Indian Journal of Science and Technology, *Vol 8(14), DOI: 10.17485/ijst/2015/v8i14/63646, July 2015*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Assessment of Waste in MEP Process through Work Sampling and Simulation

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Abstract

This paper aims to assess the waste present in execution of building services i.e., Mechanical Electrical and Plumbing (MEP) and suggest possible solutions to reduce them. Four ongoing projects were taken up for identification of waste types and quantification of waste was done on them. Works sampling was done and data from planning was used. Since the implementation of results in the site is not suggestible, so a simulation model which could be the replica of actual construction process is created and waste is assessed. STROBOSCOPE was used as a simulation tool for assessing effect of implementation of suggestions. Fire Protection System (FPS), one component of MEP, was chosen to develop a simulation model which could be the replica of actual construction process. Process improvement, resource constraints, process modification are evaluated using simulation. From results of work sampling it was found that only 20-24% of total time of worker was utilised in value adding works. Majority of their time (more than 40%) were spent on non-value adding works. After applying the improvement measures to the simulation model the FPS execution for one floor was improved from 22-23 days to 14-15 days and duration of non-value added activities were found to be reducing to greater extent. Hence it was concluded that the improvement suggested to reduce waste was effective and should be implemented to actual work site to find out the actual effect of it.

Keywords: MEP, Simulation, STROBOSCOPE, Waste, Work Sampling

1. Introduction

India has entered a phase of unprecedented economic growth. To sustain this growth good infrastructure is a prerequisite. The challenge that India faces presently is its ability to execute these projects in a short time frame, to international standards of quality and safety with an ever increasing pressure on availability of competent and skilled personnel. Thus, there is an urgent need to find ways and means to improve our procurement and delivery systems, construction processes by eliminating all wastes. There is misconception of the definition of waste. In general, the term "waste" is defined as physical construction waste rather than the real concept of waste. Waste includes both the incidence of material losses and the execution of unnecessary work that generates additional costs, but does not add value to the product. However, such waste has not been identified clearly. The causes for delay and excess cost, excluding the acts of god, were entitled to poor planning, design changes, and low productivity. A work measurement technique such as work sampling has been conducted to analyse the waste during the construction of MEP.

Indian companies has got the technology and learning to complete construction of civil structural work, but there are delays in timely delivery of Building Services (MEP) works. It is important to give enough attention to the completion of the building services as it consists of 20-25% of total project cost and as high as different sub-contractor/specialized agencies.

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Measuring waste is the first step in reducing them because it allows to identify the areas which causes the waste and potential improvement measures to be pointed. Research conducted in Netherland by Bossink and Brouwers had identified that the material waste is around 1-10% in weight of the materials purchased and identified late information and changes to design were the most fundamental causes in the wastage of materials[1].

A general frame work for the improvement of construction and reduction of the waste was developed by Alfredo Serpell which was successfully implemented to several construction sites in Chile[2]. An analysis of the relationship between buffers and construction labour performance done by Horman and Thomos in Brazil found that some buffers helped in achieving the best labour performance in construction operations[3]. Carlos T. Formoso classified waste based on previous study and collected data from three Brazilian building projects and concluded that there is a need to integrate waste control into the production planning and control process[4].

A theory of lean construction, derived from lean manufacturing theory, has been proposed to define measure and eliminate these wastes. Lean Construction by LJ Koskela is defined as a "way to design production systems to minimise waste of materials, time and effort in order to generate the maximum possible amount of value"[5]. Main principles of lean construction are Customer focus, Elimination of waste, Continuous flow and continuous improvement. Lean construction is based on production management principles, and it has better results in complex, uncertain and quick projects[6].

The most classical waste classification according to lean production philosophy was proposed by Gregory A Howell, LJ Koskela. The 7 wastes proposed by them, of which are waste of overproduction, waste of correction, waste of material movement, waste of processing, waste of inventory refer to flow of material and waste of waiting, waste of motion is due to work of men[7].

Alfredo Serpell has classified the wastes in relation to work categories as productive work (value-adding activities), contributory work (non-value-adding activities but essential for conversion process) and non-contributory work (non-value adding activities)[8]. Lauri Koskela has proposed a flow process model, in which construction activities is considered as flow of materials and information through four stages: moving, waiting, processing and inspection. According to this model only processing activities are value adding activities[9]. Hence improvement can be obtained by reducing the amount of non-value adding activities which increases the efficiency of value adding activities. Implementation of lean construction tools in Brazilian projects were studied by Bortolazza and Formoso and the findings were improvement in percent plan complete[10].

