The Clear Flow Matrix

INTRODUCTION

Lott Brothers Construction Company (LBCC) founded in 1988 by Wayne Lott and David Lott is a commercial building construction and construction management company. LBCC has constructed some 6 million square feet of completed work in Texas and nearby states. Healthcare construction accounts for about two-thirds of this amount of completed work, or some 4 million square feet. Because many of these projects were located some distance from their home office in Austin, the company was faced with managing the construction schedule and attendant production remotely from the home office. To find experienced site supervisors in those distant areas who are capable of managing the projects mentioned above was an obstacle in itself for the company. Furthermore, during the late 1980s and early 1990s, some of the technological tools that benefit communication and the flow of documents, such as the internet, cloud based scheduling, laptops and cell phones, were not readily available in that period, further complicating the efforts to receive support from construction managers in the home office. A straight-forward and visual tool for depicting production control supporting the project schedule was needed for the site supervisors in those remote projects. Considering the critical need for such a production control technique, LBCC developed the Clear Flow Matrix (CFMx). Initially, the main idea of this technique was to provide a visual and readily understandable aid to the local superintendent to help manage the trades and control the production of work required for the project while making sure the project was in compliance with the Critical Path Method (CPM) master schedule established for the project. In these earliest applications or iterations of this technique applied to renovations to critical care units of hospitals, the Clear Flow Matrix only provided the location (of rooms) and date that each trade crew was supposed to work in the rooms on a day-to-day basis. Due to the success of obtaining good project outcomes using this new tool, LBCC then proceeded to apply the Clear Flow Matrix to all of its other projects, including large renovation and new ground-up projects.

Application to larger projects required certain adjustments including the addition of a weekly tracking period to better accommodate the work flow of larger projects.

The development and the application of the Clear Flow Matrix was primarily focused on the interior finishes of hospital and commercial projects, where the coordination of the location of different subcontractors and trades in the schedule is extremely crucial and must be controlled at the very least on a weekly basis. Industry data shows that these types of projects are often confronted with cost and quality problems due to the acceleration of progress in interior finishes required as the final project completion date approaches. The crews in charge of finishing attempt to complete their work in multiple areas of the project in the last few weeks available for work in order to comply with the master schedule to finish on time, leading to trade stacking wherein multiple trades work in the same area simultaneously. The resulting high density of workers in a confined and congested space negatively or adversely affects the productivity of the trades involved. Based on this theory, the Clear Flow Matrix helps to avoid this unwanted situation. One of the primary abilities of this technique is to locate each crew activity every day on a daily basis constituting an effective production control process.

HOW THE CLEAR FLOW MATRIX WORKS

The clear flow matrix production control method provides a clear visual and intuitive mechanism for managing and controlling the production of building works. This mechanism uses a simple two-dimensional matrix of work locations and trade work items with an embedded third dimension of start date for each trade/location item. Two matrixes can represent the complete construction schedule of the entire project. The Vertical Matrix, which addresses activities with vertical flow of work such as construction of foundation elements and the concrete slab, concrete and steel structure, wall enclosure framing, roof trusses and roofing among others. The second matrix is called Interior Finishes Matrix, which represents activities inside the building with horizontal flow of work (horizontal within a single floor and horizontal within successive floors for multi-story buildings), such as drywall installation, MEP, painting, floor covering and doors among other finish activities.

The first step in composing the CFMx is the identification of appropriate finish areas by carefully splitting the entire project into smaller areas. These areas are listed in the first column of the CFMx. The work items to be performed are identified in the first row labels and are referred to as pacemaker activities, which represent all the trades required for completing the project. The order of the Pacemaker Activities placed in the matrix correspond with the correct logical sequence of activities necessary to build the segmented areas. Thus, all areas will follow the same sequence of work typically encountered in the installation of building finishes. The functional cells in the CFMx indicate the anticipated or scheduled start date of each of the indicated pacemaker activities for the area location segment. The work of each trade within the each of the location areas is to be completed in a period of one week with the starting date always on Monday as shown in the CFMx. The "diagonal line" formed by connecting cells with the same Monday date indicates a date line that represents planned work for the indicated week. During the construction progress of the project, this date line is referred to as the "Balanced Work Front" which depicts the scheduled work status at the indicated date for the various area locations. As time and the project work advance, the Balanced Workfront moves forward with time and represents the work planned/completed for the status date in each CFMx cell. Any scheduled work that is incomplete and is behind the Balanced Workfront status date is considered, by definition, to be late. All work activities that are underway but incomplete during the indicated week are marked with yellow and the activities already finished are marked in green. Late activities behind the Balanced Workfront are left in blank. In this way, clear and simple identifcation of late (behind schedule) work activities by location area and the number of weeks that such activities are behind schedule are clearly evident by visual review of the CFMx and the Balanced Work Front. Thus, the schedule update and progress review for each scheduled pacemaker work activity is binary; that is, scheduled work in the indicated location area for the week is either complete or incomplete and therefore on schedule or late.

Updating the status of the matrix is accomplished by marking each cell of the matrix with colors according to the scheduled status of the cell in relation to the status date and the Balanced Work Front. The figures 13, 14 and 15 below show this schedule status and update dynamic of the matrix for the first three weeks of an example project in which the project started on Monday, November 13th. In the example, the first activity to be started on the project start date is "Frame First Floor and Block Exterior Walls." Therefore, only the first cell must be marked with yellow indicating current progress has commenced. For the next week, Monday, November 20th, the work represented by the first activity moves to the next area in the scheduled location area sequence, and the next pacemaker activity in the trade work sequence, which is "stack pumbling first floor and exterior sheathing," is initiated in the first location area just completed by the first trade in the trade sequence. The finished area from the previous week must be colored with green. In the third week of the project, the third pacemaker activity, "Floor Trusses and Deck," is started on the project and the precedent activities move forward to the next areas. This flow of Pacemaker Activities through the location areas continues until the completion date of the project.

1st

Pacemaker Activities →

Segmented areas

Monday

AREA	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone
1	11/13	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29
2	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5
3	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12
4	12/4	12/11	[illegible]	[illegible]/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19
5	12/11	12/18	[illegible]	[illegible]/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26
6	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5
7	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
9	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
10	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
11	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
12	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16

Figure 13: Representation of the Clear Flow Matrix in the first week of the project.

Pacemaker Activities →

1st 2nd

Segmented areas

Balanced Work Front (Mondays)

AREA	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone
1	11/13	~~11/20~~	~~11/27~~	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29
2	~~11/20~~	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5
3	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12
4	12/4	[illegible]	[illegible]	[illegible]	[illegible]	1/8	1/15	1/22	1/29	2/5	2/12	2/19
5	12/11	[illegible]	[illegible]	[illegible]	[illegible]	1/15	1/22	1/29	2/5	2/12	2/19	2/26
6	12/18	[illegible]	[illegible]	[illegible]	[illegible]	1/22	1/29	2/5	2/12	2/19	2/26	3/5
7	12/25	[illegible]	[illegible]	[illegible]	[illegible]	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
9	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
10	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
11	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
12	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16

Figure 14: Representation of the Clear Flow Matrix in the second week of the project.

