Chapter 10

Improving Flow at ***<u>any</u>*** Level in a Factory

Introduction

Production Flow Analysis (PFA) is an effective sequential strategy for analyzing the material flows at different levels in a single factory. Typically, PFA is implemented in four stages:

1. Factory Flow Analysis (*FFA*)
2. Group Analysis (*GA*)
3. Line Analysis (*LA*)
4. Tooling Analysis (*TA*)

Each stage in PFA seeks to improve the flow in a progressively smaller area of the factory. First, *Factory Flow Analysis (FFA)* evaluates the flows between shops (or buildings) in the factory to eliminate wastes due to transportation, communication delays, use of large containers for WIP and use of bulk-handling material handling equipment to move the large containers over large distances. Next, *Group Analysis (GA)* evaluates the flows in *each* shop (or building) within the factory to implement manufacturing cells that will produce families of parts with identical (or similar) routings. Then, *Line Analysis* (*LA*) evaluates the flows between machines in *each* cell inside a shop. The layout of a cell is designed for efficient inter-machine material handling, multi-machine tending by any operator and minimum wasted operator movements. Finally, *Tooling Analysis* (*TA*) evaluates the flows at *each* machine in a cell to optimize the workstation layout for ease of machine operation, parts inspection, rapid setup activities (machine loading/unloading, tool changes, fixture changes, machine cleanup), etc.

This chapter gives examples of how PFA (Production Flow Analysis) can be used to analyze and improve flow at different levels of a factory, such as Factory, Shop, Cell or Machine. The examples are intended to illustrate that PFA can be used to improve flow in any high-mix low-volume work system, regardless of the size and scope of that system. All that is needed to use PFA (Production Flow Analysis) to simplify material flow in any work system is (1) a complete list of different "products" that are produced in it, (2) a complete list of "work centers" that are used to make the products, (3) a "routing" for each product that clearly shows the sequence in which different work centers in the system are used to produce the product and (4) a measure of importance/significance of each product. This data is effectively summarized using the acronym "PQR$" (P= Products, Q=Quantities, R=Routings, $= Revenues[1]). PFA is implemented using the PFAST (Production Flow Analysis and Simplification Toolkit) software which semi-automates the manual methods of PFA. It is the versatility of the suite of algorithms in PFAST that allows its use to implement all four stages of PFA depending on the size and scope of the work system in which flow has to be improved. PFAST processes the PQR$ data provided by any high-mix low-volume manufacturing facility using the different

[1] In more advanced studies, T= Time is considered with Q= Quantities to determine the frequency with which each product is produced, especially if it was ordered many times and not just once.

data mining algorithms shown in Figure 1.

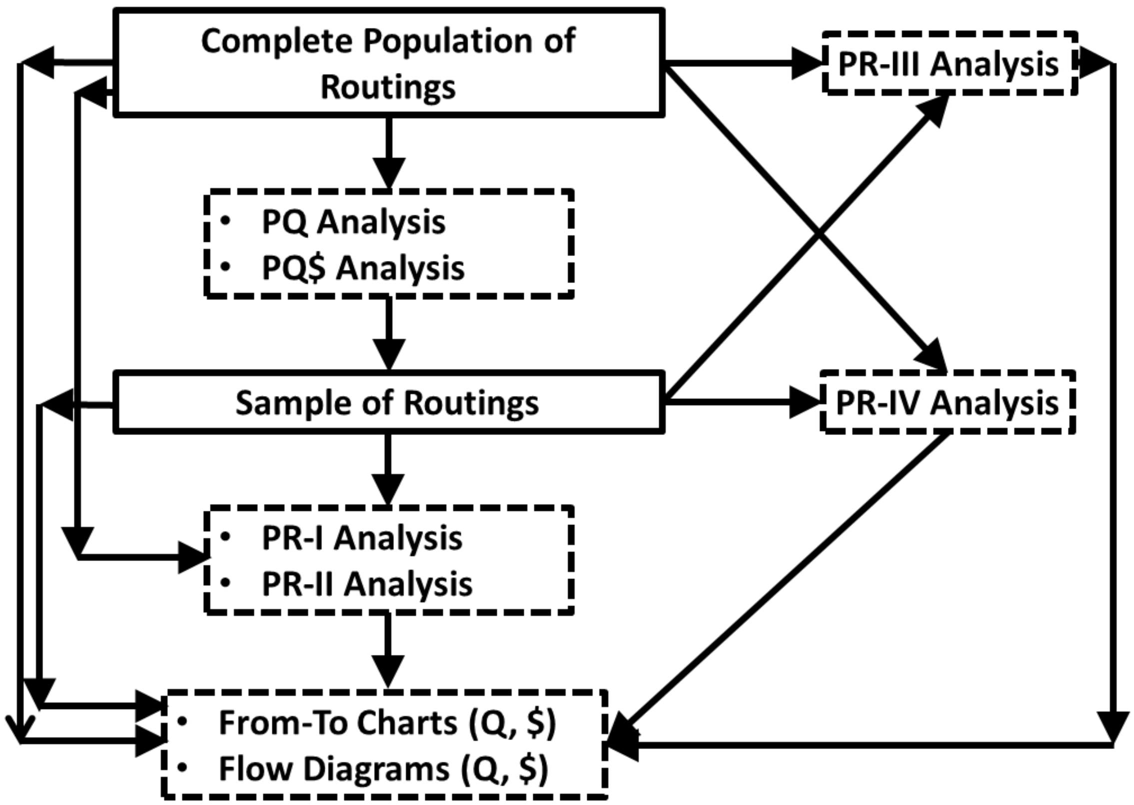

Figure 1 Typical Sequence of Usage for Data Mining Algorithms in PFAST

Examples of Factory Flow Analysis

Fabrication and Assembly of an Industrial Scale: Figure 2(a) shows the Indented Bill Of Routings for the complete product assembly. Figure 2(b) shows the Operations Process Chart for the complete product. The chart was produced from the Indented Bill Of Routings but also required interviews with key shop floor employees who were familiar with the complete product build process. The routings that were input to PFAST were developed from the Operations Process Chart. The improved layout for the factory that is shown in Figure 2(d) was developed mainly from the PR-IV Analysis shown in Figure 2(c) and the From-To Chart in the PFAST Analysis Report. For the purpose of comparison, Figure 2(e) shows the existing layout for the factory.[2]

[2] In the case of an assembled product, it is necessary to develop composite routings that connect (1) the routing of the component to (2) the routing of the sub-assembly it goes into to (3) the routing of the final product.

