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By

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CASE STUDY: SCOPE-TIME-COST INTEGRATED MODEL WITH WORK BREAKDOWN STRUCTURE

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Abstract
The purpose of this study is to demonstrate the feasibility of integrating scope cost and time for construction project planning. This study is important because it will demonstrate the use of a work breakdown structure as a classifying code to facilitate creating an integrated system. This will add to the science of project management in that the literature covering this topic does not specify how to correlate specific item's scope-cost-time information across the three models. This project matters because the solution is adaptable to work breakdown formats readily available to any construction professional.

This case study relied on project management software tools common on construction projects. The case example is an academic building constructed from concrete. The analyses of the study results are qualitative.

The results demonstrate that integrated model systems are possible using older software tools. The work breakdown classification method produced by this study is applicable in non-computer applications as well as integrated systems.

The studies purpose has been achieved. The question of how integrating scope-cost-time across software tools is accomplished has proved to be a work breakdown structure. This was not the answer expected. In preliminary informal discussions with both researchers and practitioners it was anticipated that such a system was not probable. This study was limited by the scope of the test model and by time limitations.

The practical implication is construction project planners are being advised to begin this method. Any projects implementing an integrated system should consider deriving a similar system prior to the scope-cost-time planning process. Further research is needed to determine if this method applies to more advanced BIM systems and what project types.

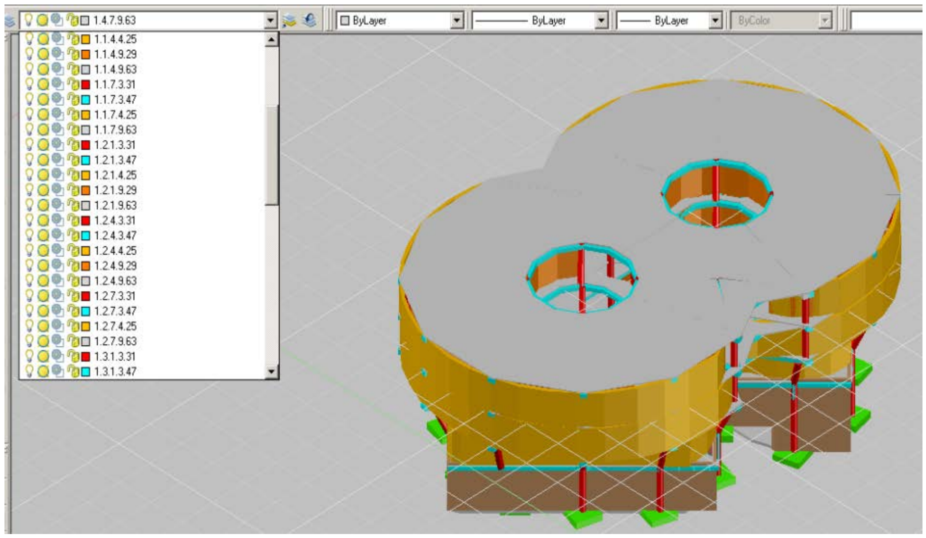
Keywords
Integrated system, Building Information Model, BIM, Product Information Model, Scope-cost-schedule, Project Planning, estimate, schedule, take-off

Introduction

The automated steam engine is said to have been invented by a young child. In the early days of steam power steam engines were used to simply push a piston connected to a rocking beam. Due to the simplicity of these machines it was necessary to manually open a valve at the end of each stroke to release the pressure on the piston. Young children were employed to open and close this valve, an occupation called the *plug man* (Deakins 2008). As the story goes, one who wanted to play stickball outside with some other children devised a mechanism from scrap steel to do his job. He connected one end of a rod to the rocking beam and the other end to the lever for the valve. As the beam rocked back and forth it opened and closed the valve. Field engineers too have the need to devise a more efficient method of completing project planning. An early integration paper (Fischer and Kunz 1993) proposes an integrated system to update project information with any change in one system component.

In this case study a work breakdown structure (WBS) is employed to allow the same data to be used repeatedly from the product model, to the cost model, then to the process model and last a 4D model. An early reference to the need for such a hierarchy is a CIFE technical report that introduces a four level work breakdown structure called a *PMAP hierarchy* to represent product model components within CAD (Ito et. al 1989). A second article expands the use of the WBS as an activity naming method using an action, object and resource (Darwiche et. al 1989). Recently this has been expanded to include an action, object, resource and work space (Mourgues et al. 2007).

The most important concept that is essential is if an object-component is not in the product model then it is not going to be built unless some form of recipe formula is written to calculate its value by reference. It will not be in the estimate, it will not be scheduled and it will have no corresponding tracking component and no billing element. Obviously there is commercial software that completes the same task of take-off and passing data through to the cost model and process model, though the process used here highlighted some details that are not always evident, specifically the importance of WBS classification. The method given here was the most effective available until recent advances in software tools (Ito et al. 1989).