Pacemaker Activities →

1st 2nd 3rd

Segmented areas

Balanced Work Front (Mondays)

AREA	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone
1	11/13	11/20	~~11/27~~	~~12/4~~	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29
2	11/20	~~11/27~~	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5
3	~~11/27~~	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12
4	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19
5	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26
6	12/18	[illegible]	[illegible]	[illegible]	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5
7	12/25	[illegible]	[illegible]	[illegible]	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8	1/1	[illegible]	[illegible]	[illegible]	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
9	1/8	[illegible]	[illegible]	[illegible]	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
10	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
11	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
12	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16

Figure 15: Representation of the Clear Flow Matrix in the third week of the project.

The figures 16 and 17 below represent the use of the Clear Flow Matrix of a healthcare project, which was constructed by LBCC beginning in 2008. Figure 16 shows the division of the entire floorplan of the project into distinct location areas of work for utilization in scheduling and production control using the CFMx. These location areas and appropriate pacemaker finish activities were then used to develop the CFMx for the project indicated in Figure 17. The location areas are recorded in the first column of the matrix and the start dates of the pacemaker activities are recorded in the appropriate row for the scheduled location area. This example represents the status of a healthcare project as of November 3, 2008 (Monday). As mentioned before, the date in each cell of the matrix is labelled with the start date (Monday) for the indicated work in the respective location area and that the work indicated should be completed by the end of that week. Statusing construction progress is straightforward and is determined by examining the amount of work that is complete, incomplete or late by comparing completion status with the Balanced Workfront (the scheduled or actual timeline). Bottlenecks and anticipated delay information may be obtained by counting cells of incomplete and late work that lag behind the scheduled Balanced Work Front. For instance, assuming the project of Figure 16 and 17, the activity “Tape/Float Prime” is four weeks behind schedule, and the “Kitchen” is three weeks delayed. In a similar fashion, is also possible to recognize activity acceleration, or work that is being performed ahead of schedule. In the project example in figures 16 and 17 the activity “MEP above ceiling” is two weeks ahead of the Balanced Work Front. As mentioned previously, the representation of CPM schedule usually requires the use of a truckload of documents, culminating in the eventual confusion with regards to the understanding of the schedule of the project as a whole. On the other hand, through the use of the CFMx, the overall construction plan that complements the project CPM schedule can be precisely represented in just a single page.

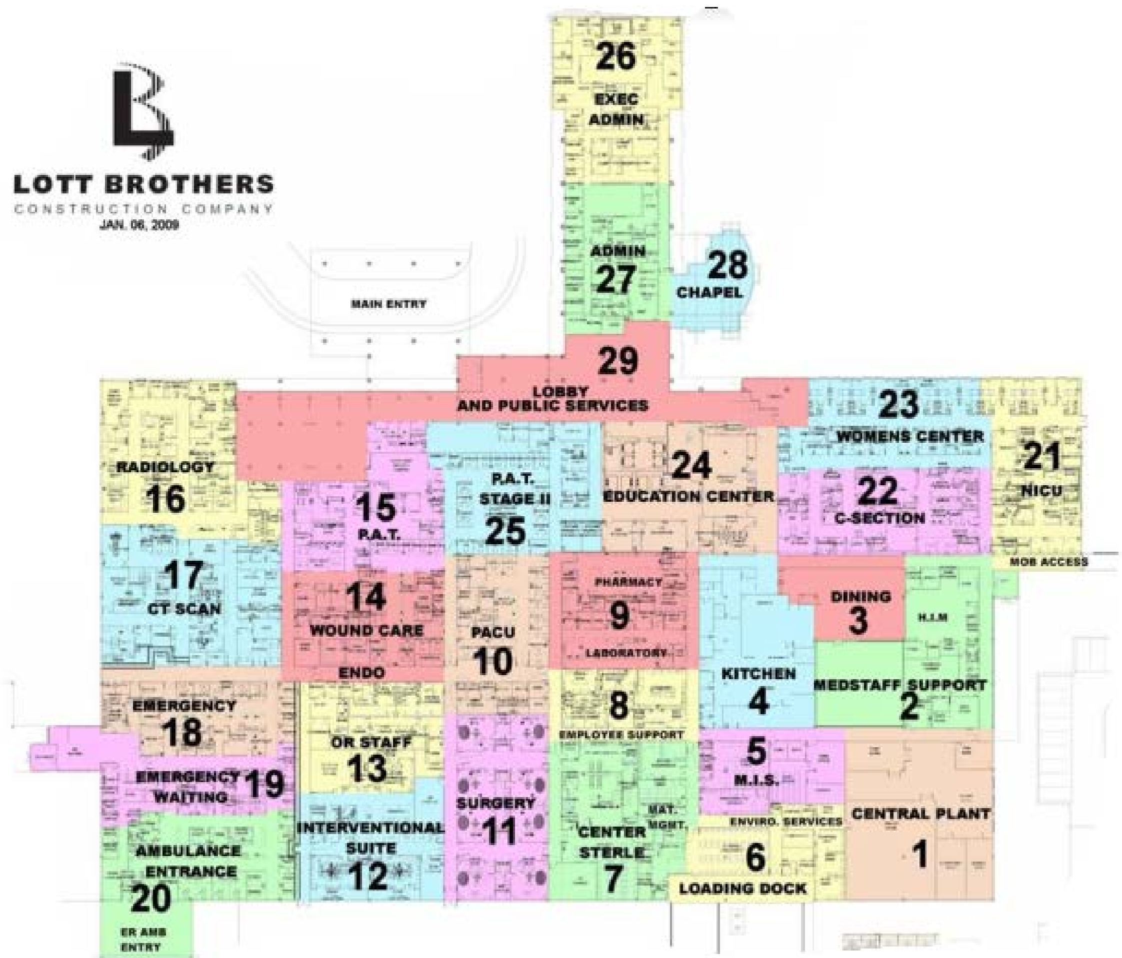


Figure 16 : Segmented areas for the Clear Flow Matrix of a healthcare project in Texas (Source: Lott Brothers Construction Company)