.5:44:14 [redacted].
ꟳUNCTION: MBIL MULTI-LEVEL BILL INQUIRY PAGE: 1
07/21/1999

PARENT: 2158002065-A DESC: 2158,[redacted],20K,5X7,4KD
RV: UM:EA RUN LT: 1 FIXED LT: 3
PLNR: 3KB PLN POL: N DRWG: TC202034

LEVEL 1...5...10	PT USE	SEQN	COMPONENT	C T	PARTIAL DESCRIPTION	QTY	UM	Q T	M B	LT OFF	SCR PCT
1	0	010	WC[R]811ASMLY	R	ASSEMBLY, F/S	1.5	HR	I	M	0	0.0
1	0	900	TB201990	N	2158,FRAME,CS,	1	EA	I	M	0	0.0
2	0	010	WC[R]763WELDM	R	WELD,MANUAL WE	.5	HR	I	M	0	0.0
2	0	020	WC[R]770WHLBR	R	SHOTBLAST,WHEE	.1	HR	I	M	0	0.0
2	0	030	WC[R]771HCFIN	R	PAINT,HEAVY-CA	.5	HR	I	M	0	0.0
2	0	900	T201972-4300	P	ANGLE,CS,7GAX2	2	EA	I	M	0	0.0
3	0	010	WC[R]763SHR16	R	SHEAR 16'	.01	HR	I	M	0	0.0
3	0	020	WC[R]763PRBRK	R	FORM,PRESS BRA	.01	HR	I	M	0	0.0
3	0	900	MZ1304010054	N	SHEET,7GAX48.7	11.96	LB	I	B	0	0.0
2	0	900	T201972-6700	P	ANGLE,CS,7GAX2	2	EA	I	M	0	0.0
3	0	010	WC[R]763SHR16	R	SHEAR 16'	.01	HR	I	M	0	0.0
3	0	020	WC[R]763PRBRK	R	FORM,PRESS BRA	.01	HR	I	M	0	0.0
3	0	900	MZ1304010054	N	SHEET,7GAX48.7	18.63	LB	I	B	0	0.0
2	0	900	TA201974	N	2158,BEARING,L	4	EA	I	B	0	0.0
2	0	900	TB201971	P	2158,FRAME COR	4	EA	I	M	0	0.0
3	0	010	WC[R]764WELDM	R	WELD,MANUAL WE	.15	HR	I	M	0	0.0
3	0	900	TB201970	P	2158,FRAME COR	1	EA	I	M	0	0.0
4	0	010	WC[R]763SHR16	R	SHEAR 16'	.01	HR	I	M	0	0.0
4	0	020	WC[R]761PUNCH	R	STRIPPIT	.1	HR	I	M	0	0.0
4	0	030	WC[R]763PRBRK	R	FORM,PRESS BRA	.02	HR	I	M	0	0.0
4	0	900	MZ1301010034	N	PLATE,1/4X72X1	10.05	LB	I	B	0	0.0
3	0	900	TN201973	N	2158,BUMPER,CS	2	EA	I	B	0	0.0
1	0	900	TB600364-1	N	LC,745,10K,5KD	4	EA	I	B	0	0.0
1	0	900	TC201989-1	N	2158,PLAT,MT,2	1	EA	I	M	0	0.0
2	0	010	WC[R]763WELDM	R	WELD,MANUAL WE	2.5	HR	I	M	0	0.0
2	0	020	WC[R]770WHLBR	R	SHOTBLAST,WHEE	.1	HR	I	M	0	0.0
2	0	030	WC[R]771HCFIN	R	PAINT,HEAVY-CA	.75	HR	I	M	0	0.0
2	0	900	MZ0901020056	N	NUT,3/4-10,HEX	4	EA	I	B	0	0.0
2	0	900	T201962-6544	P	CHAN,CS,1/4X2.	1	EA	I	M	0	0.0
3	0	010	WC[R]763SHR16	R	SHEAR 16'	.01	HR	I	M	0	0.0
3	0	020	WC[R]763PRBRK	R	FORM,PRESS BRA	.02	HR	I	M	0	0.0
3	0	900	MZ1301010034	N	PLATE,1/4X72X1	43.41	LB	I	B	0	0.0
2	0	900	T201963-6431	P	CHAN,CS,1/4X2.	3	EA	I	M	0	0.0
3	0	010	WC[R]763SHR16	R	SHEAR 16'	.01	HR	I	M	0	0.0
3	0	020	WC[R]763PRBRK	R	FORM,PRESS BRA	.02	HR	I	M	0	0.0
3	0	900	MZ1301010034	N	PLATE,1/4X72X1	68.12	LB	I	B	0	0.0
2	0	900	T201965-4738	P	CHAN,CS,1/4X2.	1	EA	I	M	0	0.0
3	0	010	WC[R]763SHR16	R	SHEAR 16'	.01	HR	I	M	0	0.0
3	0	020	WC[R]763PRBRK	R	FORM,PRESS BRA	.02	HR	I	M	0	0.0
3	0	900	MZ1301010034	N	PLATE,1/4X72X1	50.19	LB	I	B	0	0.0
2	0	900	T201966-4738	P	CHAN,CS,1/4X2.	1	EA	I	M	0	0.0
3	0	010	WC[R]763SHR16	R	SHEAR 16'	.01	HR	I	M	0	0.0
3	0	020	WC[R]761PUNCH	R	STRIPPIT	.02	HR	I	M	0	0.0
3	0	030	WC[R]763PRBRK	R	FORM,PRESS BRA	.03	HR	I	M	0	0.0
3	0	900	MZ1301010034	N	PLATE,1/4X72X1	50.19	LB	I	B	0	0.0
2	0	900	TA201967	P	FLAT,CS,3/4X3X	2	EA	I	M	0	0.0
3	0	010	WC[R]763BDSAW	R	SAW,BAND SAW	.01	HR	I	M	0	0.0
3	0	020	WC[R]771VIKIN	R	SHOTBLAST,VIKI	.01	HR	I	M	0	0.0
3	0	900	MZ1307010089	N	FLAT,3/4X3X20'	10.9	LB	I	B	0	0.0
2	0	900	TA201968	P	2158,STIFFNR W	2	EA	I	M	0	0.0
3	0	010	WC[R]763BDSAW	R	SAW,BAND SAW	.01	HR	I	M	0	0.0
3	0	020	WC[R]763ACRO	R	MACHINE,ACROLO	.01	HR	I	M	0	0.0