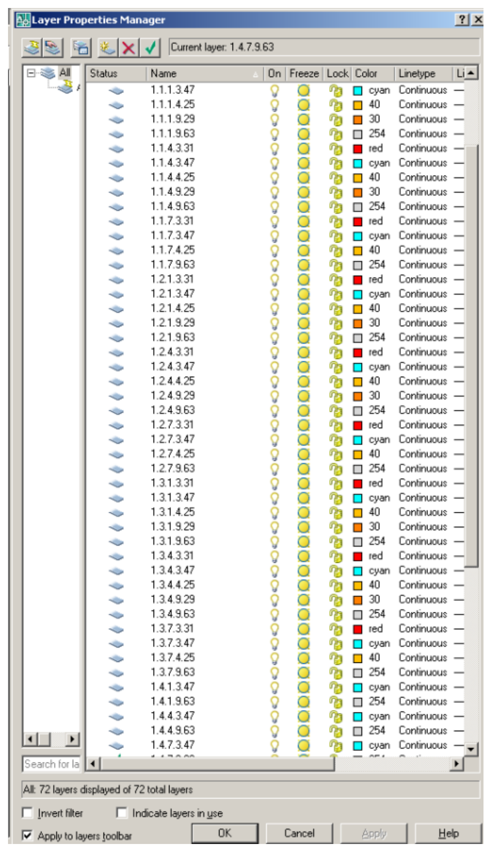


Figure 1: Within the CAD software there is the ability to export to a text file a list of all layers used in the model. With deliberate naming of layers this export can function to identify objects within the model.

CIFE Work Breakdown Structure

Work Level 1: Project

Work Level 2: Location

Work Level 3: Sub-Location

Work Level 4: Building Units / Disciplines

Work Level 5: Master Schedule Activities

Work Level 6: Objects

Work Level 7: Operations

Table 2 Basic Work Breakdown Structure containing elements needed to classify an activity. This WBS can be expanded to include additional information as needed.

Work Breakdown Structure

The first step in integrating the product model cost model and process model is a product model with layers codified using a WBS. The AIA is currently

proposing a standardized naming convention utilizing abbreviation dependent codes. "The Layer Guidelines published by the AIA (American Institute of Architects), suggest layer names that look like this (www.autodeskpress.com/resources/olcs/acad2000/jan01/command_january01.html):
`E-LGHT-EMER-NEWW
E-LGHT-SWCH-DEMO".
A number based system relying on integers sequenced to give context information on objects allows easier conversion to other software applications. The disparity between architect descriptions and construction coding is something that can be solved by the involvement of the constructor in creation of the product model. Working closely with the product modelers to determine what needs to be modeled for this purpose and what the work breakdown structure (WBS) is for each layer. In AutoDesk the layers can be named as created or imported as a predefined set. The import tool gives the modeler the option of defining what the project must contain then importing the set of codes and using these to draft the model. This is accomplished in AutoDesk by opening layers then open layers manager and select add. Assign a name to the layers set that will be created. Select ok then deselect all data; all we want is the layer codes. Select export and save the file to a folder containing other project data. We have now created a list of all the objects in the project..

Import List to Spreadsheet
After exporting the layer list from the product model then open a prepared spreadsheet. Starting with the first tab on the left, named AutoDesk model, there are column heading for the eight WBS levels. This example uses a simplified WBS than the AROW form recently proposed by Mourgues. To import the product model list of layers open data/import external data/import data then open the saved file. The file is a text file and the search needs to be expanded to include all files. The layer codes are saved as dot delineated so in the import tool check the option *other* and place a (.) in the box. Select finish and a list of the object/layer codes is imported into excel with each WBS level in a separate column. Once imported the data is not in a usable format yet and requires more manipulation before use. Importing the data in different columns allows use of the different components of the WBS to identify what object is represented by the code.

In this application the WBS was shortened to fit the time constraints on the project. In an actual application or for a more comprehensive project, the full WBS sequence of sets needs to be created in the CAD model. [graphic CAD → text → excel]

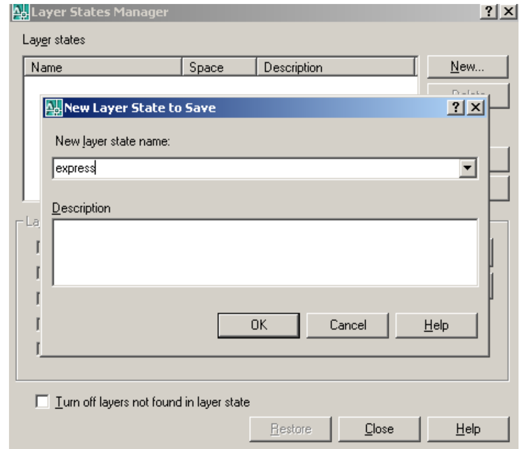


Figure 2: We need the codified layers in a format we can import to excel. The *layer states manager* provides the function to create a new *layer state name* to which the current product model layers can be saved as a text file.