Segmented areas

Pacemaker Activities

Three weeks delayed

Four weeks delayed

Balanced Work Front

Two weeks ahead schedule

Mondays Date

Area Number	AREA DESCRIPTION	MEP Above Ceiling	Frame Top out Halls	Major Mech. In Halls	Frame Interior	MEP Rough-in	Oneside	Inspections	Drywall	Tape/Float Prime	Paint 1st Finish Coat	Ceilling Grid	Millwork	MEP Ceilling Trimout	MEP Start up	Ceilling Tile	Flooring	Paint Final Coat
1	Central Plant	21-Jul	28-Jul	4-Aug	11-Aug	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov
2	Med Staff Support	28-Jul	4-Aug	11-Aug	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov
3	Dining	4-Aug	11-Aug	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov
4	Kitchen	11-Aug	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec
5	M.I.S.	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec
6	Loading Dock	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec
7	NICU	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	22-Dec
8	Women's Center	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	[illegible]	[illegible]	8-Dec	15-Dec	22-Dec	29-Dec
9	C-Section	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	[illegible]	[illegible]	15-Dec	22-Dec	29-Dec	5-Jan
10	Education	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	[illegible]	[illegible]	22-Dec	29-Dec	5-Jan	12-Jan
11	Lab/Pharmacy	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	[illegible]	[illegible]	[illegible]	[illegible]	29-Dec	5-Jan	12-Jan	19-Jan
12	Employee Support	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	[illegible]	[illegible]	22-Dec	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan
13	Center Sterile	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	[illegible]	[illegible]	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb
14	Surgery	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	22-Dec	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb
15	Pacu	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	22-Dec	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb
16	P.A.T. Stage II	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	[illegible]	[illegible]	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb
17	P.A.T. Stage II	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	[illegible]	[illegible]	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar
18	Wound Care/Endo	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	22-Dec	[illegible]	[illegible]	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar
19	P.A.T	24-Nov	1-Dec	8-Dec	15-Dec	22-Dec	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar
20	Radiology	1-Dec	[illegible]	[illegible]	[illegible]	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	[illegible]	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar
21	CT Scan	8-Dec	[illegible]	[illegible]	[illegible]	5-Jan	12-Jan	19-Jan	26-Jan	[illegible]	[illegible]	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar
22	Emergency	15-Dec	[illegible]	[illegible]	[illegible]	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr
23	Emergency Waiting	22-Dec	[illegible]	[illegible]	[illegible]	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr
24	CT Scan	29-Dec	[illegible]	[illegible]	[illegible]	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	[illegible]	[illegible]	[illegible]	[illegible]	30-Mar	6-Apr	13-Apr	20-Apr
25	Radiology	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	[illegible]	[illegible]	[illegible]	6-Apr	13-Apr	20-Apr	27-Apr
26	Exec. Admn	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May
27	Admin	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May	11-May
28	Chapel	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May	11-May	18-May
29	Lobby	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May	11-May	18-May	25-May

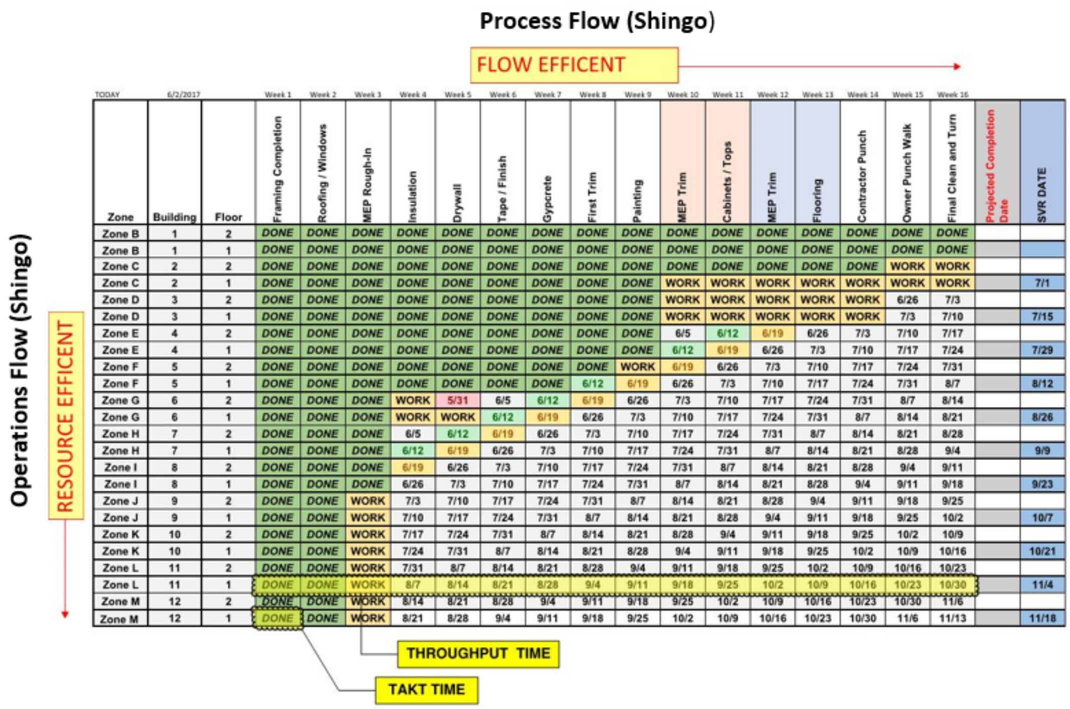
Figure 17: The Clear Flow Matrix of a healthcare project in Texas (Source: Lott Brothers Construction Company)

THE CLEAR FLOW MATRIX AND LEAN CONSTRUCTION

Lott Brothers Construction Company created the first Clear Flow Matrix in 1995. With the growing and on-going implementation of lean thinking and Toyota production concepts from the manufacturing industry into the construction industry, it became evident that the Clear Flow Matrix incorporates certain production control techniques that accomplish many of the tenets of Lean construction and Toyota production. Thus, LBCC transformed some of the Clear Flow Matrix language to better align with their client's Lean Construction terminology to utilize the technique on Lean Construction projects undertaken by the company. LBCC has continued to refine the processes involved in application of the CFMx to construction and determined that use of the CFMx is consistent with basic Lean philosophies of balancing the flow of work on the entire project and not on just improving production efficiency of a single trade at the possible expense of other trades. To be consistent with the overall purpose of the tool, LBCC titled the production control plan as the clear flow matrix to bring attention to the ways in which the technique clearly identifies the flow of the work and the relationships of flow.

In Lean construction/Toyota production terminology, the fundamental purpose of any concept that aids in the control of production, such as a production flow matrix, is the provision of a method, tool or technique which consistently balances resource efficiency and flow efficiency by effectively communicating the scheduled status of all flow units under production at each takt time interval. The status of each flow unit is easily discernable on a manufacturing line; but flow unit status is less obvious in service-type industries and even more difficult to determine adequately on large building construction projects. Because available tools for that purpose commonly used on work scheduled with activity based CPM management software programs employ some form of earned value calculation for each trade and thus the entire project is a summation of the status of the various trades.

