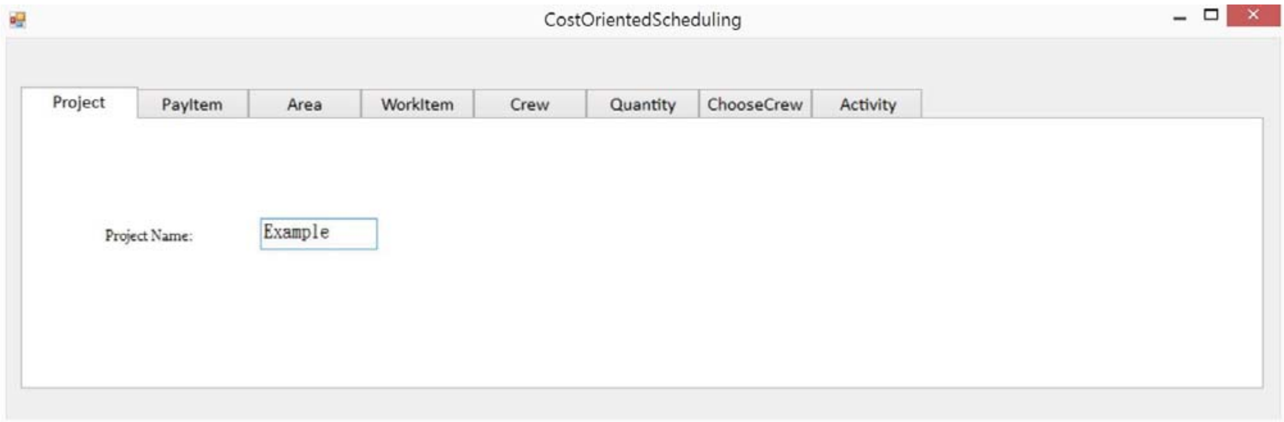
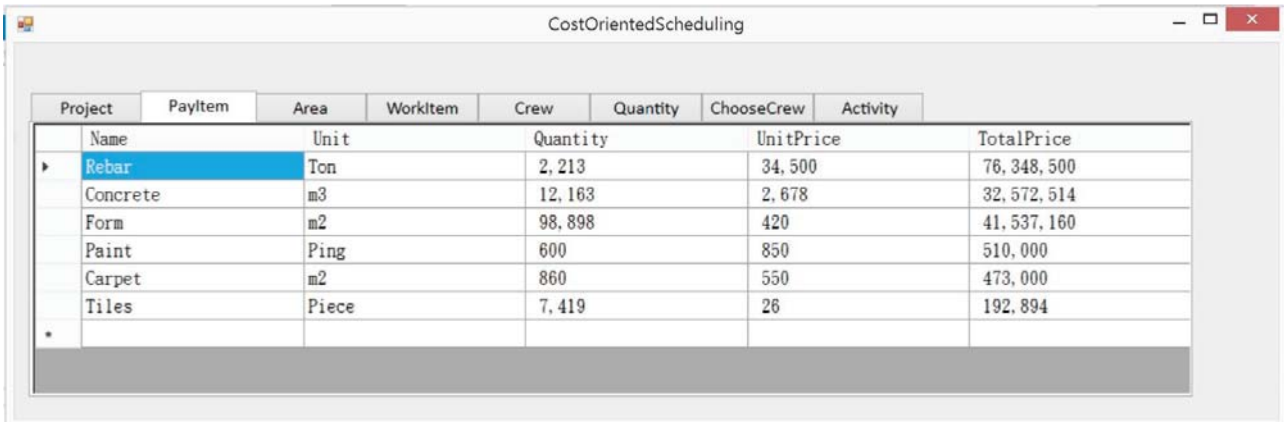


Figure 13: Project Name of the example project

From the schedule of rates, the user obtained the information of the Pay Items, as in the example project, there were 6 Pay Items as shown in the “Pay Item” box of Figure 12. The user inserted the data of these 6 Pay Items in the PayItem Tab as in Figure 14.



Name	Unit	Quantity	UnitPrice	TotalPrice
Rebar	Ton	2, 213	34, 500	76, 348, 500
Concrete	m3	12, 163	2, 678	32, 572, 514
Form	m2	98, 898	420	41, 537, 160
Paint	Ping	600	850	510, 000
Carpet	m2	860	550	473, 000
Tiles	Piece	7, 419	26	192, 894

Figure 14: Pay Items of the example project

From the WorkItem Tab, the names of Pay Items inputted in Figure 14 were shown in the first column of the WorkItem Tab as shown in Figure 15. The user could define the related Work Items in the second column, or insert one more row if necessary, as shown in Figure 12, or from the Pay Item “Rebar,” the Work Item “Rebar Tie-Up” was defined and also for the other 5 Pay Items as illustrated in Figure 15.