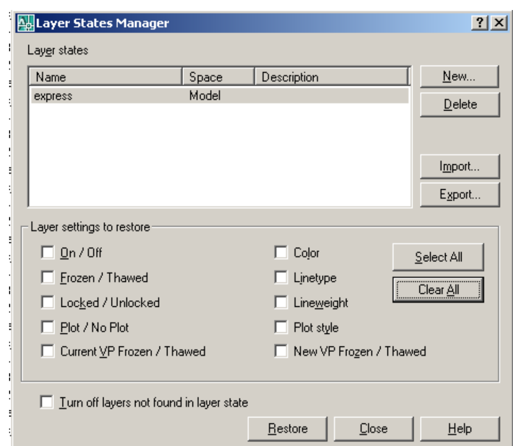


Figure 3: We do not want all the information associated with a layer, we only need the layer name itself since this is codified with information. With the *layer states manager* select the layer settings to export, for our purposes we only need the layer names

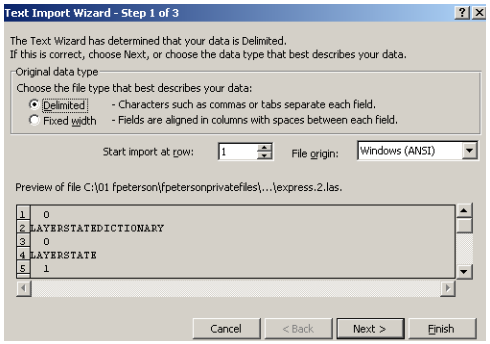


Figure 4: Once the layers are exported to a text file, the list can then be imported into excel using the excel import function. This function provides the ability to define delineation for columns.

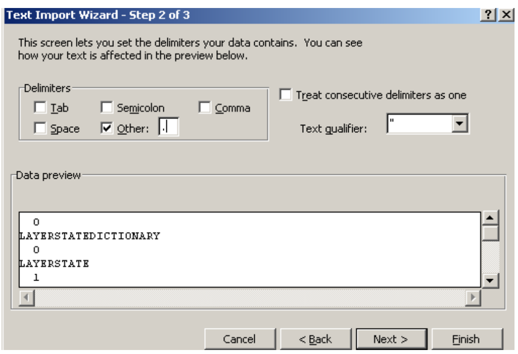
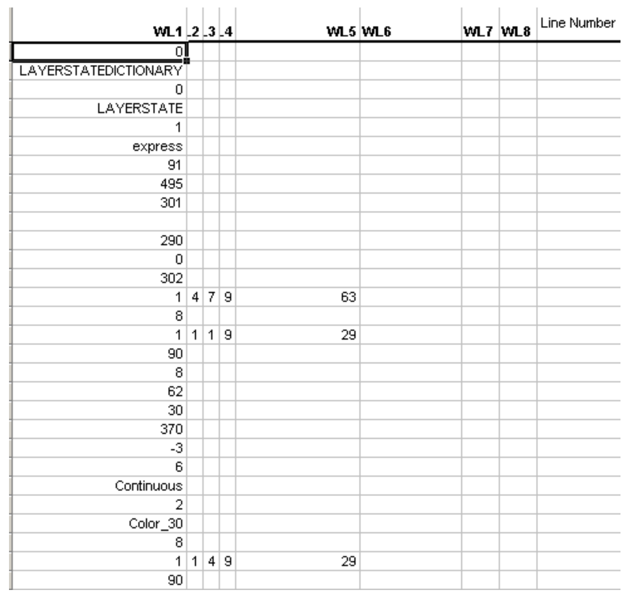


Figure 5: We want the breakdown codes delineated in different columns so we can then use a lookup function to identify the code components. Select the delineation between breakdown codes; in this case dots are used. Tab, semicolon, comma and space are other options.

An issue that arose while creating a more automated version of the model is the conversion from columns to dot delineation. Using text files it is possible to go from dot delineation to spreadsheet but going from spreadsheet to dot delineation is not possible. This causes some difficulty in moving classifications around the spreadsheet and appears to be one of the limitations of spreadsheets.