The Matrix below (figure 18) is an example that shows the terminology of Lean Construction, introducing terms such as; Flow Efficiency, Resource Efficiency, Throughput Time and Takt Time. In construction projects, flow efficiency is associated with the process efficiency of the handoff of production in one location area to the next trade in the sequence of work and resource efficiency is related to the operational efficiency of each trade as the trade moves through the sequence of location areas. The balance between resource efficiency and flow efficiency is necessary to have the production running at its most efficient (Modig & Åhlström, 2016). This balance can be achieved through the "Balance Work Front" in the matrix. Looking at the Clear Flow Matrix shown below, it is also evident to visualize the priorities from Owner´s and Subcontractor´s perspective regarding flow efficiency and resource efficiency. The owner's desire to have a completed project is best served by assuring high flow efficiency with focus on the throughput time thereby assuring a faster completion date of the project. On the other hand, trade contractors focus on high resource efficiency. As discussed previously in the literature review, trade contractors tend to finish their work rapidly to reduce their labor cost and to move available crews to other contracts. With the reference of the Clear Flow Matrix presented below, a production plan which focuses on flow efficiency alone might produce a completed section of the building very effectively only if all the needed resources were available in that area. In other words, conducting the work of the trades in a purely flow-efficient manner or resource-efficient manner does not effectively produce the completed product for the client. Producing completed areas in the building (units or location areas) without other completed areas wastes time, just as completing the entire work of each trade in turn also wastes time. Indeed, it is not possible to complete buidling finishes unless the trade sequence required for the work is respected. The client cannot accept the building until the entire building is completed. The objective is then to develop and follow a production plan framework that balances flow efficiency and resource efficiency so that the client and construction team members are served in a balanced way.



TODAY	6/2/2017		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16		
Zone	Building	Floor	Framing Completion	Roofing / Windows	MEP Rough-In	Insulation	Drywall	Tape / Finish	Gypcrete	First Trim	Painting	MEP Trim	Cabinets / Tops	MEP Trim	Flooring	Contractor Punch	Owner Punch Walk	Final Clean and Turn	Projected Completion Date	SVR DATE
Zone B	1	2	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE		
Zone B	1	1	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE		
Zone C	2	2	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	WORK	WORK		
Zone C	2	1	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	WORK	WORK	WORK	WORK	WORK	WORK	WORK		7/1
Zone D	3	2	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	WORK	WORK	WORK	WORK	WORK	6/26	7/3		
Zone D	3	1	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	WORK	WORK	WORK	WORK	WORK	7/3	7/10		7/15
Zone E	4	2	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	6/5	6/12	6/19	6/26	7/3	7/10	7/17		
Zone E	4	1	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	6/12	6/19	6/26	7/3	7/10	7/17	7/24		7/29
Zone F	5	2	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	WORK	6/19	6/26	7/3	7/10	7/17	7/24	7/31		
Zone F	5	1	DONE	DONE	DONE	DONE	DONE	DONE	DONE	6/12	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7		8/12
Zone G	6	2	DONE	DONE	DONE	WORK	5/31	6/5	6/12	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14		
Zone G	6	1	DONE	DONE	DONE	WORK	WORK	6/12	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21		8/26
Zone H	7	2	DONE	DONE	DONE	6/5	6/12	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28		
Zone H	7	1	DONE	DONE	DONE	6/12	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4		9/9
Zone I	8	2	DONE	DONE	DONE	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11		
Zone I	8	1	DONE	DONE	DONE	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18		9/23
Zone J	9	2	DONE	DONE	WORK	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25		
Zone J	9	1	DONE	DONE	WORK	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2		10/7
Zone K	10	2	DONE	DONE	WORK	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9		
Zone K	10	1	DONE	DONE	WORK	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9	10/16		10/21
Zone L	11	2	DONE	DONE	WORK	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9	10/16	10/23		
Zone L	11	1	DONE	DONE	WORK	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9	10/16	10/23	10/30		11/4
Zone M	12	2	DONE	DONE	WORK	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9	10/16	10/23	10/30	11/6		
Zone M	12	1	DONE	DONE	WORK	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9	10/16	10/23	10/30	11/6	11/13		11/18

Figure 18: Clear Flow Matrix with Lean terminology

In the earlier stages of the project, the same crews begin to move from area to area shown vertically on the matrix and highlighted as “resource efficient” with little disruption since they are not dependent on other trades to complete their work. As the initial crews complete an area (unit) and move to the next/unit, they prepare to hand off the area/unit to the next crews. Here is where the reality of flow efficiency vs. resource efficiency comes to light. The handoff must be managed correctly for the flow of the complete unit (shown horizontally) to progress at the same efficiency as in the earlier stages. This handoff is a perfect place to apply last planner techniques and the planned percent complete is well defined measurable against both flow and resource efficiency.

The clear flow matrix shown above reflects the status of a project comprised of 12 wood-framed 2-story apartment buildings located in Waco, Texas. This project was several months behind schedule, and the progress on the project was not sufficient to regain the original schedule completion date; thus, the project was effectively out of control. For this reason, the owner of the project contracted with LBCC to provide consultation regarding the project progress and schedule completion status. The original technique used for scheduling and production control on the project was a CPM network based Gantt Bar-Chart depicting detailed schedule activities for each of the buildings. The resulting schedule was presented in some 38 letter sized pages of Gantt chart schedule information. LBCC staff reviewed in the field the current completion status of each building of the project and input this data into a CFMx production control plan to establish a projected date for the completion of the project. This effort generated only one page of information that represents the completion schedule for interior finishes for the entire project. This example use of the CFMx production plan highlights the ease with which managers may employ the CFMx to identify not only the delays, bottlenecks and the trades responsible for delays but also the trade and location areas required for acceleration to complete the project. The status of work completed on the project indicates clearly the poor results that typically result in projects, which do not focus attention on both flow efficiency and operations efficiency on a frequent, perhaps weekly basis. At the Waco apartment project, the first two trades of the project accelarated their work and partially completed their location activities ahead of schedule and effectively left the project with incomplete work in some locations. However, even with the supposed high operations efficiency of these two trades, the project was still delayed because of bottlenecks that developed later and for re-entrant work required to complete work of the supposed operations efficient trades. This situation highlights the need of having a balance between resource efficiency (trades operation) and flow efficiency (process of trade exchange/handoff).

The amount of work required to recover from the delays is clearly depicted on the Clear Flow Matrix by referencing the “06/19” date cells (Figure 18). These constant date cells form a “diagonal” row across the CFMx and depict not only the planned/actual work for the indicated takt time but also the “Balanced Work Front” of construction progress. The Balanced Workfront helps align the late trade-areas with the planned completion schedule and highlights the location areas in which the affected trades are required to work to bring production into alignment with the proposed completion schedule.