After that, the user defined the sequence of Work Items according to technical reasons; technically, the construction sequence of these 7 Work Items was “Form Assembly” → “Rebar Tie-Up” → “Concrete Pouring” → “Ceiling Painting” → “Wall Painting” → “Carpet Flooring” or “Tile Flooring.” Therefore, the sequence number for “Form Assembly” was 1, “Rebar Tie-Up” was 2, and so on. Moreover, as there was no fixed sequence between “Carpet Flooring” and “Tile Flooring,” the technical sequence numbering of “Carpet Flooring” and “Tile Flooring” was the same as shown in Figure 15.

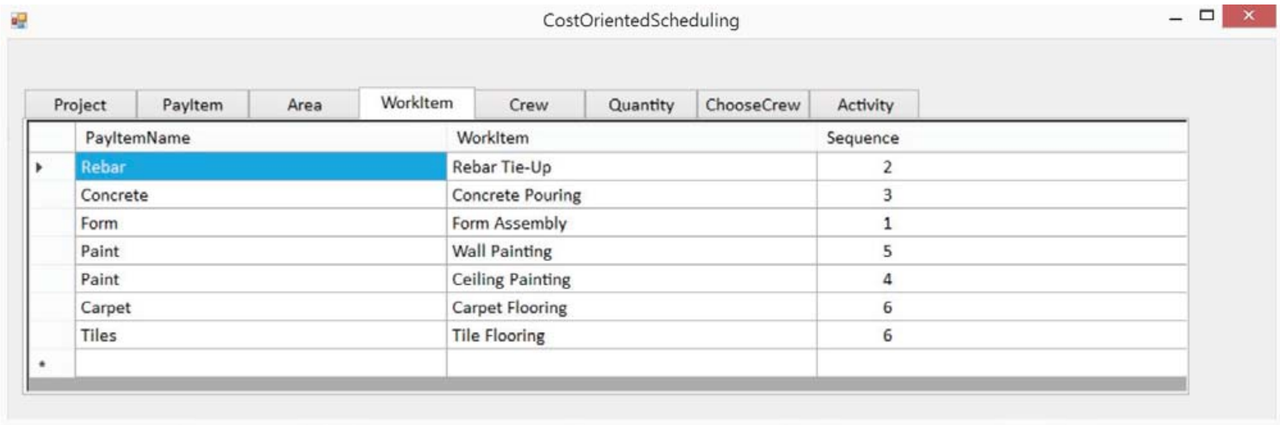
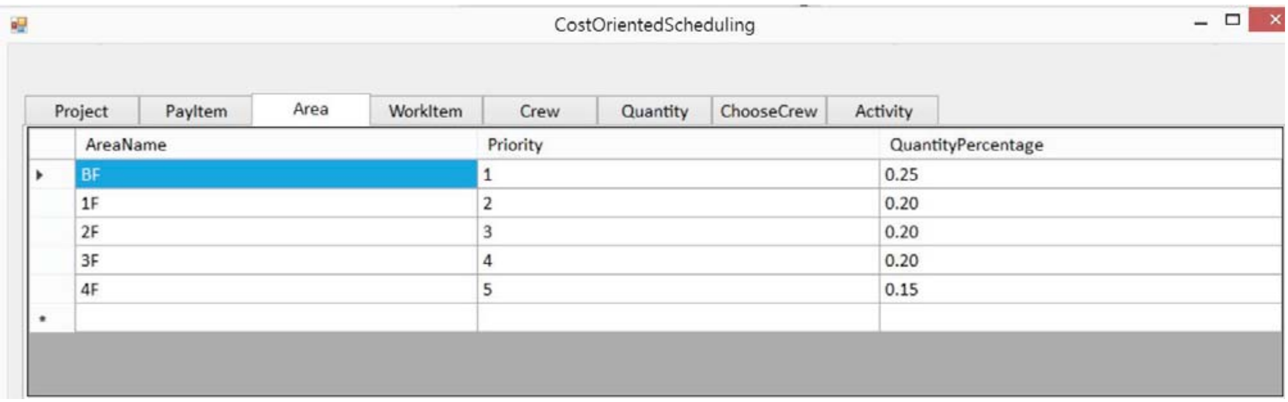


Figure 15: Work Items

From the drawing and the specifications of the project, the user further defined site layout and the Areas where Work Items would be performed. As in Figure12, there were 5 Areas, namely, BF, 1F, 2F, 3F, and 4F.