A simulation is a tool to represent a real-life situation on a computer and studied how the process works. Standridge and Marvel describes the necessity of simulation in application of lean concepts[11].

STROBOSCOPE (State and Resource Based Simulation of Construction Processes), developed by Julio C. Martinez is an effective simulation software for the construction processes[12]. M. El-Said have successfully validated the simulation model developed using STROBOSCOPE in "bridge deck construction" and "performance quantification of web based and traditional bidder inquiry processes" respectively[13,14].

The scope of the research is limited to execution of building services (Mechanical & Electrical) in building construction projects. Waste during execution of Fire Protection System (FPS), measured. All waste present in construction site cannot be quantified. Hence material scrap waste, waste due to excess inventory and waste due to labour inefficiency were quantified in terms of cost.

2. Observations

Several visits were made to four different building construction sites for problem identification. People working at sites and work processes were closely monitored and following observations are made:

- Many workers were found to be idle or waiting at the site.
- Poor housekeeping was one of the major findings of the observation.
- Late start and late reporting to work was common phenomenon found at work.
- Workers were found doing rework at site due to lack of knowledge during first attempt to work.
- Workers were observed in trouble due to lack of co-ordination among different crews working at same location.
- Workers were missing from work area (No Contact) due to time taking procedures of issuing of materials from store.

Table 1. Waste categorization from observation

Sl. No	Observations	Waste Category
1	Chit-chatting, idle and waiting for materials or person	Waste of waiting
2	Movement of labourers with or without materials	Waste of motion
3	Workers engaged in supporting work	Waste of processing
4	Poor housekeeping	Waste of inventory
5	Late start and unauthorised breaks	Waste of waiting
6	Rework and re fabrication of damaged components	Waste of correction
7	Switching to works at different levels	Waste of processing and motion
8	Delay in work due to co-ordination among different crew	Waste of process and waiting
9	Worker missing from site – no contact	Waste of motion and processing

The most common observations on the activities of the labour in the site and category of the waste are represented in the Table 1.

2.1 Work Sampling

Work sampling is a work measurement technique. It was used to assess percentage of time of labourers being spent on different activities. There are three methods of work sampling-tour based work, crew based and modified crew work sampling. All three methods of work sampling were adopted at different phases of data collection.

Tour based work sampling was used in the initial phase to find out the problem area. Works were categorised in five categories-direct work, enabling work, idle, moving and material handling. Tours were made in interval of one hour and observations were noted. After 3 days of sampling results were analysed and problem areas in site were identified.

Crew based work sampling was done for all problem associated processes as identified by tour based work sampling. For doing crew work sampling all activities of the process had to be listed by observation. Activities listed before and during the crew work sampling were categorised in three Category-Value Added (VA), Non-Value Added (NVA) and Non-Value Added but Required (NVAR) activities.

Tour work sampling and crew work sampling were necessary in identification and understanding of the problems respectively but none of them actually able to represent the overall picture of any process. Modified crew approach was then followed to get the waste in each process.

First step in doing modified crew approach was to make a list of all activities of each process. Each work was done at different location. Location of all the activities for each process was identified and then a path was selected to cover all activities of a process. Tours were made at an interval of 5-20 minutes based on the time consumed in one tour. Tour based work sampling for each activity was done for 2 weeks on each site and the observations were recorded.

From the observation of work sampling, percentage of time spent on each activity were calculated. From these values overall time spent on VA, NVAR and NVA activities were calculated. From the results of work sampling it is evident that only 20-24 % of total time is being spent on value added works. A big share of total time (more than 40%) is being spent on non-value added activities which can be eliminated immediately with management actions. Work sampling indicates that considerable amount of effort (33% - 38%) are made towards NVAR activities. These activities seems necessary at the current work environment but can be eliminated by management actions in process improvement.

2.2 Waste Due to Labour Inefficiency

Data regarding labour inefficiency was obtained from work sampling. Percentage of Value Added time, Non-Value Added time and Non-Value Added but Necessary time were calculated from work sampling and were used in calculate the cost of labour inefficiency. Non value added time was taken as the time for inefficiency.