Sorting List

Once the product model object/layer list is in the spreadsheet then the list need to be manipulated to obtain a list of codes. Using the sort function, data/sort, sort by some column of the WBS other than the first. The codes will be listed sequentially and any extra data will be after the codes. Delete the unneeded extra data. Next import a second set of codes from the same AutoDesk export file. The second set of codes is not delineated by column and is kept as a dot delineated. This second set of codes is used in place of the ability to restore the dot delineation from columns delineation of the codes. The list needs to be sorted so that both the column delineated data and the dot delineated data corresponds with each other in there respective rows. To achieve this use the data sort function and highlight the column delineated codes and sort by WBS 2, WBS 3 and WBS 4. The two sets of codes should now be in the same sequence.



WL1	.2	.3	.4	WL5	WL6	WL7	WL8	Line Number
0								
LAYERSTATEDICTIONARY								
0								
LAYERSTATE								
1								
express								
91								
495								
301								
290								
0								
302								
1	4	7	9	63				
8								
1	1	1	9	29				
90								
8								
62								
30								
370								
-3								
6								
Continuous								
2								
Color_30								
8								
1	1	4	9	29				
90								

Figure 6: Once the layer list text file is imported to excel we must cleanup additional layer information not needed in this applications. Material type or other identifying information could be useful in a different setup, for this case delete this information.

WL1	WL2	WL3	WL4	WL5	WL6	WL7	WL8	Line Number
1	0	0	3	30				1.0.0.3.30
1	0	0	3	30				1.0.0.3.30
1	0	0	3	30				1.0.0.3.30
1	0	0	3	30				1.0.0.3.30
1	0	0	3	31				1.0.0.3.31
1	1	1	3	31				1.1.1.3.31
1	1	1	3	47				1.1.1.3.47
1	1	1	4	25				1.1.1.4.25
1	1	1	9	29				1.1.1.9.29
1	1	1	9	63				1.1.1.9.63
1	1	4	3	31				1.1.4.3.31
1	1	4	3	47				1.1.4.3.47
1	1	4	4	25				1.1.4.4.25
1	1	4	9	29				1.1.4.9.29
1	1	4	9	63				1.1.4.9.63
1	1	7	3	31				1.1.7.3.31
1	1	7	3	47				1.1.7.3.47
1	1	7	4	25				1.1.7.4.25
1	1	7	9	63				1.1.7.9.63
1	2	1	3	31				1.2.1.3.31
1	2	1	3	47				1.2.1.3.47
1	2	1	4	25				1.2.1.4.25
1	2	1	9	29				1.2.1.9.29
1	2	1	9	63				1.2.1.9.63
1	2	4	3	31				1.2.4.3.31
1	2	4	3	47				1.2.4.3.47
1	2	4	4	25				1.2.4.4.25
1	2	4	9	29				1.2.4.9.29
1	2	4	9	63				1.2.4.9.63
1	2	7	3	31				1.2.7.3.31
1	2	7	3	47				1.2.7.3.47
1	2	7	4	25				1.2.7.4.25
1	2	7	9	63				1.2.7.9.63
1	3	1	3	31				1.3.1.3.31
1	3	1	3	47				1.3.1.3.47
1	3	1	4	25				1.3.1.4.25
1	3	1	9	29				1.3.1.9.29
1	3	1	9	63				1.3.1.9.63
1	3	4	3	31				1.3.4.3.31
1	3	4	3	47				1.3.4.3.47
1	3	4	4	25				1.3.4.4.25
1	3	4	9	29				1.3.4.9.29
1	3	4	9	63				1.3.4.9.63
1	3	7	3	31				1.3.7.3.31
1	3	7	3	47				1.3.7.3.47
1	3	7	4	25				1.3.7.4.25
1	3	7	9	63				1.3.7.9.63
1	4	1	3	47				1.4.1.3.47
1	4	1	9	63				1.4.1.9.63
1	4	4	3	47				1.4.4.3.47
1	4	4	9	63				1.4.4.9.63

3D Autodesk / Estimate / WBS Naming / Schedule

Figure 7: With the extra layer parameters deleted the list can now be sorted to create a column separated list of object-components contained within the product model. In this list each Work Breakdown Level (WL) code contains specific identifying information, cumulatively providing an exact identification.

Cost Model Estimate

With the two sets of codes in the dot delineated and column delineated formats, the codes are now ready to be copied to the next tab. The next tab is the estimating tab. To copy, highlight all eight columns of the WBS and the one column of the dot delineated set. Open the estimating tab and paste in the corresponding columns. The spreadsheet is formatted so the codes can be directly copied and pasted. The codes can now be sorted by the WBS columns into the estimate break down desired.