In the Area Tab, these 5 Areas were prioritized as in Figure 16. The priority of the Area referred to the technical sequence of the Area. As in this example, BF would be performed first and in the sequence 1F, 2F, 3F, and 4F, that was, BF → 1F → 2F → 3F →4F.

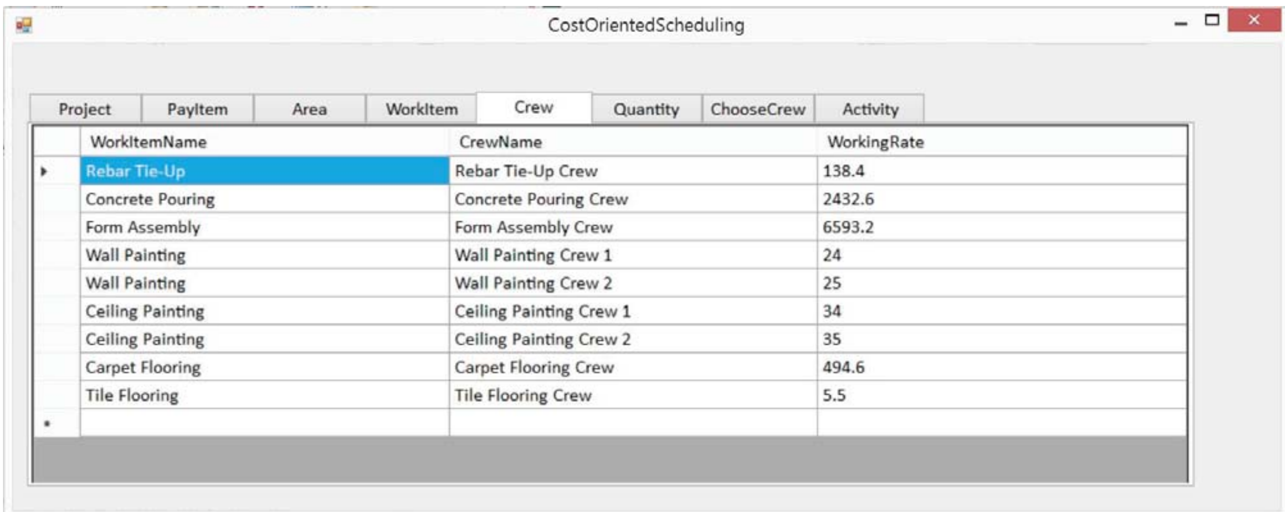
The quantity percentage then could be inserted or kept blank. The quantity percentage referred to the Percentage of the quantity of a Pay Item in the Area to the total quantity of that Pay Item in which it assumed that for each Area the percentage was the same for each Pay Item. If that was not the case, the user then could leave the QuantityPercentage column blank and insert the exact quantity later in the Quantity Tab.



AreaName	Priority	QuantityPercentage
BF	1	0.25
1F	2	0.20
2F	3	0.20
3F	4	0.20
4F	5	0.15

Figure 16: Areas of the example project

From the Crew Tab, the Work Items defined in the WorkItem Tab were shown in the first column, and the user could then define the crews to perform the Work Items accordingly, as shown in Figure 12. There was one Crew for each Work Item, except that there were two Crews for Wall Painting and Ceiling Painting. From past experience, the Working Rate of each Crew could be defined and inputted as illustrated in Figure 17.



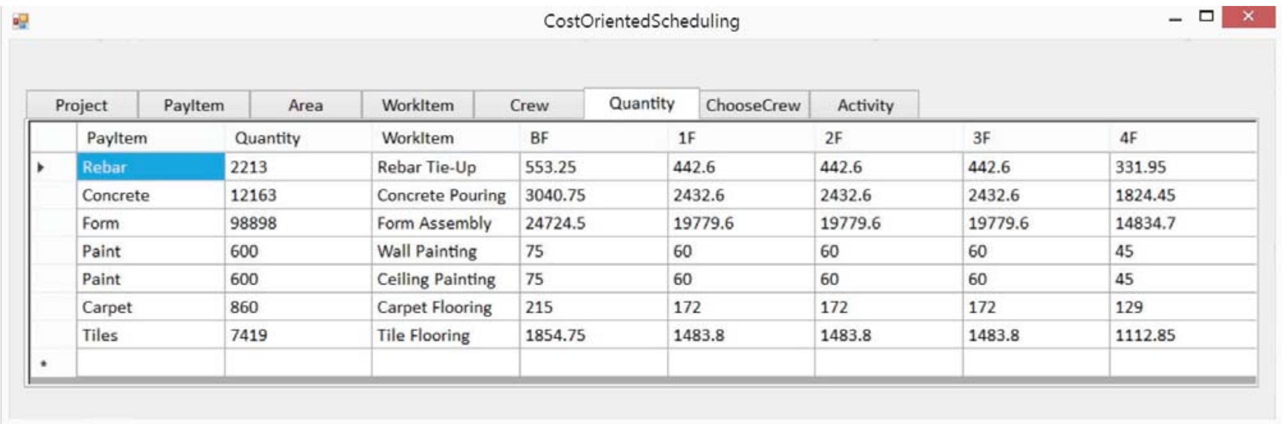
WorkItemName	CrewName	WorkingRate
Rebar Tie-Up	Rebar Tie-Up Crew	138.4
Concrete Pouring	Concrete Pouring Crew	2432.6
Form Assembly	Form Assembly Crew	6593.2
Wall Painting	Wall Painting Crew 1	24
Wall Painting	Wall Painting Crew 2	25
Ceiling Painting	Ceiling Painting Crew 1	34
Ceiling Painting	Ceiling Painting Crew 2	35
Carpet Flooring	Carpet Flooring Crew	494.6
Tile Flooring	Tile Flooring Crew	5.5