It represents the labour waste in two category - NVAR and NVA. Waste due to NVA can be removed immediately and easily if appropriate actions are taken. On the other hand NVAR can only be removed by changes in process over a period of time. The cost due to labour inefficiency is obtained around 0.9% to 2.93% of the total cost of the project in the four sites.

3. Development of Conceptual Model

3.1 Components of FPS Work

Basic components of fire protection system and the flow of activities are shown in Figure 1. Components of FPS work can be divided into six major categories - Cutting, Fabrication, Erection, Anchorage, Painting and Sprinkler fixing.

A conceptual model of the existing Fire Protection System (FPS) execution practice was developed using STROBOSCOPE as simulation software.

3.2 Components of Stroboscope

Following are the components of STROBOSCOPE which have been used in development of conceptual model that are represented in Table 2.

3.2.1 Links

Links are components of STROBOSCOPE which connect nodes of network and indicate direction and type of resource that flow through them. Properties of links can be entered through the Graphical User Interface (GUI) window. There are two types of links, draw link and release link. Draw link draws resource from queue and have properties of draw amount, draw duration, draw until and enough. Release link releases resource from combi or normal to queue or normal and has properties of release amount and type of resource.

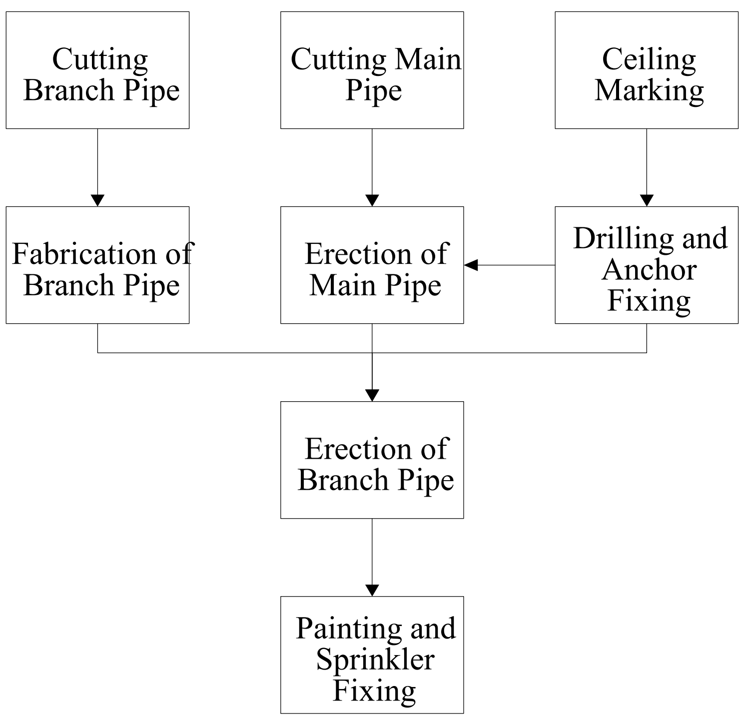


Figure 1. Components of Fire Protection System.

3.2.2 Queues

Queues are nodes in network to hold resources that are idle. A queue can hold only one type of resource. Queues can receive resource from normal and combi activities but can release resource to combi activities only. Properties of a queue, name and type of resource, can be entered through Graphical User Interface (GUI).

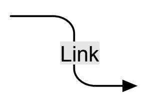
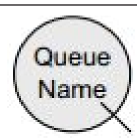
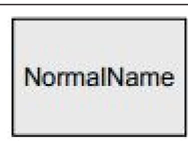
3.2.3 Combi Activities

Activities are represented on nodes. An activity which needs some conditions to be met to start is represented on combi. The conditions to start a combi are mainly resource availability of certain types which are flowing to them from queues through links. Combis can acquire only inactive resources which reside in queues; hence predecessors to a combi must be queues. Properties of combi can be entered using GUI named combi properties in which its name, duration and other control statements can be entered.

3.2.4 Normal Activities

Normal activities are those activities which start only when it's preceding activities finishes. Normal activities receive resources from preceding activities only. After completion of a normal activity it can release resources to any or all among queues, combis and normals.