Once the WBS codes are pasted into the estimate tab then the entire estimate is basically complete. All of the corresponding costs and production rates are automatically looked up and appear in the estimate. There is a database located on the production RS Means tab that contains a partial database of RS Means production rates copied from the RSMeans website for free [web address].

Take-off Scope

The takeoff quantity for each item can now be entered into the spread sheet. The takeoff quantities are possible to be exported from a Building Information Model (BIM) and would facilitate their automated import. The number of crews that are placed on each activity can be adjusted to obtain the desired durations. This may take several iterations to have the resources leveled properly. Another option is to import to the process model, level the resources then export back to excel.

In this instance once the WBS codes are copied to the estimate tab and the crews were assigned for the correct durations, the project estimate is complete.

Historical Library

The production rates in the RS Means database are compiled from empirical measurements, the basic format or concept can be retained but actual data should be project region specific, wage rate specific, and modified for project climate conditions. The production rates should also be scaled on a variable range to account for learning curve, and repetitiveness of work. In the current RS Means library codes are not dot delineated between sets. For the data needed for this project I had to manually add dots.

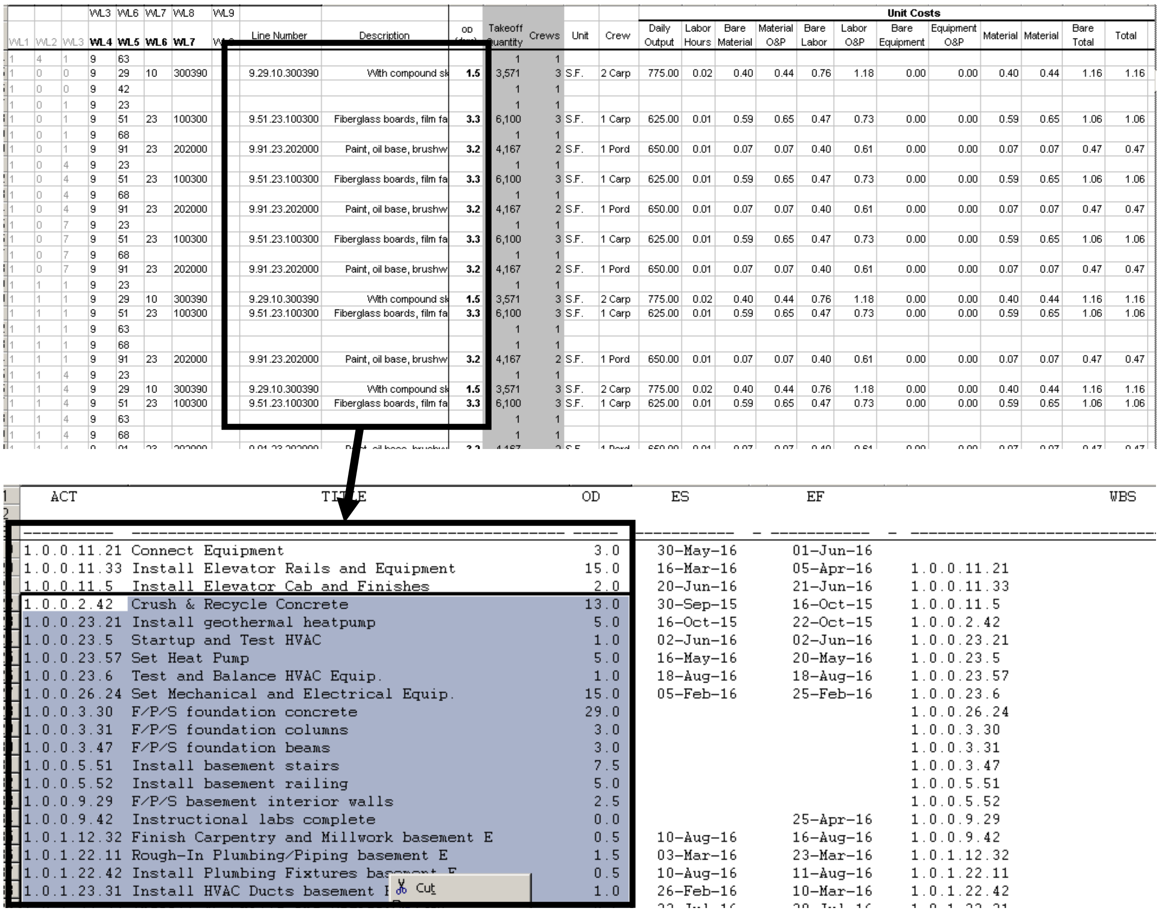


Figure 8: The correlation between cost model cost code and process model activity code is shown here. This correlation creates a one-to-one match for each estimate item or group of estimate items, resulting in improved integration between the tools.