As mentioned above, the Clear Flow Matrix easily pinpoints the bottleneck activity, which is represented by columns (trades) composed of white cells (activity not started yet) or yellow cells (activities in the process). As the sequence of pacesetter activities goes from left to right in the first row of the matrix, if one specific trade is delayed, it holds back the trades that follow. The matrix below shows (figure 19) an example status of a project in which the “Floor Truss and Deck” work is the bottleneck activity. Without the installation of floor trusses and deck, the structural frames to be placed on that floor deck cannot be performed. With this situation, it is evident that bottleneck activities worsen the flow efficiency leading to project delay. On the other hand, trades working in areas beyond the Balanced Workfront are wasting effort and resources by creating work inventory that does not improve scheduled completion of the project.

AREA	BLDG #	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	*Shingles and Metal Roofing*	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone	Exterior Paint	Downspouts and Gutters	Finish Flat Work	Touch Up	Landscaping
1	Club	11/13	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5
2	11A	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12
3	8A	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
4	3B	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
5	6B	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
6	2A	12/18	12/25	1/1	1/8	[illegible]	[illegible]	[illegible]	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
7	1B	12/25	1/1	1/8	1/15	[illegible]	[illegible]	[illegible]	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16
8	5A	1/1	1/8	1/15	1/22	1/29	[illegible]	[illegible]	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23
9	4A	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30
10	7B	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7
11	9B	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7	5/14
12	10B	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7	5/14	5/21

Bottleneck

Activity holding the project

Figure 19: Clear Flow Matrix with bottleneck activity

TAKT TIME AND AREA BREAKDOWN

The weekly basis duration of the Clear Flow Matrix is consistent with the standard planning period routinely used in scheduling and production control on large-scale construction projects. In Lean Construction terminology, this is also the rate of customer acceptance, which is the “Takt Time” for completing and turning over each trade-area as each location area is finished in turn. The use of takt-time planning serves the sustained work flow objective by providing the sequence of trades in defined location areas with the same amount of time (Faloughi et al., 2015). To maintain the one week “Takt Time” for the project, it is necessary during the pre-construction phase to break down the area of the project into smaller pieces, taking into consideration the complexity of each trade. To complete this, some information is required at this stage to determine the most appropriate location area segmentation plans for scheduling the project and preparation of its attendant production control plan reprsented by the Clear Flow Matrix:

- Quantity takeoffs by areas
- Available trade labor information
- Published and in-house crew hour production rates
- Crew composition data
- Supply chain

The goal of any production control system is to deliver the final product that meets client demand. In building construction projects, the final product (building) is composed of several rooms and the customer demand is met when all the rooms are finished, not only part of them. Only by tracking a portion of the total customer needs can the processes be analyzed and improved to achieve a balance between flow efficiency and resource efficiency.

In construction, resources move physically through the rooms (locations) rather than production units move through the workstation as in manufacturing industry. Therefore, it is easy to identify physical portions of a project as units to be completed that will result in the overall completion of the project. This physical portion could be, for instance, walls, slabs, interior finishes and all tied back to the completion of the project through physical constraints and milestone dates established by the customer. Trades should be scheduled to complete portions of the work so that the whole project is not subjected to extreme inefficiencies in completing extensive areas in very reduced times.

These segregated areas have to be correctly sized so that all trades to perform their job in those areas in one week. It allows that the handoffs can be made and tracked on a weekly basis. Faloughi et al. (2015) confirmed what was mentioned earlier that one-week handoff is rational with project control systems. A study conducted by O’Brien (2000) demonstrates that the size of work areas released to subcontractor trades plays an important role on the productivity rate. His research shows that the productivity rate may increase when the available area also increases. However, this relationship continues to a certain point. After achieving a peak, the productivity tends to decrease with the growth in the area. The chart below (figure 20) shows this relationship between work area and productivity. Demotivation of workers explains this decrease of productivity rate when areas become too large (O'Brien, 2000).

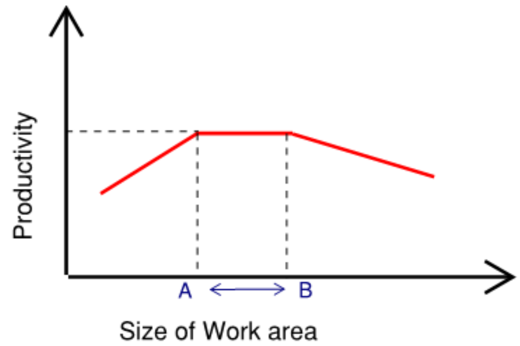


Figure 20: Relationship between the size of work area and productivity (adapted from O'Brien, 2000)

In construction, it is common to have trade contractors requesting large areas to work, so that they can continue the same activity for long as possible. However, the figure above indicates that large areas is not synonymous to being the most productive. Contractors must understand this relationship shown in the chart above (figure 20) correctly size the work areas for subcontractors to achieve a high productivity level and at the same time, meet the as-planned schedule. To set up a scheduling using the CFMx technique it is necessary to combine the takt time of one-week duration and the size of work areas, in which ideally have to be within the two points (A and B) shown in the figure 20 .

Pacemaker Activities

The literature review has shown that production systems must combine both resource efficiency/operations flow and flow efficiency/process flow to achieve good project outcomes. However, productivity has still a high priority and organizations must not neglect it. The Clear Flow Matrix provides a reasonable and competitive pace of production by selecting the pacemaker activities that will include the significant trades on the project. The pacemaker activities are identified in the first row of the matrix and can be one trade or a combination of various trades. The areas should be sized to accommodate the total number of tradesmen. The sum of work of the pacemaker activities result in the completion of the area, and as shown in Figure 18, equal the throughput duration of the area. The throughput duration must be reasonable and often seems a little relaxed when considering one area as a standalone project.

However, as the project progresses, the pressure to maintain flow (completing each area) comes to bear as each trade must prepare to start the next area/unit as well as finish the activities in the current area allowing the next trade to start the following Monday. The trades of each pacemaker activity must complete their work per area in one week, which is represented by one single cell in the matrix. Following this protocol, it avoids out of sequence work. In construction projects, the pacemaker activities are commonly delayed to start closer to the final project completion instead at each area completion. This situation leads to delaying the supply chain activities and inevitably results in the crash programs that have almost become the norm.

CPM and improper pull planning can appear to encourage postponing the “finishes” and later pacemaker for the convenience of site coordination, access, and supply chain decisions. This is so-called convenience is resource efficiency taking priority over flow efficiency. This situation results in multiplying change orders and incomplete work throughout the entire project rather than forcing those decisions and resources to complete the customer demand rate per area. Once again, the early inconveniences drive projects to the costly trade stacking, rework, and overtime required to recover from the early decisions. Mockups, BIM, and prefabrication are allowed to be an even greater benefit as areas finish early, and they provide tools to convey information to the following areas.