Table 2. Components of STROBOSCOPE

Links	
Queues	
Combi Activities	
Normal Activities	

Duration and priority are two major attributes of combi and normal activities.

3.2.5 Networks

A network is formed by connecting nodes (for example queues, combis and normals) by links. A network represents a high level of description of the operation being modelled.

3.3 Modelling of FPS

A conceptual model of the existing Fire Protection System (FPS) execution practice was developed using STROBOSCOPE as simulation software.

STROBOSCOPE resource code can be generated from the network drawn in Microsoft Visio. Conceptual model was drawn by keeping the actual flow of activities at site. The created model can be simulated from the Microsoft Visio 2003 file. Control statements if required can be written in the global code dialog box. The simulation report is shown in the Figure 2. Time to complete one floor of FPS work was calculated based on standard productivity and number of labourers present at site and it was found to be 22 days. The results that are obtained from the work sampling results from the site and after simulation are almost similar and are represented in the Table 3.

4. Improvement Measures

Improvements for some of the problems are listed and implemented in the conceptual model developed.

4.1 Process Improvement

No contact was found as a very serious problem at sites. Duration of material shifting was observed as high as 30-60 minutes per shift. Current process of material issue requires signature of site engineer, section in charge and store in charge. From the experience of site engineers and workers 15-20 minutes was appropriate time for shifting of materials from store to site if only signature of site engineer is required. Assuming this reduction in material shifting time from 30-60 minutes to 15-20 minutes conceptual model was modified and it was simulated. The simulation report is shown in the Figure 3.

The duration to complete the FPS work for one floor was reduced by 5 days. The new duration of FPS for one floor was estimated to 17-18 days. Around 5% reductions

Table 1. Comparison of Simulation results

Activity	Actual site results (%)	Simulation results (%)
Value Added	19.5	18.3
Non-Value Added but Required	35.4	37.5
Non-Value Added	45.1	44.3

```
                                *****REPORT*****
*******************************************************************************
Total number of Skilled Labours                          -  5
Total number of UnSkilled Labours                        -  8
Total number of Labours                                  -  13

Time Take to Complete FPS Work                           -  22 Days
*******************************************************************************
Idle Time for Fitter                                     - 26 Hours
Idle Time for Helper                                     - 196 Hours
Idle Time for Welder                                     - 94 Hours
Idle Time for Driller                                    - 12 Hours
Idle Time for Supervisor                                 - 148 Hours
Total Time for Welding                                   - 113 Hours
Total Time for Cutting                                   - 147 Hours
Total Time for Supporting                                - 378 Hours
Total Time for Drilling and Anchor Fixing                - 45 Hours
Total Time for Measuring & Marking                       - 25 Hours
Total Time for Moving Scaffold                           - 52 Hours
Total Time for Moving with Materials                     - 172 Hours
Total Time for Material Handling                         - 158 Hours
Total Time for Drawing Study                             - 17 Hours
Total Time for Giving Directions                         - 58 Hours
Total No Contact Time                                    - 163 Hours
*******************************************************************************
Total Idle Time in Percentage                            - 26.385809 %
Total Welding Time in Percentage                         - 6.2638581 %
Total Cutting / Grinding Time in Percentage              - 8.1485588 %
Total Supporting Time in Percentage                      - 20.953437 %
Total Drilling / Anchor fixing Time in Percentage        - 2.4944568 %
Total Measurement & Marking Time in Percentage           - 1.3858093 %
Total Moving Scaffold Time in Percentage                 - 2.8824834 %
Total Moving With Material Time in Percentage            - 9.5343681 %
Total Material Handling Time in Percentage               - 8.7583149 %
Total Drawing Study Time in Percentage                   - 0.94235033 %
Total Instructions Giving Time in Percentage             - 3.2150776 %
Total No Contact Time in Percentage                      - 9.0354767 %
*******************************************************************************
Total Value Added Time                                   -  305 Hours
Total Non Value Added and Required Time                  -  688 Hours
Total Non Value Added Time                               -  811 Hours
Total Effective Time of Work                             -  1804 Hours
*******************************************************************************
Total Value Added Time In Percentage                     -  16.906874 %
Total Non Value Added and Required Time In Percentage    -  38.137472 %
Total Non Value Added Time In Percentage                 -  44.955654 %
*******************************************************************************
Total Cost of Labour to complete FPS Process             -  Rs.57200
Cost of Labour Inefficiency                              -  Rs.25714.634
*******************************************************************************

-------------------------------------
Execution    Time = 4.027 seconds
```