RS Means provided access to their data base for free for a limited time. They gave me permission to copy as much data as I needed. Due to the setup of their website it is time consuming to copy the data and then manipulate to a usable state.

Classification

The CSI MasterFormat used by RS Means is also reused for this model. The construction specification institute (CSI) 16 division master format has been expanded by CSI to a 31 division format and now more recently to 50 divisions [website]. Some of the 31 divisions are not used so the actual number of divisions is less.

The WBS structure used for this project is a compilation of the work breakdown structure (WBS), cost breakdown structure (CBS) and project breakdown structure (PBS). This combination of breakdown structures results in one work breakdown for all three breakdown structures.

	31113200500	WL1	WL2	WL3	WL4	WL5	WL6	WL7	WL8						
	1.0.0.3.11.13.200500.1	1	0	0	3	11	13	200500	1						
	WL1	**Express**													
	WL2		**Basement**												
	WL3			**Basement**											
	WL4				**3 Concrete**										
	WL5					**0311 Concrete Forming**									
	WL6						**031113 Structural Cast-In-Place Concrete Forming**								
	WL7							**Exterior spandrel, job-built plywood, 12" wide, 1 use**							
	WL8								**Labor**						
exp.	*1.0.0.3.11.13.50015.1*	**install**	**031113 Structural Cast-In-Place Concrete Forming**												
		WL1	WL2	WL3	WL4	WL5	WL6	WL7	WL8	WL1	WL2	WL3	WL4	WL5	WL6
		1	0	0	3	11	13	200500	1	Express	Basement	Basement	3 Concrete	0311 Concrete Forming	031119 Insulating Concrete Forming
	WL1: Construction project	1	2	7	3	31			1	Express	2nd floor	center	3 Concrete	0311 Concrete Forming	031113 Structural Cast-In-Place Concrete Forming
1	Express	1	2	7	3	31			1	Express	2nd floor	center	3 Concrete	0311 Concrete Forming	031113 Structural Cast-In-Place Concrete Forming
		1	2	7	3	47			1	Express	2nd floor	center	3 Concrete	0311 Concrete Forming	031113 Structural Cast-In-Place Concrete Forming
	WL2: Construction areas	1	2	7	4	25			1	Express	2nd floor	center	4 Masonry	0311 Concrete Forming	031113 Structural Cast-In-Place Concrete Forming
0	Basement	1	2	7	9	63			1	Express	2nd floor	center	9 Finishes	0311 Concrete Forming	031113 Structural Cast-In-Place Concrete Forming
1	1st floor	1	3	1	3	31			1	Express	3rd floor	Module E	3 Concrete	0311 Concrete Forming	031113 Structural Cast-In-Place Concrete Forming
2	2nd floor	1	3	1	3	47			1	Express	3rd floor	Module E	3 Concrete	0311 Concrete Forming	031113 Structural Cast-In-Place Concrete Forming
3	3rd floor	1	3	1	4	25			1	Express	3rd floor	Module E	4 Masonry	0311 Concrete Forming	031113 Structural Cast-In-Place Concrete Forming
4	Roof	1	3	1	9	29			1	Express	3rd floor	Module E	9 Finishes	0311 Concrete Forming	031113 Structural Cast-In-Place Concrete Forming
5	Sitework														

Figure 9: This view of the classification code provides a breakdown of several codes by work level. From WL 1 through WL 8, each level provides some additional information reducing the possible objects this classifies. Using this form of work Breakdown Structure (WBS) provides a simple and repeatable method to create and derive classifications.