Figure 17: Crews

6.2 Further Criteria

After inputting or importing the basic data, there were two more sets of criteria to be defined.

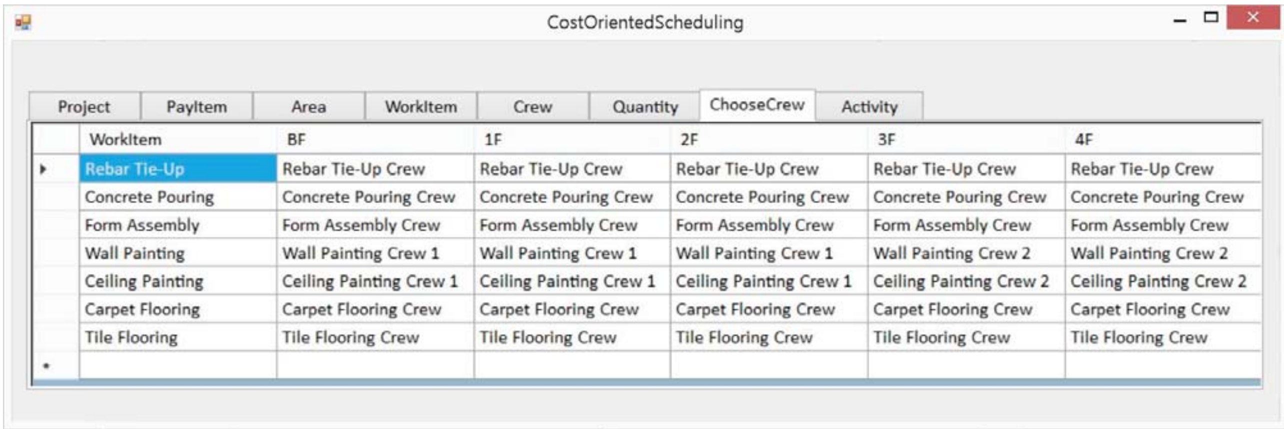
(1) From the Quantity Tab, the user may insert the quantity of the Work Item in each Area, or the user may choose to use the default ones, which is calculated by taking the quantity of each Pay Item by the quantity percentage data that is input in the Area Tab in Figure 16. As shown in the example project in Figure 15, from the “Paint” Pay Item, there were two Work Items “Wall Painting” and “Ceiling Painting,” and there are 5 Areas. The quantity percentages of Area 1 to Area 5 were 0.25, 0.2, 0.2, 0.2, and 0.15, respectively, as shown in the Area Tab. Therefore, the default quantity of “Wall Painting” in BF to 4F was the quantity of “Paint” (600) divided by 2 (as there are two related Work Items), then multiplies with the quantity percentages of each Area, which were 75, 60, 60, 60, and 45, as illustrated in Figure 18. The default values were approximate values; if the user has the exact quantity data, the user may revise the quantity data in the Quantity Tab as in Figure 18.