BALANCED WORK FRONT

As the project progress to completion, new trades start to work on the project while others move into different areas. During the midpoint of the project when the many different trades are on the job site, it is common to have a stacking of trade, which usually becomes a problem for construction productivity, and large inactive areas. The construction industry needs a good management system to avoid this unwelcome situation. Ideally, different trades can be spread in smaller crews and redirected to multiple areas throughout the job site with specific duties. The Balanced Workfront shows this optimal model exactly, demonstrating where and when each trade is supposed to work.

Furthermore, the Balanced Workfront can depict the workload of the project. As the project advances, the number of current work locations (yellow cells) increases from the beginning until a certain time. The workload achieves the peak usually around in the midpoint of the project when all the locations are being worked in. After achieving the peak, either the workload remains the same for a period and starts to decrease or starts immediately to decrease (it depends on the relationship between a number of areas and the number of trades in the matrix). The Balanced Workfront identifies the variation of workload through the project. The figures below illustrate three different situations. The first (figure 21) shows a status of the project when the numbers of work areas still increase over the time. The second picture shows an example (figure 22) when the project reaches a peak in term of workload, at which point all areas are occupied by trades. The third matrix (figure 23) shows the project status when the amount of work decreases over time.

BLDG #	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone	Exterior Paint	Downspouts and Gutters	Finish Flat Work	Touch Up	Landscaping
Club	11/13	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5
11A	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8A	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
3B	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
6B	12/11	12/18	12/25	1/1	1/8	[illegible]	[illegible]	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
2A	12/18	12/25	1/1	1/8	1/15	[illegible]	[illegible]	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
1B	12/25	1/1	1/8	1/15	1/22	[illegible]	[illegible]	[illegible]	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16
5A	1/1	1/8	1/15	1/22	1/29	[illegible]	[illegible]	[illegible]	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23
4A	1/8	[illegible]	[illegible]	1/29	2/5	[illegible]	[illegible]	[illegible]	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30
7B	[illegible]	[illegible]	[illegible]	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7
9B	[illegible]	[illegible]	[illegible]	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7	5/14
10B	[illegible]	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7	5/14	5/21

Balanced Work Front progress

Increase of work areas

Figure 21: Representation of the Balanced Workfront when the project has not still achieved the peak of workload. The work areas increase over the time.

BLDG #	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone	Exterior Paint	Downspouts and Gutters	Finish Flat Work	Touch Up	Landscaping
Club	11/13	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5
11A	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8A	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
3B	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
6B	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
2A	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
1B	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16
5A	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	[illegible]	[illegible]	3/12	3/19	3/26	4/2	4/9	4/16	4/23
4A	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	[illegible]	[illegible]	3/19	3/26	4/2	4/9	4/16	4/23	4/30
7B	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	[illegible]	[illegible]	3/26	4/2	4/9	4/16	4/23	4/30	5/7
9B	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	[illegible]	[illegible]	4/2	4/9	4/16	4/23	4/30	5/7	5/14
10B	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7	5/14	5/21

Balanced Work Front progress

Figure 22: Representation of the Balanced Workfront when the project achieved the peak of workload. All areas have trades working.

BLDG #	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone	Exterior Paint	Downspouts and Gutters	Finish Flat Work	Touch Up	Landscaping
Club	11/13	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5
11A	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8A	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
3B	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
6B	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
2A	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	[illegible]	[illegible]	4/9
1B	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	[illegible]	[illegible]	4/16
5A	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	[illegible]	[illegible]	[illegible]	[illegible]	4/23
4A	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	[illegible]	[illegible]	4/16	4/23	4/30
7B	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	[illegible]	[illegible]	4/23	4/30	5/7
9B	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	[illegible]	[illegible]	4/30	5/7	5/14
10B	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	[illegible]	[illegible]	5/7	5/14	5/21

Decrease of work areas

Balanced Work Front progress

Figure 23: Representation of the Balanced Workfront when the work locations decrease over the time.

Focusing on the start date of a trade location activity rather than end date helps all project participants and managers emphasize the need for supply chain success in lieu of pressuring last planners and installers to accelerate installations to meet promised end dates. Supply chain issues in construction projects are often responsible for completion delays and consequently, trade contractors should be encouraged to complete submittals and other supply chain issues as early as reasonably possible to improve successful on-time starts of their work, which improves on-time completions. The CFMx production control plan provides such emphasis on the need to complete supply chain issues. This focus encourages all work participants to overcome the natural human tendency to wait until the last minute to start preparing for a trade location activity start. The clear and visual nature of the CFMx provides the management clarity required to encourage on-time completion of supply chain issues that are often out of the direct control of the trade supervisors and last planners. This helps supply chain vendors and construction manager support personnel anticipate and schedule the needs for materials, workforce, and space to support trade installations at the construction pace of the Balanced Work Front.

The figure 24 below represents the requirements for a proper flow of the construction project. Many of these requirements are outside of the direct control of the construction manager's site supervisor. Four of the items are prerequisites to start the work activity at the construction site. These are detailing, materials, manpower and space. These items must be planned and scheduled to be available for the trade contractors at the beginning of the activities and not provided sometime during the performance of the work operation. The CFMx through the Balanced Workfront highlights the need for these items before the execution of the activity. The lack of availability of such items as drawings, RFI answers, proper fit details, other trade interference, late material deliveries are often presented as reasons and excuses which delay starting of trade work as trade contractors are requested to initiate work on the site or in a location.

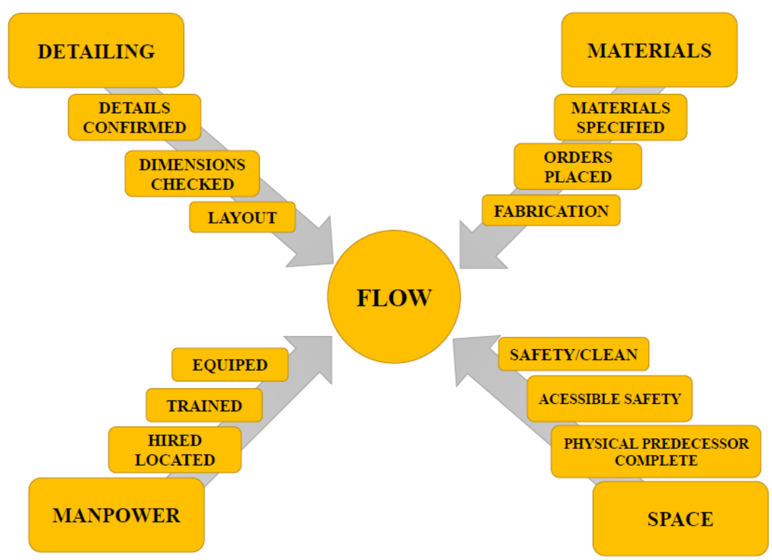


Figure 24: Scheme representing four main elements for achieving proper construction flow.