			WL3	WL6	WL7	WL8	WL9													
WL1	WL2	WL3	**WL4**	**WL5**	**WL6**	**WL7**	WL8	Line Number	Description	Unit	Crew	Daily Output	Labor Hours	Bare Material	Material O&P	Bare Labor	Labor O&P	Bare Equipment	Equipment O&P	Material
			3	11	13	50015		31113050015	Aluminum, smooth face, 3' x 8', buy	SFCA				12.80	14.10					12.80
			3	11	13	50020		31113050020	2' x 8'	SFCA				15.95	17.55					15.95
			3	11	13	50050		31113050050	12" x 8'	SFCA				22.00	24.50					22.00
			3	11	13	50100		31113050100	6" x 8'	SFCA				21.50	23.50					21.50
			3	11	13	50150		31113050150	3' x 4'	SFCA				16.00	17.60					16.00
			3	11	13	50200		31113050200	2' x 4'	SFCA				17.90	19.70					17.90
			3	11	13	50250		31113050250	12" x 4'	SFCA				24.00	26.00					24.00
			3	11	13	50300		31113050300	6" x 4'	SFCA				27.50	30.50					27.50
			3	11	13	50500		31113050500	Textured brick face, 3' x 8', buy	SFCA				14.50	15.95					14.50
			3	11	13	50550		31113050550	2' x 8'	SFCA				19.20	21.00					19.20
			3	11	13	50600		31113050600	12" x 8'	SFCA				25.50	28.00					25.50
			3	11	13	50650		31113050650	6" x 8'	SFCA				35.50	39.00					35.50
			3	11	13	50700		31113050700	3' x 4'	SFCA				16.75	18.45					16.75
			3	11	13	50750		31113050750	2' x 4'	SFCA				21.00	23.00					21.00
			3	11	13	50800		31113050800	12" x 4'	SFCA				28.50	31.50					28.50
			3	11	13	50850		31113050850	6" x 4'	SFCA				46.00	50.50					46.00
			3	11	13	51000		31113051000	Average cost incl. accessories but not incl. ties	SFCA				21.50	23.50					21.50
			3	11	13	51100		31113051100	Rent per month	SFCA				2.15	2.37					2.15
			3	11	13	52000		31113052000	Metal framed plywood 2' x 8' buy	SFCA				7.20	7.95					7.20
			3	11	13	52050		31113052050	2' x 3'	SFCA				7.95	8.75					7.95
			3	11	13	52100		31113052100	1' x 3'	SFCA				10.80	11.90					10.80
			3	11	13	52200		31113052200	Average for corners & specials	SFCA				14.40	15.85					14.40
			3	11	13	52300		31113052300	Rent per month	SFCA				0.97	1.07					0.97
			3	11	13	53000		31113053000	Plywood modular prefabricated 2' x 8' buy	SFCA				2.01	2.21					2.01
			3	11	13	53050		31113053050	Average cost for corners, fillers & specials	SFCA				2.61	2.87					2.61
			3	11	13	53200		31113053200	Average cost incl. accessories but not incl. ties	SFCA				2.71	2.98					2.71
			3	11	13	53500		31113053500	Steel 2' x 4' buy	SFCA				7.95	8.75					7.95
			3	11	13	53550		31113053550	2" x 4'	SFCA				14.40	15.85					14.40

Figure 10: This view of the cost model shows copying the product model layer codes and pasting them to the estimate tab results in an automatic estimate of each object. The only additional information needed is the takeoff quantities provided by either a BIM takeoff or manual takeoff. The simplicity in the system is the classification codes correlating with the cost models classification system, resulting in an automated takeoff. The additional upfront time spent defining layer names is regained in iterations of estimates.

Time, Process Model or Schedule

Once the data in the estimate has been audited for project specific corrections then the classification, description and durations are ready to be imported into the schedule. The P3 schedule tab is formatted for importing into Primavera P3 process model software. Copy the code column, description and duration columns, then paste into the schedule tab. For the schedule to be imported into primavera the schedule tab needs to be copied into a new worksheet and saved. Then with the primavera application open, open the tools/project utilities/import. Link the import tool to the file location of the excel schedule tab. Once the file is imported then all of the activity codes, descriptions and durations will be listed. The sequencing and logic of the schedule must be manually completed. It could be possible to create an excel listing of standard logic sequences for various activity codes. The most common sequences would remove the need to define these in every schedule. Once the logic is complete press F9 and update the schedule. After review, if any changes to the schedule durations are necessary, export the schedule back into the excel file. In the excel spreadsheet copy the data from the schedule tab back into the estimate tab. Adjust the durations by reassigning the number of crews to the activities. Once the durations

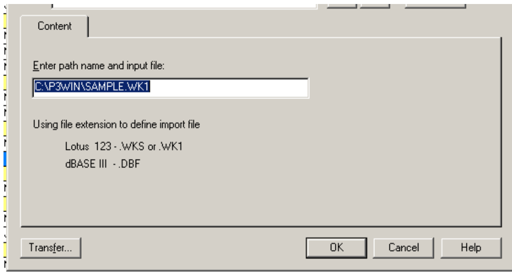


Figure 11: One of the more difficult tasks with Primavera P3 has been made easier with version P5 and subsequent versions, exporting and importing data. This is the true secret to professional scheduling. What one scheduler could spend a week doing another will have completed in less than several hours.

are as desired then import the data back into primavera and update again. In the P3 version of Primavera schedule the WBS is manually created.