PayItem	Quantity	WorkItem	BF	1F	2F	3F	4F
Rebar	2213	Rebar Tie-Up	553.25	442.6	442.6	442.6	331.95
Concrete	12163	Concrete Pouring	3040.75	2432.6	2432.6	2432.6	1824.45
Form	98898	Form Assembly	24724.5	19779.6	19779.6	19779.6	14834.7
Paint	600	Wall Painting	75	60	60	60	45
Paint	600	Ceiling Painting	75	60	60	60	45
Carpet	860	Carpet Flooring	215	172	172	172	129
Tiles	7419	Tile Flooring	1854.75	1483.8	1483.8	1483.8	1112.85

Figure 18: Quantity of Work Items in Different Areas

(2) From the ChooseCrew tab, the user may input the Crew in each Area according to the Crew allocation as shown in Figure 12, that was, “Wall Painting Crew 1” works in as BF-indoor, 1F-indoor, and 2F-indoor, whereas “Wall Painting Crew 2” worked in 3F-indoor and 4F-indoor as illustrated in Figure 19.



WorkItem	BF	1F	2F	3F	4F
Rebar Tie-Up	Rebar Tie-Up Crew	Rebar Tie-Up Crew	Rebar Tie-Up Crew	Rebar Tie-Up Crew	Rebar Tie-Up Crew
Concrete Pouring	Concrete Pouring Crew	Concrete Pouring Crew	Concrete Pouring Crew	Concrete Pouring Crew	Concrete Pouring Crew
Form Assembly	Form Assembly Crew	Form Assembly Crew	Form Assembly Crew	Form Assembly Crew	Form Assembly Crew
Wall Painting	Wall Painting Crew 1	Wall Painting Crew 1	Wall Painting Crew 1	Wall Painting Crew 2	Wall Painting Crew 2
Ceiling Painting	Ceiling Painting Crew 1	Ceiling Painting Crew 1	Ceiling Painting Crew 1	Ceiling Painting Crew 2	Ceiling Painting Crew 2
Carpet Flooring	Carpet Flooring Crew	Carpet Flooring Crew	Carpet Flooring Crew	Carpet Flooring Crew	Carpet Flooring Crew
Tile Flooring	Tile Flooring Crew	Tile Flooring Crew	Tile Flooring Crew	Tile Flooring Crew	Tile Flooring Crew

Figure 19: Crew Allocation

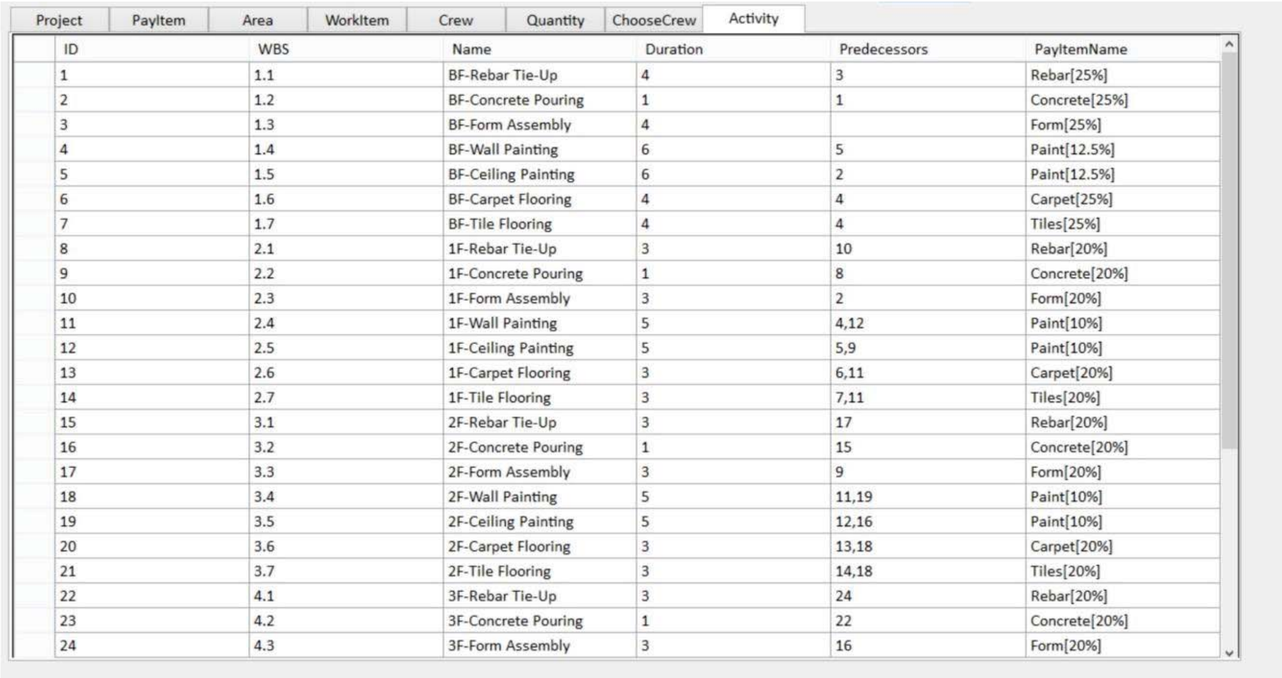
7. Result

After the above-mentioned process, the system generated a schedule with activities based on the input shown in Figure 20.