The literature review shows the importance of balancing flow efficiency and resource efficiency in production management systems. The existing production management techniques applied in the construction industry neither address these two types of efficiencies nor do not clearly represent them. In contrast to existing CPM scheduling management software and production control techniques, the CFMx tracks and balances the tension between flow and resource efficiencies as represented by the Balanced Work Front. As work progresses, the diagonal produced by the same Monday start date becomes the visible scheduled progress and the current status of the project. The CFMx provides a significant planning tool that points out precisely not only which trade contractors and pacemaker activities are behind schedule but also provides specificity regarding the location of the bottleneck and the anticipated delay to the completion date of the project.

The concepts of production stated in Little´s Law indicate that a reduction in throughput time of the project will require a reduction in either work in process (WIP) or an increase in the throughput rate (faster). However, any reduction in WIP to decrease throughput time must not result in a reduction to a WIP amount less than the critical WIP required to deliver the project corresponding to client demand. The Balanced Workfront depicts the critical WIP for the project, that is, the optimal amount of work by trade and location area required per takt period in order to just meet the as-planned master project schedule completion date without any disruption. By working on critical WIP production, the construction manager must ensure that none of the critical WIP trade location area activities undertaken will be starved for any items required for the full planned production of the WIP activities. All the prerequisites to start the work such as resources, information, laborers and location areas will be available for all WIP-involved trades. Working at the pace of the Balanced Work Front, the project will not exhibit any single bottleneck activity, because all trades will have the same WIP and the same time to handoff their work (five days of takt time). Therefore, all trades are working at the flow pace necessary to just deliver the client throughput and thus are avoiding bottlenecks. If trades are working ahead of the critical WIP, this guarantee of resource availability may not occur, depending upon the trade work under consideration. In construction projects, trade contractors tend to accelerate their schedule so that they can finish their job and move on to other contracts or to accelerate their as-planned payments from later billing periods to earlier ones. However, this often leads to a situation in which areas are not ready for them to start their work, requiring the subject trade to either wait for completion of the preceding trade or to move to some other location within the project to work ahead of another trade. Waiting is a typical example of waste in construction that can be avoided with production management techniques, such as the CFMx. Trades working ahead of the Balanced Workfront are not adding value but are, instead, creating additional WIP that does not increase throughput nor shorten the schedule. This highlights in practice the efficiency paradox and clearly shows that all trades must finish their work in-turn according to the CPM master schedule reflected in the CFMx production control plan at the pace of critical WIP indicated by the Balanced Work Front.

This is an ideal production concept that results in the optimal work flow for the project required to complete the client demand in accordance with the master CPM schedule developed for the project. This does not mean that the proposed or planned schedule is the overall optimal delivery schedule for the project as such an optimal schedule may not be identifiable (Goldratt, 1997). It does however mean that the CFMx will deliver the customer demand as scheduled by the planned approach without waste caused by bottlenecks or waste caused by excessive WIP.

Sacks et al. (2016) state that a good flow in construction projects exists when the workers can work continuously in different locations at a stable production rate. The figure 25 below presents an ideal project with the optimal workflow. The lines represent the movement of trades through different locations of the project. The continuous lines mean that for this project the ideal workflow is achieved, indicating that there are neither activities requiring re-entrance nor is there any need for workers to wait to perform their work. The parallel lines indicate that the trades are working at the same pace, ensuring the project to have a continuous and smooth handoff process. This ensures that each area has only one trade working, which prevents the stacking of trade situations. On the other hand, the Figure 26 below presents three projects with a discontinuous workflow. The inclination of the lines varies through trades and through the time. It means that the trades are working in different rhythms. This unwelcome situation leads the trades to have waiting times and to work in the same area with other trades at the same time.

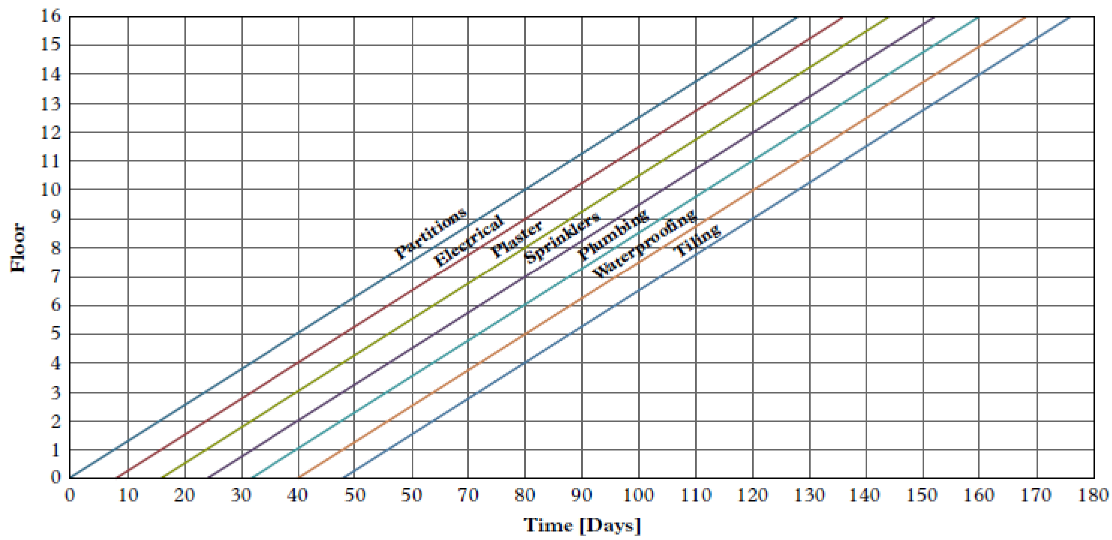


Figure 25: The optimal work flow (Sacks et al., 2017).

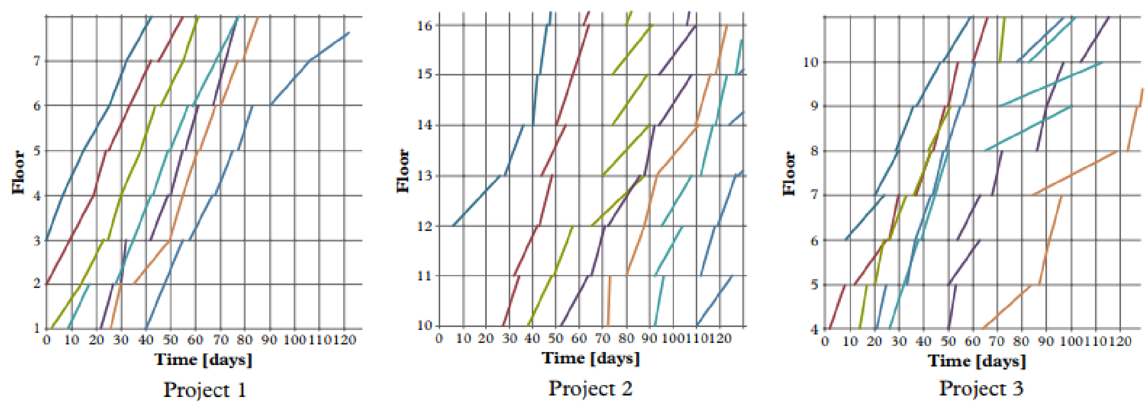


Figure 26: Three projects with discontinuous work flow (Sacks et al., 2017).