*** continued on next page ***

Figure 2(a) Indented Bill of Routings (IBOR) for the Complete Product

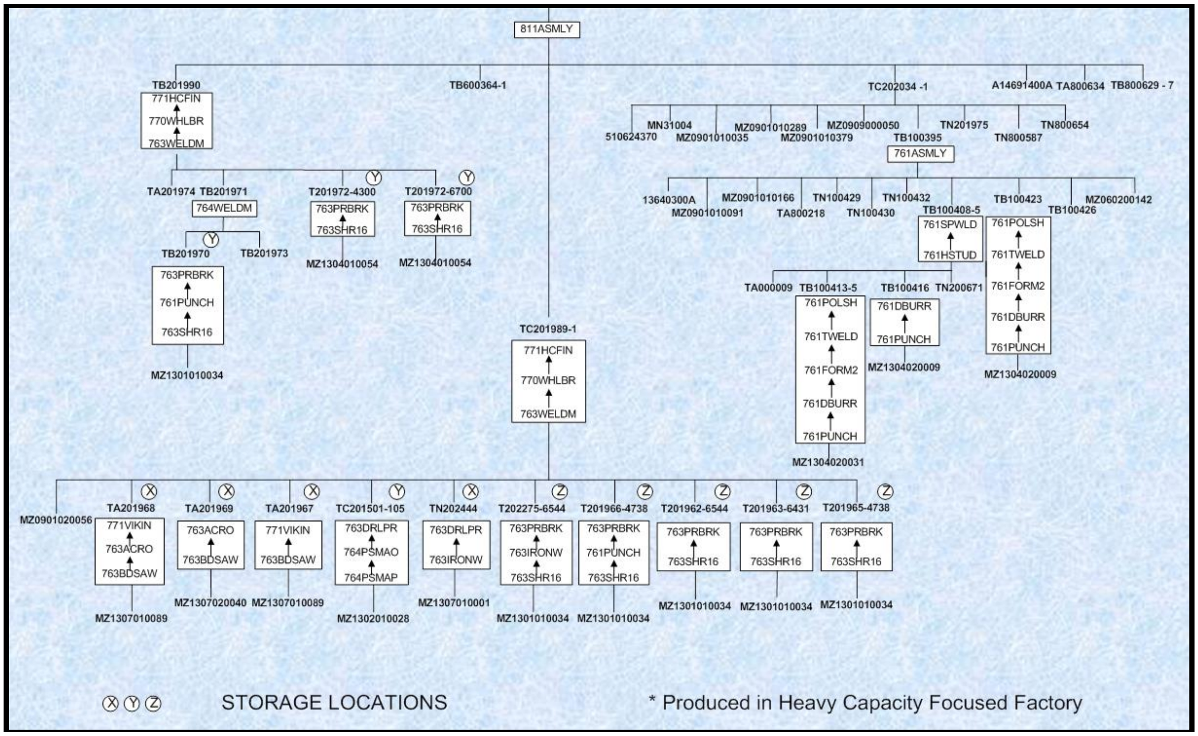

Figure 2(b) Operations Process Chart for the Complete Product

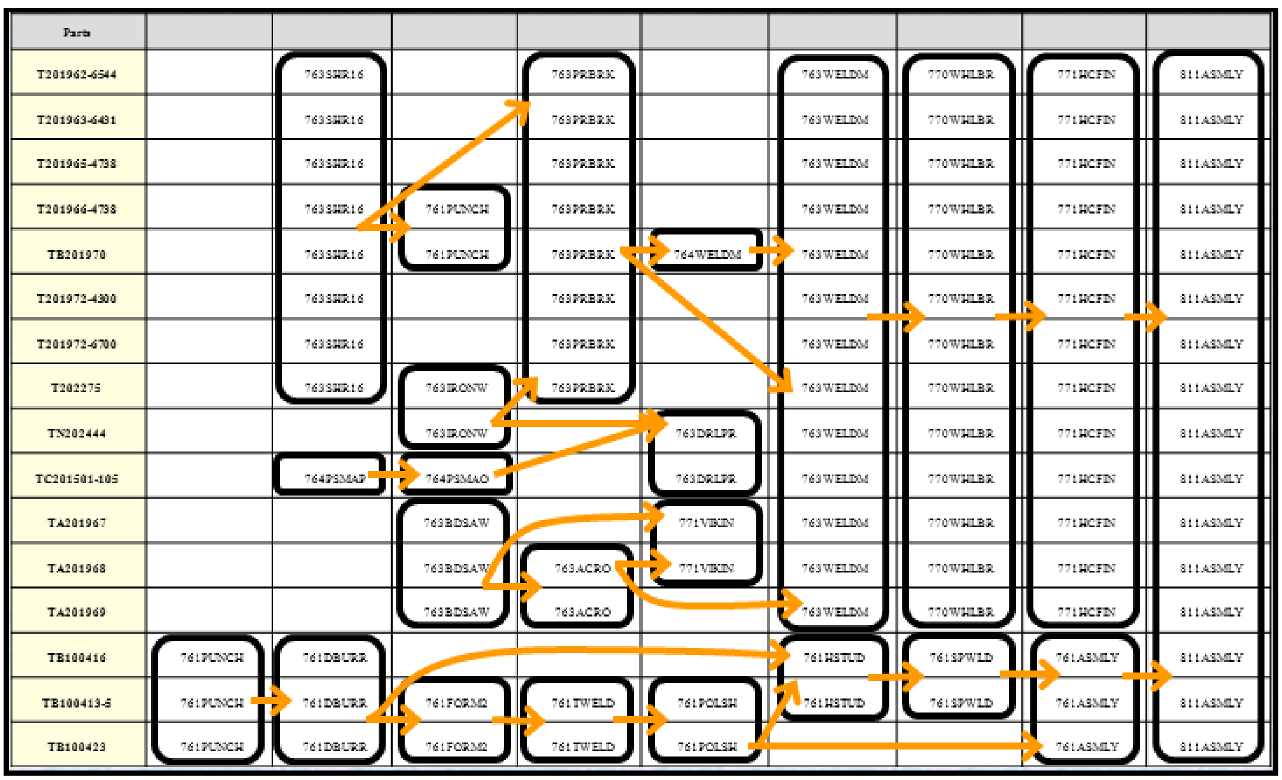

Figure 2(c) PR-IV Analysis of the Routings in the Operations Process Chart

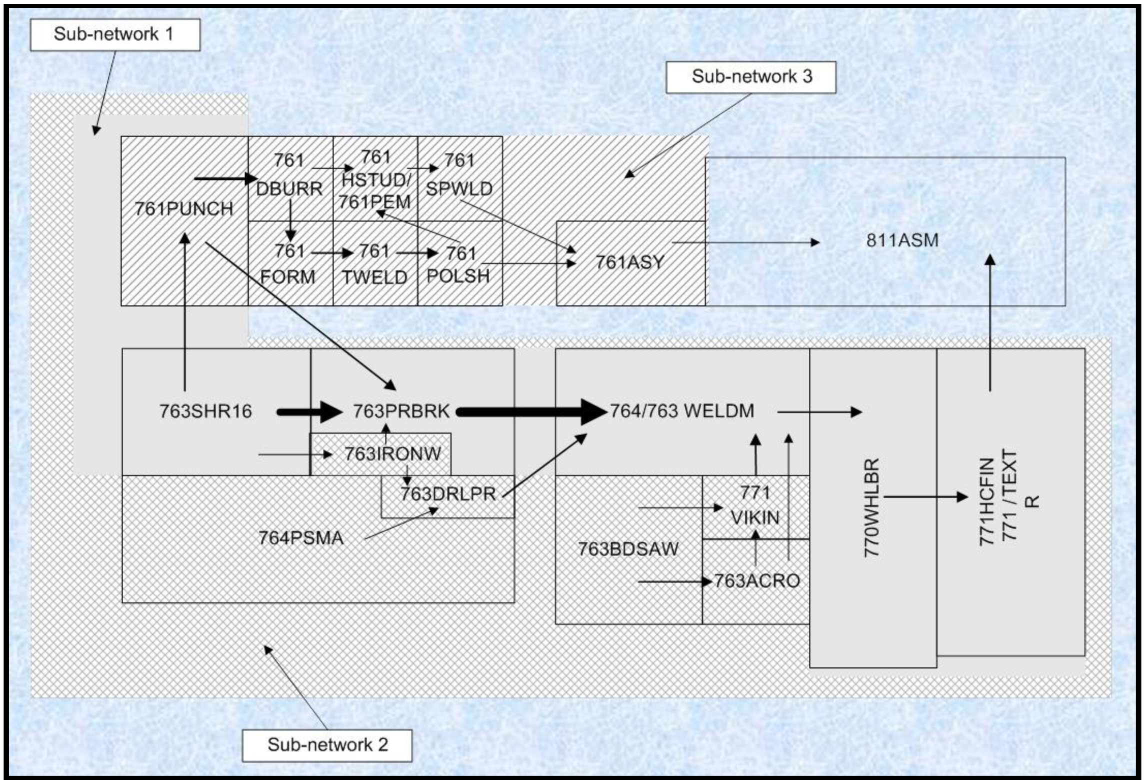

Figure 2(d) Proposed Layout for the Factory

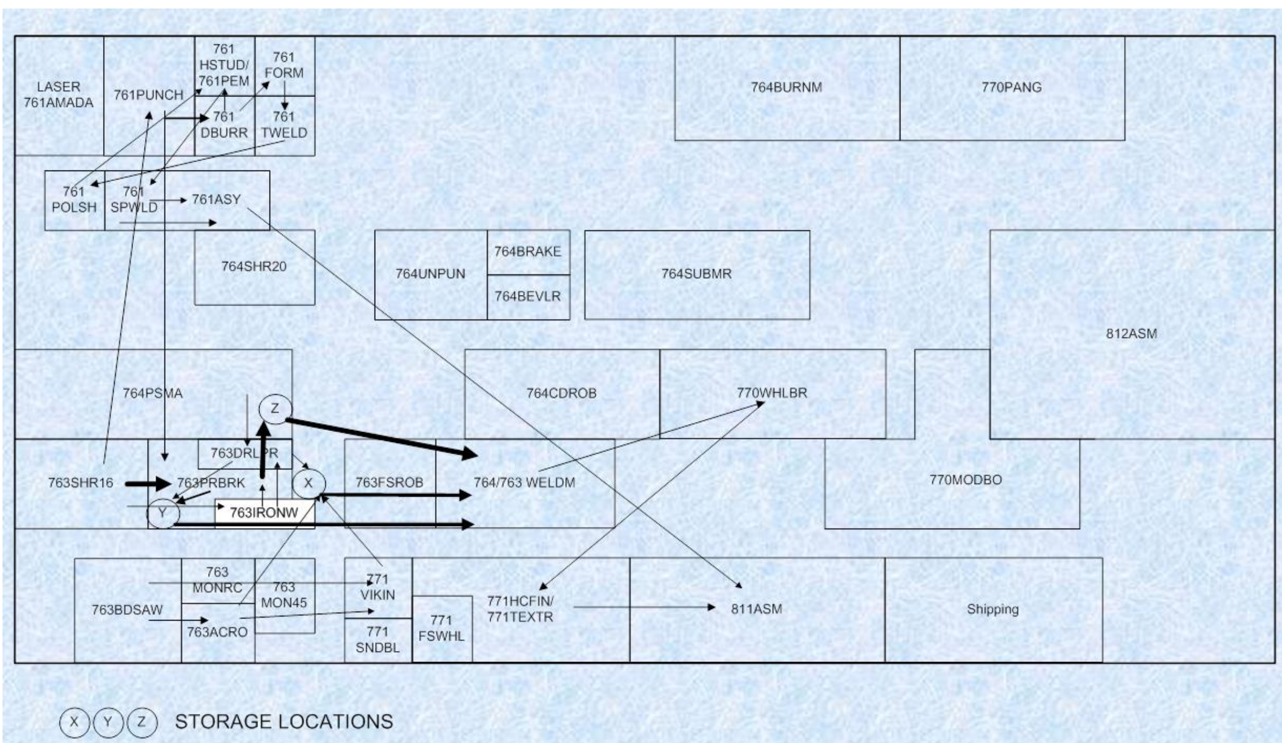

Figure 2(e) Existing Layout for the Factory

Fabrication and Assembly of a Duct Assembly: In this project, we assisted an aerospace and defense supplier. First, we emailed them the case study described earlier in Figures 2(a)-2(e) and explained the methodology for designing a facility layout using Production Flow Analysis. They provided the PFAST Input File for a multi-component duct assembly that also needed several outsourced operations. We ran the data through PFAST and emailed them the PFAST Analysis Report. Next, we followed up with a couple of conference calls to explain to their Lean implementation team how to utilize the PR-IV Analysis and From-To Chart to recognize part families and work centers connected by heavy traffic flow, respectively. Figure 3(a) shows the initial paths (and distances) that the product traveled in the factory. Figure 3(b) shows the new paths (and distances) that the product travelled in the factory after layout changes were made. Table 1 shows the results that they reported to us in return for our pro bono assistance.[3]