Activities were defined and named as Area Name-Work Item Name. As shown in Figure 12, there were 7 Work Items to be performed in 5 Areas; therefore, there were 7 * 5 = 35 Activities as shown in Figure 20. Then, it exported to MS-Project, where, the name, duration, predecessors, Resource (the Pay Item and Percentage), and Earned Value at Completion (EAC) were exported in MS-Project for revision and the future schedule update or EVM as shown in Figure 21.

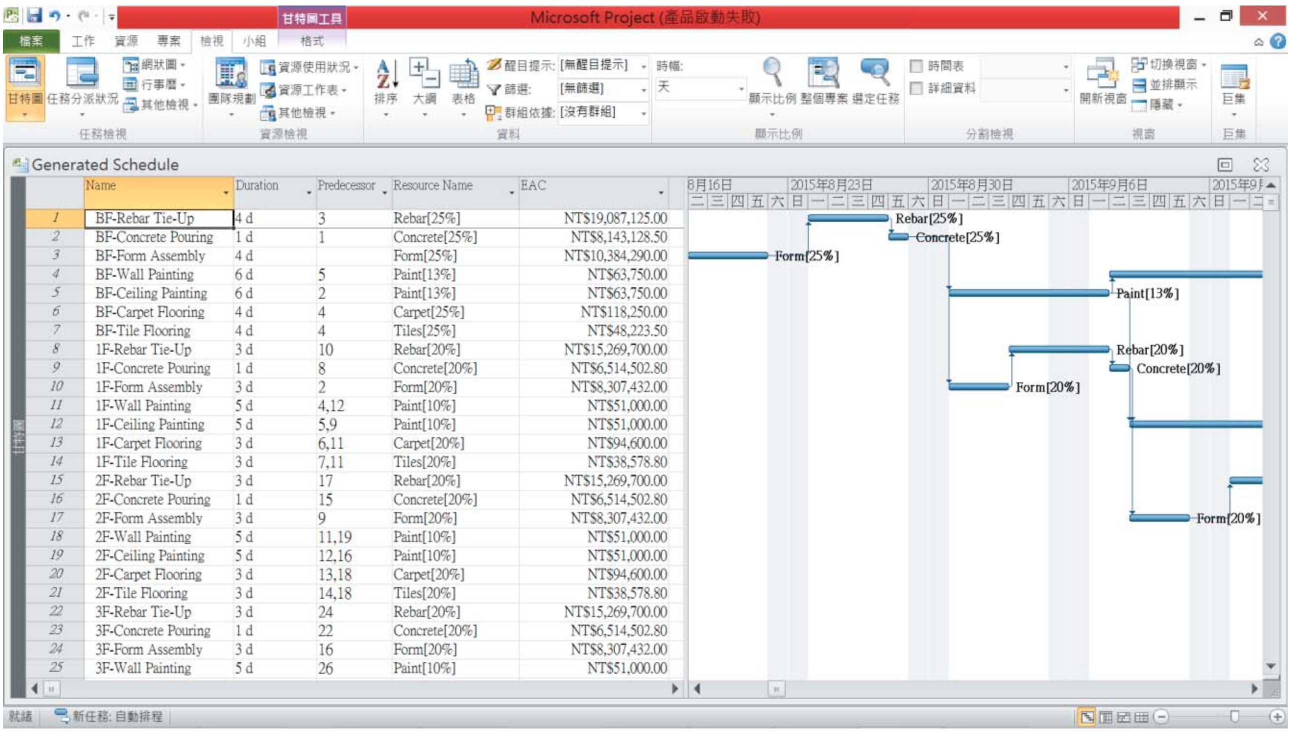
Duration would also be calculated automatically with the quantity of that Area of Work Item defined in Figure 17 that divided the Productivity Rate of the Crew defined in Figure 18. For example, regarding Rebar Tie-Up at BF, the Activity name was “BF-Rebar Tie-Up,” the related Crew was “Rebar Tie-Up Crew” as shown in Figure 17, the Productivity Rate was 138.7, and the Quantity of that Area was 553.25 as in Figure 18, thus, the duration was calculated as 553.25/138.7 and after rounding off to the integer, it became 4 as shown in Figure 20 and Figure 21.

The logic of these 35 Activities was automatically identified by the system as shown in the “Predecessor” column by the sequence of Work Items given in Figure 15, the Priority of Areas given in Figure 16, and the Crew Allocation assigned in Figure 19. After exporting to MS-Project, Figure 22 illustrates the network view of the data.