Figure 2. Simulation report of conceptual model.

```
*****REPORT*****
*********************************************************************************
Total number of Skilled Labours                         -  5
Total number of UnSkilled Labours                       -  8
Total number of Labours                                 -  13

Time Take to Complete FPS Work                          -  18 Days
*********************************************************************************
Idle Time for Fitter                                    - 27 Hours
Idle Time for Helper                                    - 192 Hours
Idle Time for Welder                                    - 90 Hours
Idle Time for Driller                                   - 13 Hours
Idle Time for Supervisor                                - 102 Hours
Total Time for Welding                                  - 114 Hours
Total Time for Cutting                                  - 147 Hours
Total Time for Supporting                               - 377 Hours
Total Time for Drilling and Anchor Fixing               - 46 Hours
Total Time for Measuring & Marking                      - 25 Hours
Total Time for Moving Scaffold                          - 52 Hours
Total Time for Moving with Materials                    - 119 Hours
Total Time for Material Handling                        - 158 Hours
Total Time for Drawing Study                            - 18 Hours
Total Time for Giving Directions                        - 57 Hours
Total No Contact Time                                   - 67 Hours
*********************************************************************************
Total Idle Time in Percentage                           - 26.433915 %
Total Welding Time in Percentage                        - 7.1072319 %
Total Cutting / Grinding Time in Percentage             - 9.1645885 %
Total Supporting Time in Percentage                     - 23.503741 %
Total Drilling / Anchor fixing Time in Percentage       - 2.8678304 %
Total Measurement & Marking Time in Percentage          - 1.5586035 %
Total Moving Scaffold Time in Percentage                - 3.2418953 %
Total Moving With Material Time in Percentage           - 7.4189526 %
Total Material Handling Time in Percentage              - 9.8503741 %
Total Drawing Study Time in Percentage                  - 1.1221945 %
Total Instructions Giving Time in Percentage            - 3.553616 %
Total No Contact Time in Percentage                     - 4.1770574 %
*********************************************************************************
Total Value Added Time                                  -  307 Hours
Total Non Value Added and Required Time                 -  687 Hours
Total Non Value Added Time                              -  610 Hours
Total Effective Time of Work                            -  1604 Hours
*********************************************************************************
Total Value Added Time In Percentage                    -  19.139651 %
Total Non Value Added and Required Time In Percentage   -  42.830424 %
Total Non Value Added Time In Percentage                -  38.029925 %
*********************************************************************************
Total Cost of Labour to complete FPS Process            -  Rs.46800
Cost of Labour Inefficiency                             -  Rs.17798.005
*********************************************************************************

------------------------------------
Execution    Time = 6.719 seconds
```

Figure 3. Simulation report of Process improvement.

in no contact time were recorded after improving the process. Tremendous reduction in NVAR and NVA activities time, 150 and 53 man hours respectively were observed.