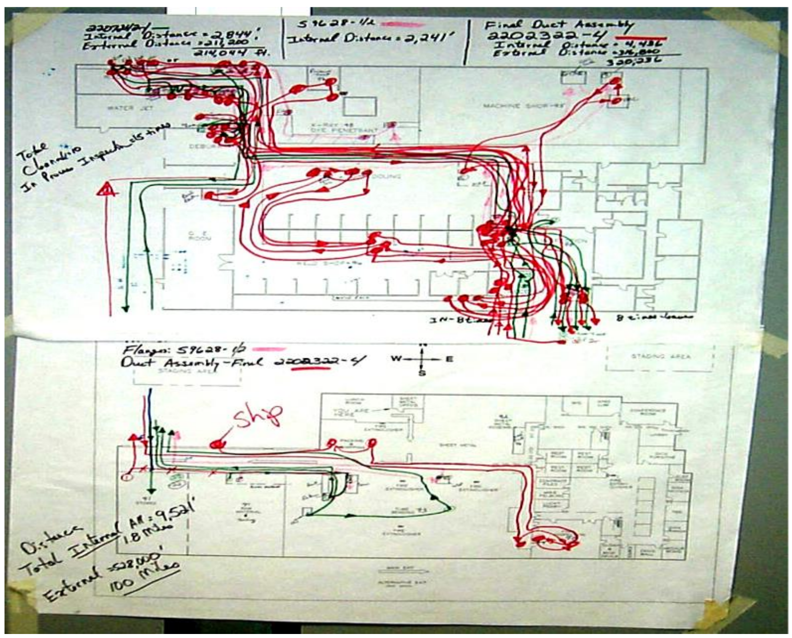

Figure 3(a) Travel Distances for the Duct Assembly in the Initial Layout

[3] PFAST was developed as part of a research contract that had been awarded to The Ohio State University by the Department of Defense. Such pro bono projects helped to please our sponsors above and beyond what they expected! ☺

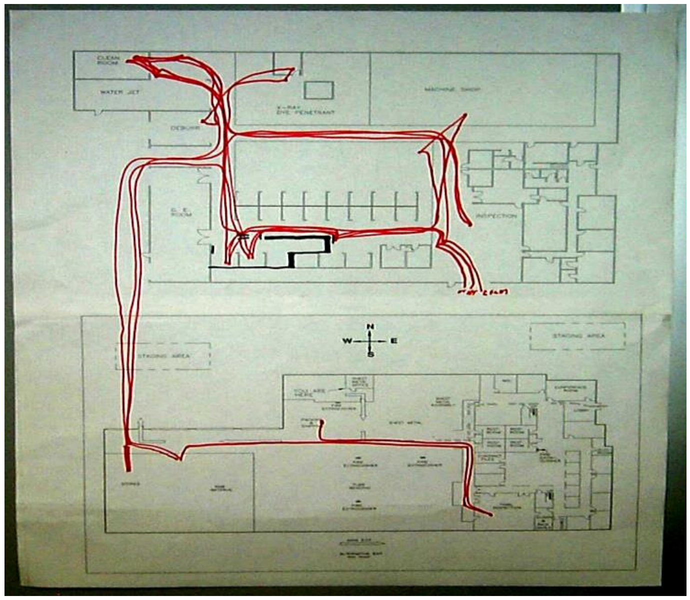

Figure 3(b) Travel Distances for the Duct Assembly in the New Layout

Table 1 Impact of Layout Changes on Key Performance Metrics for Duct Assembly

Metric	**Before Layout Changes**	**After Layout Changes**	**% Reduction**
Lead Time	7 weeks	3.5 weeks	50%
Cycle Time	8 hours	6 hours	25%
Part Travel	2450 ft.	1578 ft.	36%
Walking	3150 ft.	1578 ft.	50%
WIP	360 pcs.	200 pcs.	44%

Make-To-Order Fabrication of Pipes: In this project, we assisted a high-mix low-volume pipe fabricator. We used PFAST to design the factory layout shown in Figure 4. In this proposed layout, we had two Cells and two Layout Modules (aka Partial Cells) but left *untouched* the Process Layout for the rest of the facility. We recommended that the two cells be immediately implemented. However, we did *not* recommend that the two Layout Modules be implemented because (1) there were too many machines in either module and (2) it was more important that they "right-size" the single large washing line (Workcenter #825) which was a monument located in the center of the facility. "Right-sizing" required them to replace it with multiple washing stations (or smaller washing lines catering to different pipe geometries and size ranges). Otherwise, the WIP and queuing delays caused by this bottleneck work center could not be reduced.

In addition, the "long tail" in the PQ Analysis produced by PFAST indicated that (1) they were offering an extremely diverse catalog of products and (2) they were accepting many orders of very small quantities[4] which resulted in numerous setups on the shop floor.

[4] Naturally, the small orders had small profit margins!

Also, the From-To Chart contained too many machines in the routings! This was because parts with similar, sometime identical routings, contained different Machine #s even when those machines were from the same functional group. Consequently, the PR-I Analysis matrix was sparse and the usual blocks of 1's representing part families were not recognizable.

Other recommendations that we made to this pipe fabricator were (1) the complex material flow in the existing factory layout would not be impacted significantly by investing first in an extensive re-layout of the factory, (2) they should form an internal team to rationalize their product mix which would eliminate the large number of "Cats and Dogs" (or Strangers) for which their sales people were accepting orders and (3) they should "scrub" their routings to make them more amenable for a future analysis using PFAST.