ID	WBS	Name	Duration	Predecessors	PayItemName
1	1.1	BF-Rebar Tie-Up	4	3	Rebar[25%]
2	1.2	BF-Concrete Pouring	1	1	Concrete[25%]
3	1.3	BF-Form Assembly	4		Form[25%]
4	1.4	BF-Wall Painting	6	5	Paint[12.5%]
5	1.5	BF-Ceiling Painting	6	2	Paint[12.5%]
6	1.6	BF-Carpet Flooring	4	4	Carpet[25%]
7	1.7	BF-Tile Flooring	4	4	Tiles[25%]
8	2.1	1F-Rebar Tie-Up	3	10	Rebar[20%]
9	2.2	1F-Concrete Pouring	1	8	Concrete[20%]
10	2.3	1F-Form Assembly	3	2	Form[20%]
11	2.4	1F-Wall Painting	5	4,12	Paint[10%]
12	2.5	1F-Ceiling Painting	5	5,9	Paint[10%]
13	2.6	1F-Carpet Flooring	3	6,11	Carpet[20%]
14	2.7	1F-Tile Flooring	3	7,11	Tiles[20%]
15	3.1	2F-Rebar Tie-Up	3	17	Rebar[20%]
16	3.2	2F-Concrete Pouring	1	15	Concrete[20%]
17	3.3	2F-Form Assembly	3	9	Form[20%]
18	3.4	2F-Wall Painting	5	11,19	Paint[10%]
19	3.5	2F-Ceiling Painting	5	12,16	Paint[10%]
20	3.6	2F-Carpet Flooring	3	13,18	Carpet[20%]
21	3.7	2F-Tile Flooring	3	14,18	Tiles[20%]
22	4.1	3F-Rebar Tie-Up	3	24	Rebar[20%]
23	4.2	3F-Concrete Pouring	1	22	Concrete[20%]
24	4.3	3F-Form Assembly	3	16	Form[20%]

Figure 20: Schedule Generated by the System



	Name	Duration	Predecessor	Resource Name	EAC
1	BF-Rebar Tie-Up	4 d	3	Rebar[25%]	NT$19,087,125.00
2	BF-Concrete Pouring	1 d	1	Concrete[25%]	NT$8,143,128.50
3	BF-Form Assembly	4 d		Form[25%]	NT$10,384,290.00
4	BF-Wall Painting	6 d	5	Paint[13%]	NT$63,750.00
5	BF-Ceiling Painting	6 d	2	Paint[13%]	NT$63,750.00
6	BF-Carpet Flooring	4 d	4	Carpet[25%]	NT$118,250.00
7	BF-Tile Flooring	4 d	4	Tiles[25%]	NT$48,223.50
8	1F-Rebar Tie-Up	3 d	10	Rebar[20%]	NT$15,269,700.00
9	1F-Concrete Pouring	1 d	8	Concrete[20%]	NT$6,514,502.80
10	1F-Form Assembly	3 d	2	Form[20%]	NT$8,307,432.00
11	1F-Wall Painting	5 d	4,12	Paint[10%]	NT$51,000.00
12	1F-Ceiling Painting	5 d	5,9	Paint[10%]	NT$51,000.00
13	1F-Carpet Flooring	3 d	6,11	Carpet[20%]	NT$94,600.00
14	1F-Tile Flooring	3 d	7,11	Tiles[20%]	NT$38,578.80
15	2F-Rebar Tie-Up	3 d	17	Rebar[20%]	NT$15,269,700.00
16	2F-Concrete Pouring	1 d	15	Concrete[20%]	NT$6,514,502.80
17	2F-Form Assembly	3 d	9	Form[20%]	NT$8,307,432.00
18	2F-Wall Painting	5 d	11,19	Paint[10%]	NT$51,000.00
19	2F-Ceiling Painting	5 d	12,16	Paint[10%]	NT$51,000.00
20	2F-Carpet Flooring	3 d	13,18	Carpet[20%]	NT$94,600.00
21	2F-Tile Flooring	3 d	14,18	Tiles[20%]	NT$38,578.80
22	3F-Rebar Tie-Up	3 d	24	Rebar[20%]	NT$15,269,700.00
23	3F-Concrete Pouring	1 d	22	Concrete[20%]	NT$6,514,502.80
24	3F-Form Assembly	3 d	16	Form[20%]	NT$8,307,432.00
25	3F-Wall Painting	5 d	26	Paint[10%]	NT$51,000.00