4D Model

Once the schedule is completed then create the 4D model. Import the CAD .dwg file and schedule into CommonPoint, and then map the product model objects to process model operations. If the classification codes in the product model match the classification codes in the process model then the mapping task is simplified. The integrating spreadsheet created for this worked well and allowed for a much shorter turnaround time in design iterations. The final product of an integrated 3D model, estimate, schedule and 4D model is rudimentary but establishes that it is possible. The model can use more work and macros could automate

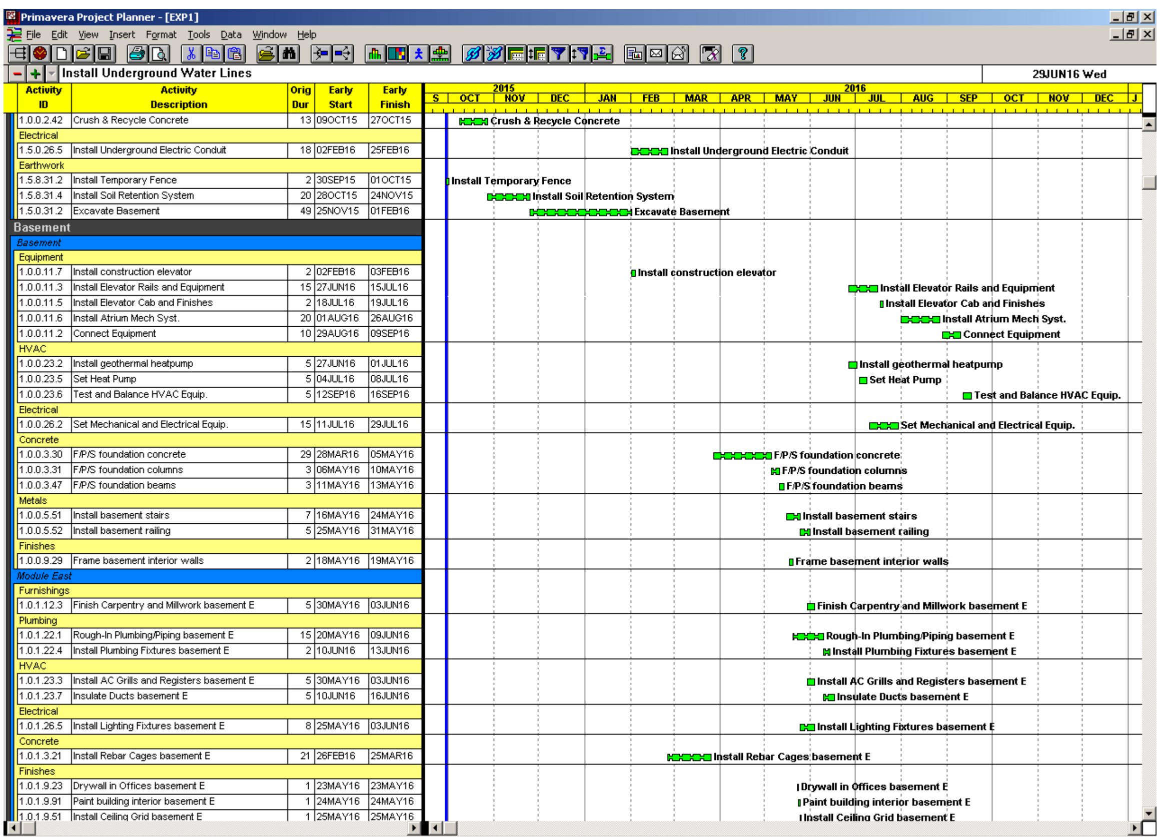


Figure 12: The completed process model. Following the process given here results in durations based on estimated production rates, classifications that correlate to other project management tools and the ability to update with changes in design. The entire process from product model through cost model and to process model is completed in less than half an hour, in what was once a several day task. Details of estimating and scheduling are still relevant and can not be replicated in this system, requiring someone with experience to review and add any missing information.

many of the manual operations that must be done.

Conclusion

The results are a success. This case study of integrating four common software tools highlights the importance of common classification and macro tools. Many steps were repetitive and with a few simple macros have been automated. The classification work breakdown structure appears to be the key to identifying the same operation across multiple software tools. Updating these same tools later during project progress would be much simpler with a common classifying system. As stated previous there are commercial applications that complete these tasks. That a system can be patched together in this way shows it is possible. All of the software used here is of 1990's vintage and the method outlined requires no special knowledge beyond those expected of any graduate or undergraduate construction engineer.

The work breakdown structure is a useful project management tool that is ignored by many field engineers. Through the use of the Construction Specification Institute (CSI) MasterFormat or derivations, operations are possible to track across applications. This allows easier updating of project planning and control tools with less ambiguity of line item descriptions. These tools will continue to progress as integration becomes more complete and robust. Understanding the underlying importance of a common classification system provides an understanding of underlying topics and issues.

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