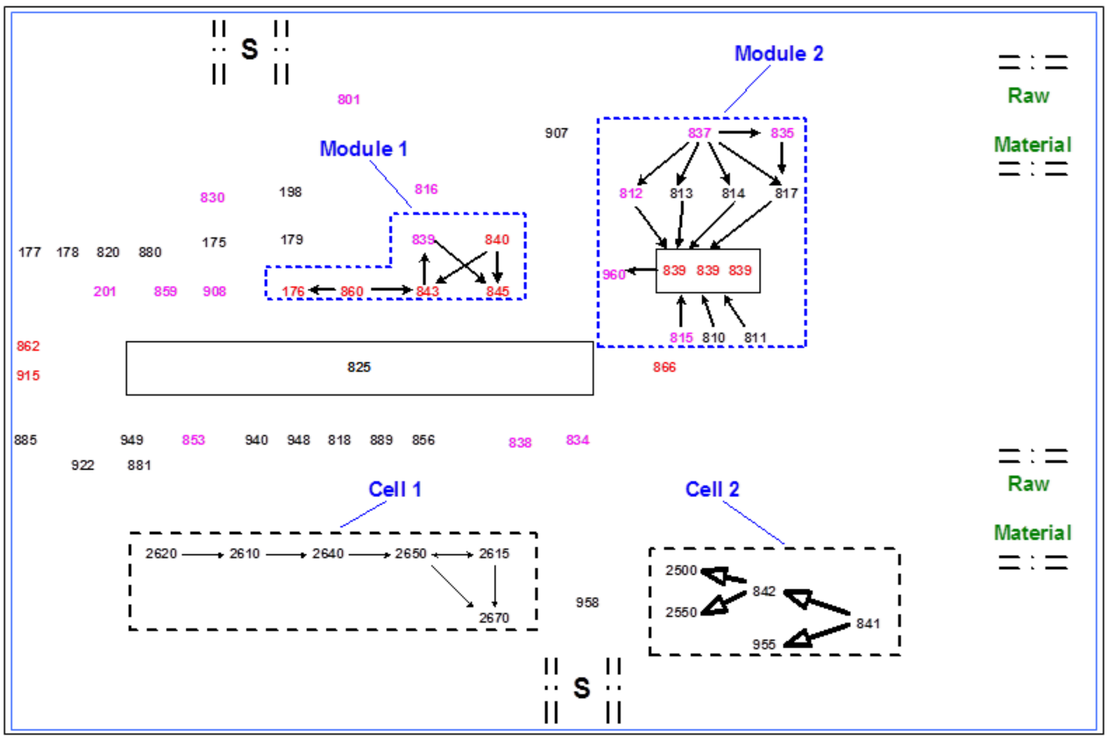

Figure 4 Hybrid Layout for Pipe Fabrication Jobshop

Examples of Line Analysis

Welding Cell: In this project, the same aerospace and defense supplier referenced in Figures 3(a) and 3(b) provided another PFAST Input File for a large number of weldments produced for aircraft engines. We ran the data through PFAST. The PR-I Analysis indicated that the sample of routings corresponded to a single homogeneous part family because they were mostly identical, or similar. So the project's goal reduced to designing the layout of a cell that would produce the entire family of weldments. There was no need to find part families! We emailed the complete PFAST Analysis Report to the aerospace and defense supplier with instructions on how to use only the From-To

Charts and Flow Diagrams in the PFAST Analysis Report. They implemented the welding cell layout shown in Figure 5.

Unfortunately, since the weldments were used in fighter jet airframes, ITAR (International Traffic in Arms Regulations) rules prevented them from providing us specific data on financial benefits or other KPI (Key Performance Indicators) improvements gained from implementing the cell. However, we have reproduced below the following comments that they made about the cell:

- Co-located machines, equipment, tooling and processes helps to minimize parts transportation and waiting.
- Emphasis is on FLOW!
- Eliminated wasteful steps that impede the speed at which parts can flow through the assembly process.
- Created a visual workplace that is self-explaining, self-regulating and self-improving.
- Waste has no place to hide!

The above comments did not come as a surprise because Cellular Manufacturing and Lean go hand-in-hand!

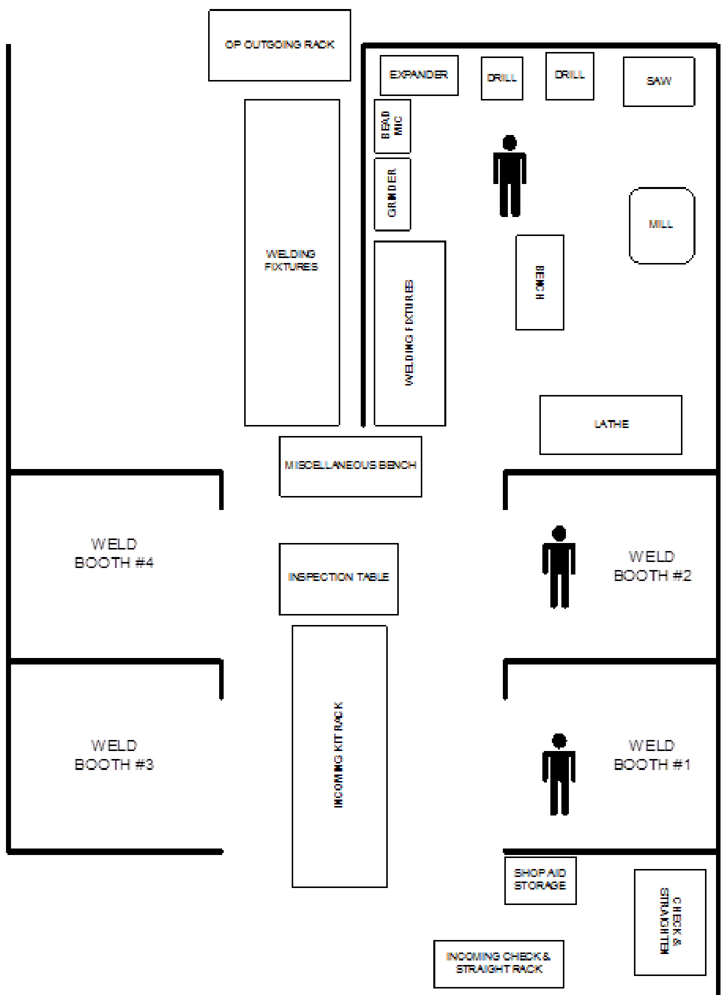

Figure 5 Layout for Welding Cell

Grinding Cell: In this project, we designed a layout for a finishing cell in an investment casting (lost wax) job shop. The PFAST Input File contained the routings and Annual Volumes for upwards of 500 different castings. Only the From-To Charts and Flow Diagrams generated by PFAST were used to produce the Spaghetti Diagram for the Current cell layout and block layout for the Proposed cell layout, as shown in Figure 6. The Proposed layout significantly reduced travel distances between most pairs of machines with significant volume of traffic flowing between them. Prior to the cell implementation, we organized a 5S event which helped to eliminate trash, broken furniture, and other clutter on the floor.

The castings were heavy. So they were pushed on floor-mounted roller conveyor segments that connected the work stations in the cell. In the new layout, we reduced the lengths of the different segments to achieve (1) FIFO (First In First Out) flow between the work stations and (2) limit how many castings would be in process at any given time inside the cell. Initially, there was considerable resistance to this idea both from management and the employees who worked in the cell. However, it was only a matter of time before they saw the WIP in the cell reduce as they pulled work into the cell to match the available manpower and realistic throughput limits of the cell.

The shortened conveyor segments ***also*** improved the material handling ergonomics and safety conditions in the cell. Previously, every cell operator tried to maximize the number of castings he/she processed without any concern for the productivity of the other operators. In the new cell, no castings could be put on the floor if the conveyor segment leaving a work station was full. This stopped the practice of lifting a heavy casting off the conveyor and putting it on the floor in order to start working on the next casting!