Figure 21: Generated Schedule Exported to MS-Project

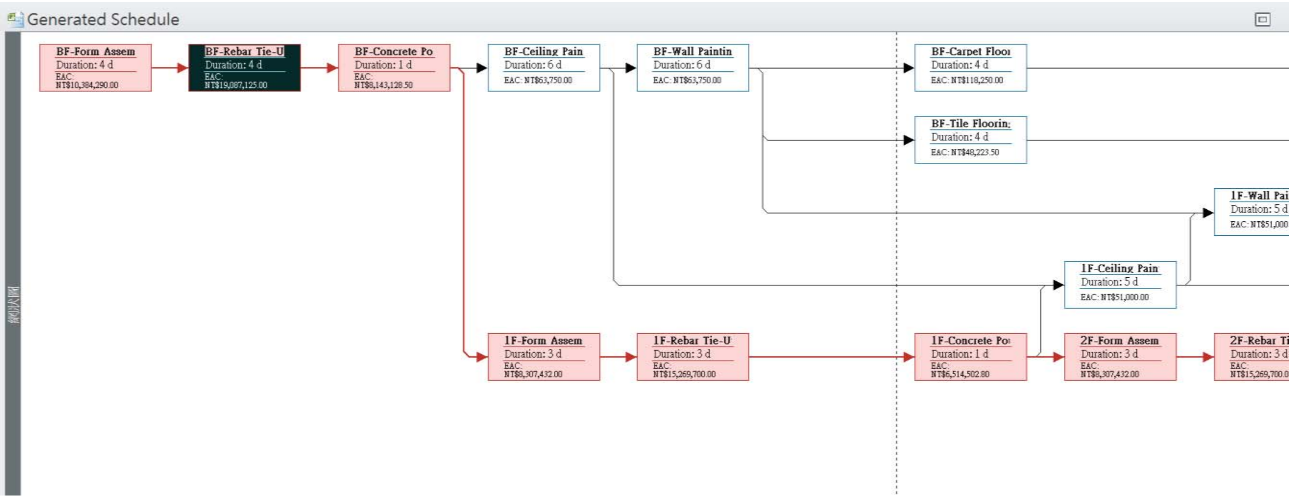


Fig. 22 Network View of Generated Schedule Exported to MS-Project

8. Discussion

The system has successfully integrated the cost and schedule control systems, and the schedule information is generated automatically based on the criteria of the resource allocation and preferential technical concerns given. In other words, the link between the Pay Items and schedule information is generated automatically. This is a novel spontaneous attempt where the conventional approach needs to be executed manually, and it is time consuming and bound to create many errors because of the complicated relationship between Pay Items and schedule activities. The proposed system can be modified to suit the required criteria of the resource allocation and technical concerns that can be inputted by the user. As a result, the system can then generate the schedule based on Pay Items, and also the activities that are linked of the Pay Items.

Nevertheless, certain limitations need to be considered. The system with the object-oriented approach is implemented and developed using Microsoft Visual C#. The system cannot be applied to all operating systems (OS) because of the incompatibility of the computing platform. However, it will function perfectly well in all Window-based operating systems, which are the common OS in the market.

As the proposed approach uses the duration from the costs items in the schedule rates, certain doubts might be raised about changes of the quantities that happen during the construction stage. It is because the quantities are variables and, in most cases, are different than calculated in the planning stage. This doubt or concern serves as future research for the proposed approach. The current scope and implementation of the proposed approach refer only to the revised and finalized duration of the project. In other words, if the quantity of the actual progress is different than the original, the schedule needs to be updated before implementing this proposed approach.

Furthermore, various case studies under the proposed object-oriented approach should be carried out in various project environments with different conditions in project delivery systems, contract types, and management policy to test its practicability. The different data sets would be able to further improve the cost and schedule integration, particularly to provide quality information for decision making. The limitations analyzed through these case studies should sow the seeds for future research.

9. Conclusion

An effective and easy scheduling approach is proposed based on the cost and schedule integration. This enables contractors to develop a schedule based on the cost accounts. All the activities of the schedule are integrated with the Pay Items automatically. A case study is presented on how we can generate a schedule by the system using Microsoft Visual C#. The results show a true synchronization between the cost and schedule functions. The proposed concept renders a new insight into the cost-schedule integration. It is a generic approach that can be used across all types of scenarios and procurement systems. On the other hand, considering the limitations on uncertainties that might happen in the construction stage, the following are recommended for future research. First, the system can be extended to track and monitor the cost and schedule information throughout the project lifecycle. Second, the system can be further investigated for its measureable performance in the project. Third, other procurement systems can be compared and tested using the proposed system.

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