4.2 Resource Constraints

Resource constraint such as material availability at work place can be removed by providing all necessary material at the work site before commencement of the work. Hence conceptual model was modified with the assumption that all pipes are present at the work site at the start of the work and the simulation report is shown in the Figure 4.

```
                                    *****REPORT*****
**********************************************************************************
Total number of Skilled Labours                        -  5
Total number of UnSkilled Labours                      -  8
Total number of Labours                                -  13

Time Take to Complete FPS Work                         -  16 Days
**********************************************************************************
Idle Time for Fitter                                   - 26 Hours
Idle Time for Helper                                   - 190 Hours
Idle Time for Welder                                   - 89 Hours
Idle Time for Driller                                  - 12 Hours
Idle Time for Supervisor                               - 84 Hours
Total Time for Welding                                 - 116 Hours
Total Time for Cutting                                 - 146 Hours
Total Time for Supporting                              - 375 Hours
Total Time for Drilling and Anchor Fixing              - 45 Hours
Total Time for Measuring & Marking                     - 24 Hours
Total Time for Moving Scaffold                         - 51 Hours
Total Time for Moving with Materials                   - 91 Hours
Total Time for Material Handling                       - 157 Hours
Total Time for Drawing Study                           - 18 Hours
Total Time for Giving Directions                       - 55 Hours
Total No Contact Time                                  - 0 Hours
**********************************************************************************
Total Idle Time in Percentage                          - 27.112914 %
Total Welding Time in Percentage                       - 7.8431373 %
Total Cutting / Grinding Time in Percentage            - 9.8715348 %
Total Supporting Time in Percentage                    - 25.35497 %
Total Drilling / Anchor fixing Time in Percentage      - 3.0425963 %
Total Measurement & Marking Time in Percentage         - 1.6227181 %
Total Moving Scaffold Time in Percentage               - 3.4482759 %
Total Moving With Material Time in Percentage          - 6.1528059 %
Total Material Handling Time in Percentage             - 10.615281 %
Total Drawing Study Time in Percentage                 - 1.2170385 %
Total Instructions Giving Time in Percentage           - 3.7187289 %
Total No Contact Time in Percentage                    - 0 %
**********************************************************************************
Total Value Added Time                                 -  307 Hours
Total Non Value Added and Required Time                -  680 Hours
Total Non Value Added Time                             -  492 Hours
Total Effective Time of Work                           -  1479 Hours
**********************************************************************************
Total Value Added Time In Percentage                   -  20.757268 %
Total Non Value Added and Required Time In Percentage  -  45.977011 %
Total Non Value Added Time In Percentage               -  33.26572 %
**********************************************************************************
Total Cost of Labour to complete FPS Process           -  Rs.41600
Cost of Labour Inefficiency                            -  Rs.13838.54
**********************************************************************************

-------------------------------------
Execution    Time - 4.814 seconds
```

Figure 4. Simulation report of Resource constraints.

Simulation result with elimination of resource constraints shows elimination of no contact time. Further savings in NVAR and NVA activities time were observed as 90 and 34 man hrs respectively. Duration of FPS for one floor was reduced by two days and was reduced to 16 days.

4.3 Process Modification

Current practice of FPS execution is to complete the erection of header line (main pipe) first and then start the erection of branch pipes. This process was modified by making erection of main pipes and branch pipes parallel.

```
                              *****REPORT*****
*******************************************************************************
Total number of Skilled Labours                          -  5
Total number of UnSkilled Labours                        -  9
Total number of Labours                                  -  14

Time Take to Complete FPS Work                           -  15 Days
*******************************************************************************
Idle Time for Fitter                                     - 26 Hours
Idle Time for Helper                                     - 189 Hours
Idle Time for Welder                                     - 89 Hours
Idle Time for Driller                                    - 12 Hours
Idle Time for Supervisor                                 - 74 Hours
Total Time for Welding                                   - 113 Hours
Total Time for Cutting                                   - 146 Hours
Total Time for Supporting                                - 375 Hours
Total Time for Drilling and Anchor Fixing                - 45 Hours
Total Time for Measuring & Marking                       - 25 Hours
Total Time for Moving Scaffold                           - 52 Hours
Total Time for Moving with Materials                     - 91 Hours
Total Time for Material Handling                         - 156 Hours
Total Time for Drawing Study                             - 18 Hours
Total Time for Giving Directions                         - 56 Hours
Total No Contact Time                                    - 0 Hours
*******************************************************************************
Total Idle Time in Percentage                            - 26.584867 %
Total Welding Time in Percentage                         - 7.7027948 %
Total Cutting / Grinding Time in Percentage              - 9.9522836 %
Total Supporting Time in Percentage                      - 25.562372 %
Total Drilling / Anchor fixing Time in Percentage        - 3.0674847 %
Total Measurement & Marking Time in Percentage           - 1.7041581 %
Total Moving Scaffold Time in Percentage                 - 3.5446489 %
Total Moving With Material Time in Percentage            - 6.2031357 %
Total Material Handling Time in Percentage               - 10.633947 %
Total Drawing Study Time in Percentage                   - 1.2269939 %
Total Instructions Giving Time in Percentage             - 3.8173142 %
Total No Contact Time in Percentage                      - 0 %
*******************************************************************************
Total Value Added Time                                   -  304 Hours
Total Non Value Added and Required Time                  -  682 Hours
Total Non Value Added Time                               -  481 Hours
Total Effective Time of Work                             -  1467 Hours
*******************************************************************************
Total Value Added Time In Percentage                     -  20.722563 %
Total Non Value Added and Required Time In Percentage    -  46.489434 %
Total Non Value Added Time In Percentage                 -  32.788003 %
*******************************************************************************
Total Cost of Labour to complete FPS Process             -  Rs.42000
Cost of Labour Inefficiency                              -  Rs.13770.961
*******************************************************************************

-------------------------------------
Execution    Time - 4.266 seconds
```

Figure 5. Simulation Report of Process modification.