The achievement of the optimal workflow in construction projects is a difficult task for the construction delivery team to accomplish due to high uncertainties in the marketplace, weather and project site conditions and constraints. Trade contractors tend to focus on their task without considering how the variability in their capacity affects the project workflow due to the interdependency among different trades. Through management techniques, construction projects can enhance their plan reliability, consequently enhancing the workflow. A reliable workflow makes sure that all resources are available at the right time (Thomas, 2002). The Balanced Workfront is a tool that helps improve production reliability by balancing the two types of flow, operations flow and process flow. The standardization of the pace of work (one week takt time) for all trades provides projects with a structured framework to use to deliver the project team with more predictable and stable flow that meets the client demand. It is worth highlighting that achieving the optimal construction flow is not equivalent with stating that all trades have achieved the maximum productivity; it is, however, the optimal productivity achievable for the trade, given client demand and subject to consideration of other trade contractor work all in accordance with the delivery program of the CPM master schedule. This is because of the variation of location areas and the content of work through the different locations of the project. However, most work by trade contractors is conducted in a marketplace which can place other-project portfolio demands for labor being utilized on any project of interest. Stable demand and predictable increases or decreases in the trade-labor demand of the project of interest can be managed through effective application of the PPO model (Portfolio, Process and Operations) as suggested and described by Sacks (2016). It is common that some trades do not need one week (takt time) to perform their work in a specific location area. Trades can finish earlier their work and can move to other contracts to avoid idle time on the project of interest with a scheduled return as planned. In application of the CFMx technique, pre-construction planning with the major trade contractors helps reduce between location-area variations of work for the trades.

Sacks et al. (2016) defined optimal conditions that lead to the ideal workflow as mentioned in the chart above (figure 25). Through application of the Balanced Workfront of the CFMx production control framework, the construction managers may obtain the majority of these conditions, which are shown below as adapted from Sacks (2016):

1. Uniform takt time for all trade location areas;
2. Each trade should occupy only one location during the same takt time;
3. Reduce time buffer between trade exchanges;

4. Reduce number of operations to essential minimum required (critical WIP) to prevent waste;
5. Reduce re-entrant workflow;
6. Reduce rework through handoff acceptance;
7. Workflow is made reliable through the make-ready process to remove contraints;
8. The number of locations with work in progress is equal to the number of trade crews, that is, work on critical WIP to reduce WIP buffers;
9. Provide stable within-trade operation production rates to extent practical across locations given client demand schedule;
10. Wasted operation time for each trade is reduced by careful design of handoff/make-ready process.

HANDOFF PROCESS

In today's building construction marketplace, the installation is often performed by trade contractors rather than by direct-hire employees of the construction manager or general contractor. Trade contractors desire to complete as much work as quickly as possible to not only maximize within-project production but also to employ surplused labor on other backlog work in their portfolio of projects. In building work, it is very important for all trades to realize that their work is tied inexorably to the trades that preceed and follow their work in the building, it is the very nature of building construction. Thus, each trade contractor must acknowledge that the project delivery team must work together within a production control plan or framework that delivers a quality product to the client within the time constraints of the construction manager's agreement with the client.

As mentioned in the literature review, flow efficiency is crucial in any type of production system. In construction projects, this efficiency depends on the handoff process between trades. Each trade supervisor must respect and be accountable to the other trade supervisors to create the teamwork atmosphere imperative to a balanced project. As the team begins to develop, the emphasis on accountability to each other grows and is demonstrated daily, as the preparations for location area handoffs become the prime topic of coordinating day to day activities. **Using the Clear Flow Matrix production control plan, the handoff process transitions or transfers between trades tend to improve over the course of the project. From the beginning to the end of the project, the trades follow the same sequence. This protocol enhances the work atmosphere among different trade contractors**.

Moreover, the Clear Flow Matrix gives each supervisor transparency of which area their trade must complete in the current week and which area their trade should prepare to undertake for their work during the following week. As the Clear Flow Matrix shows precisely the amount of work (areas) per week during the construction, trades have plenty of time to prepare supply chain and other constraints for the pace of the project and establish the ideal crew size. Effective communication among all trades and the construction manager is vital to project success. All project participants must touch base with the schedule status, which must be clear so that everybody can understand. The Clear Flow Matrix provides the information of the project status in one single page. Application of the clear flow matrix to construction projects suggests that the CFMx should be formatted to be printed on 11x17 sheets that also show the location area plan and other important information. The sheets may be laminated for durability prior to distribution to each trade supervisor and trade foreman. In practice, it is common to see the laminated CFMx plans in craft tool boxes. Updating (showing completed work) of the CFMx during the weekly construction meetings assures excellent communication among all trades and this works to highlight supply chain and other constraints as well as limiting any confusion concerning production needed to maintain the contracted construction schedule.

The activities of the site supervisors on Fridays as they complete the work of an area and prepare to move into next area are outlined below. The chart below (figure 27) emphasizes the routine that can be established to avoid the confusion and uncertainty promoted by vague and verbal instructions. The Balanced Workfront leaves no room for confusion and ample time for planning.

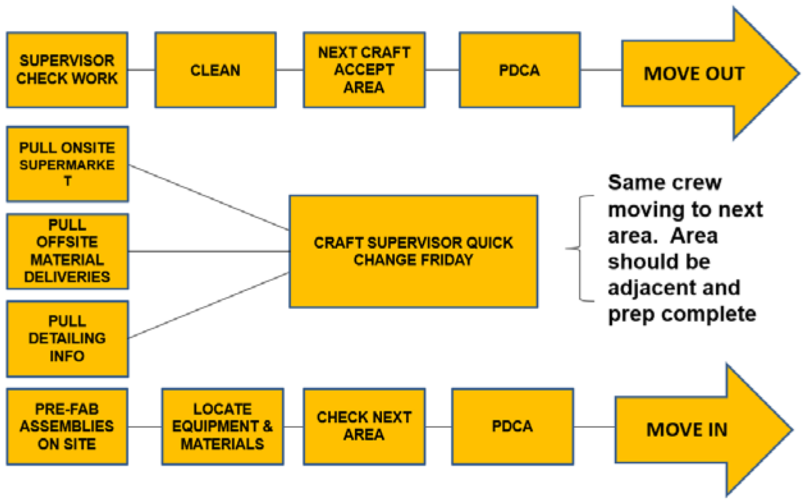


Figure 27: Scheme of handoff process