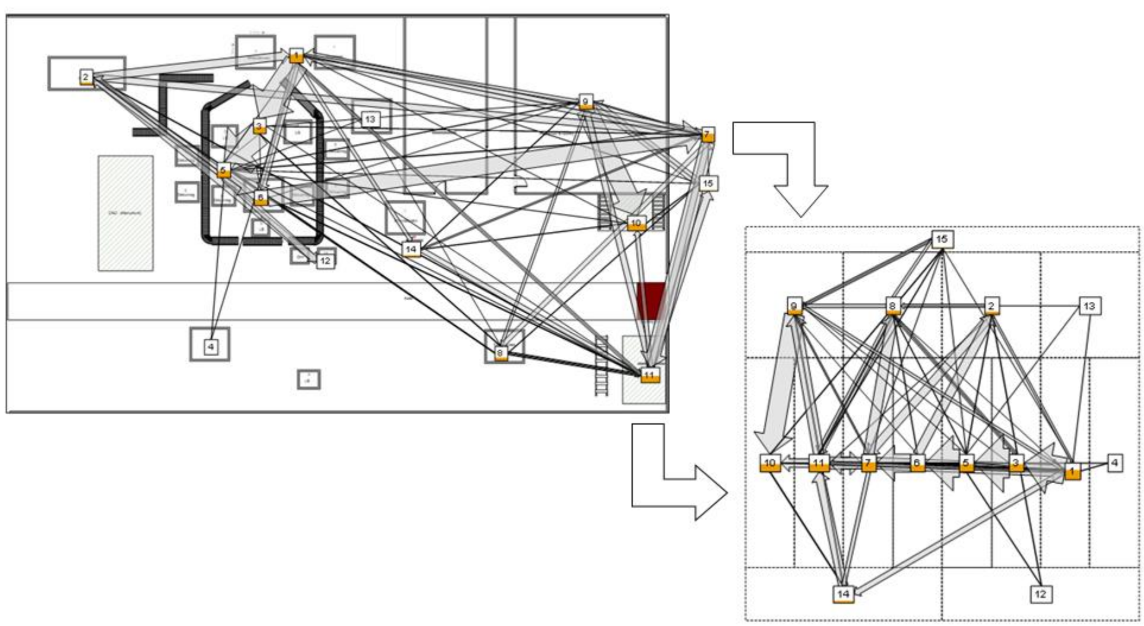

Figure 6 Spaghetti Diagrams for Current vs. Proposed Layouts for the Grinding Cell

Examples of Tooling Analysis

Cold Forging Press Work Space Layout: Setup time on any machine includes the time that the machine remains idle because the operator is moving to/from different locations around the machine to perform activities required to run the next job. Figure 7(a) displays the movements of the operator around a cold forging press throughout a setup cycle. This was *before* any improvements were made in the operator's work space around the press. Figure 7(b) displays the movements of the same operator after layout changes were made. Here is how PFA was used in this project. First, the sequence of steps performed by the machine operator during a complete setup cycle was determined. The location at which each step was performed was also noted. Next, this information was input to PFAST which converted the single routing into a From-To Chart. The chart showed the frequency of trips between any pair of locations that the operator visited consecutively during a press setup, as shown in Figure 7(c). The thick (or thin) arrows in the Flow Diagram are a visual estimate of high (or low) frequency of moves between any two locations. The Q-type From-To Chart produced by PFAST was input to the STORM software for facility layout. Figure 7(d) illustrates how the STORM software was used to approximate a circular location grid with the press at its center. The theoretical layout for the press' work space that STORM produced was given to the operator who "massaged" it to accommodate real-world constraints that the software failed to consider.

Conclusion

Production Flow Analysis (PFA) can be used to analyze and improve material flow in any high-mix work flow system, regardless of whether the "material" is products, people, tools, etc. If the work flow system is a traditional factory that manufactures and assembles products, then the work flows could be improved at different levels, such as the entire factory, a single shop in the factory ex. the machine shop, a single cell inside a shop or a single machine inside any cell. All that is needed to use PFA (Production Flow Analysis) to simplify material flow in any work system is (1) a complete list of the different "products" that are produced in the system, (2) a complete list of "work centers" that are used to make the products and (3) a "routing" for each product that clearly shows the sequence in which different work centers in the system are used to produce the product. This data for each product is effectively summarized using the acronym "PQR$" (P= Products, Q=Quantities, R=Routings, $= Revenues[5]).

[5] In more advanced studies, T= Time is also included with Q= Quantities to better clarify the frequency with which each product is produced.

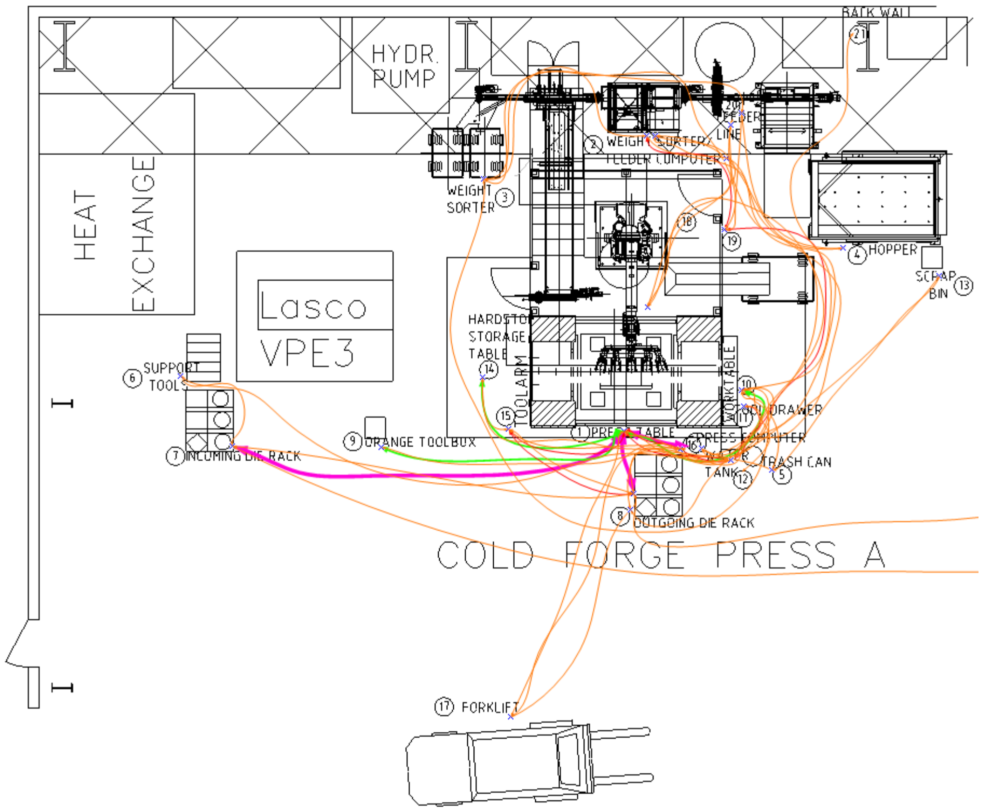

Figure 7(a) Flow Diagram for Operator's Movements during Press Setup ***before*** Layout Improvements

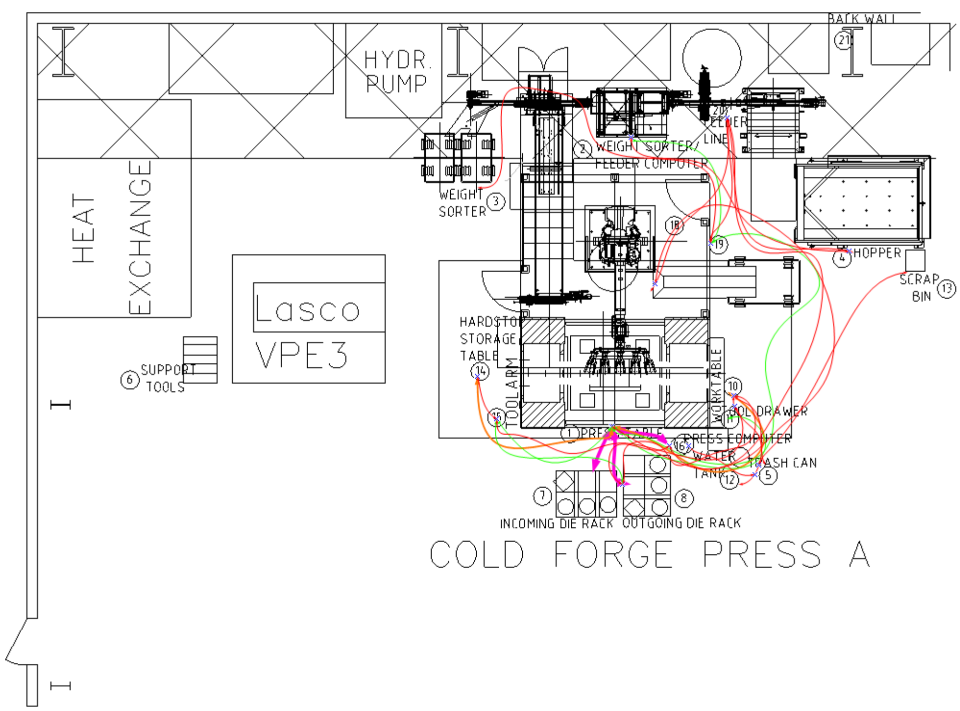

Figure 7(b) Flow Diagram for Operator's Movements during Press Setup ***after*** Layout Improvements

W/C	11	14	15	16	1	7	8	10	9	3	6	12	17	5	13	2	19	18	4	20	22	21
11				1	4																	
14	1		1		6																	
15		1		1	4	1	1															
16					12	3	1	1					1			1		1	1			
1	4	7	4	17		11	15	6	8	1	1	1	1	3	1	1	1	1		1		
7					18			3			1											
8			3		13	1		1								1					1	
10				1	6	3	2			2		1							1			1
9					7			1														
3					3			1								1						
6					2	1																
12								1			1											
17						1	1															
5				1	2			1														
13														1								
2				1													3		1			
19					2					1								1		1		
18					1											1	1		1			
4					2			1												2		
20					1					1								1	1			
22						1																
21								1														

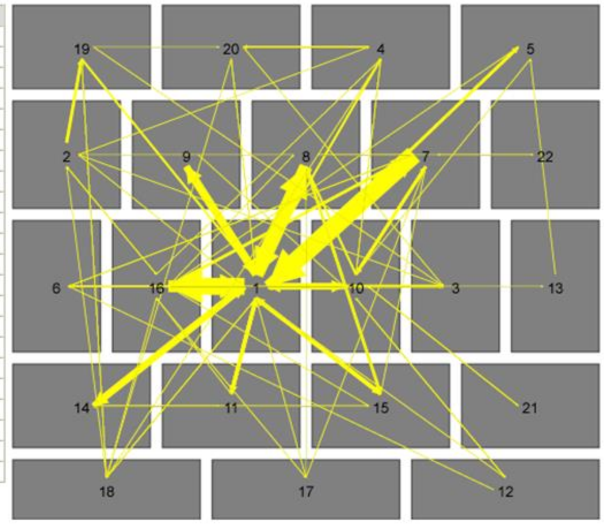

Figure 7(c) From-To Chart and Flow Diagram for Operator’s Movements produced by PFAST

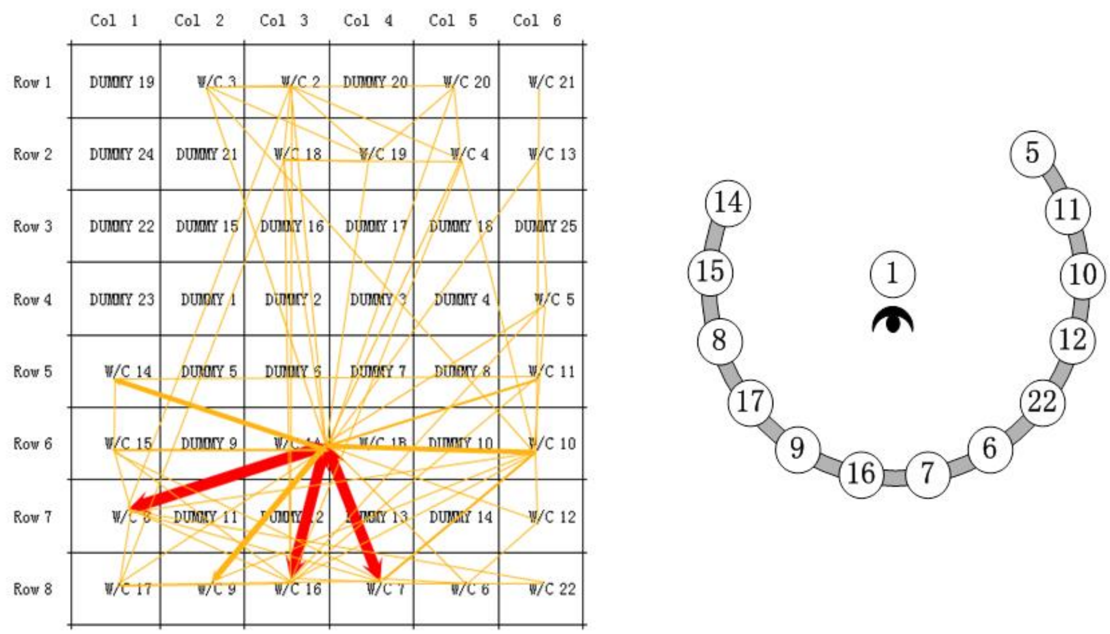

Figure 7(d) STORM-generated Layout vs. Actual Layout that was Implemented