Process modification was implemented in the conceptual model by modifying the priority of the erection of branch pipes over that of main pipes.

Process modification resulted in reduction of one day from the previous model. Duration of FPS for one floor was reduced to 15 days and simulation report is shown in the Figure 5. Since considerable amount of reduction in time and resources have been observed with process improvement and resource constraint elimination, further savings in resource was limited to 1 day.

The comparison of simulation output of activities before applying and after applying the lean principles is shown in the Figure 6.

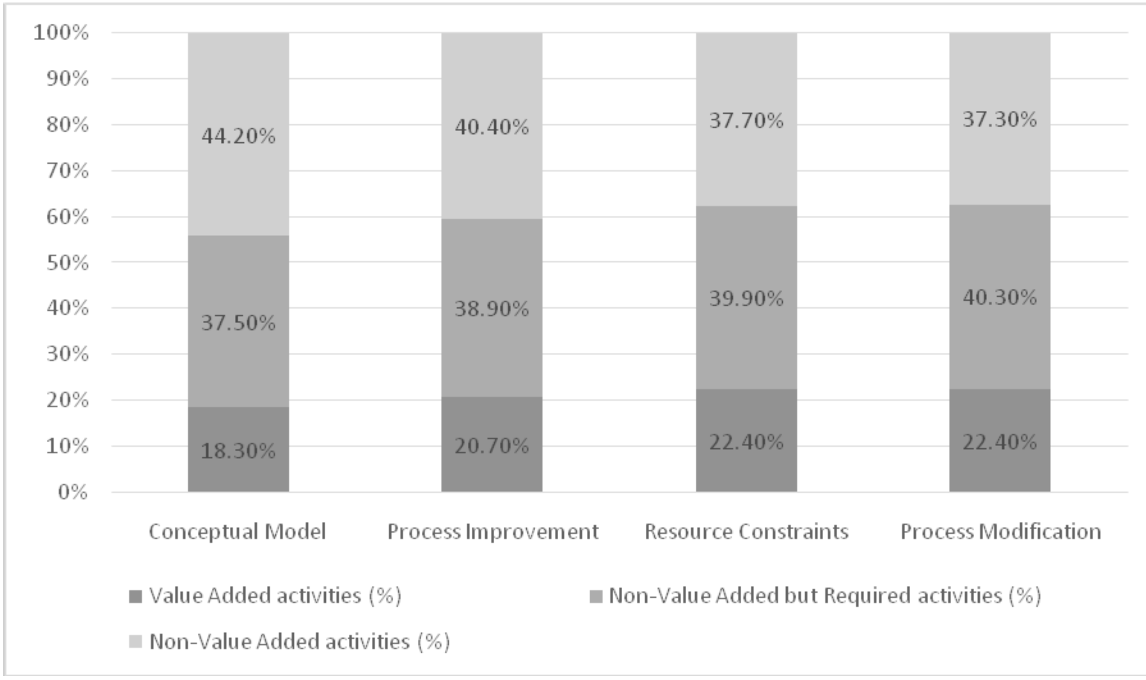


Figure 6. Comparison of simulation outputs.

5. Conclusion

From the site data it is observed that the duration of execution of FPS per floor is 22 days, 19-25% of total time were utilised in value added works and more than 40% of total time were wasted in Non-Value Added activities. The cost of labour inefficiencies calculated as percentage of total FPS cost was varying from 0.9% to 2.93%. By implementing the improvement measures to the simulation model the duration of the project and the percentage of the value added activities has improved a lot. By using proper process improvement execution has been tremendously reduced to 18 days from 22 days. During resource constraints duration of FPS for one floor was reduced by two days and was reduced to 16 days from 18 days. In process modification i.e. the execution of both main line and branch line in parallel manner, the duration FPS for one floor had come as 15 days after simulation

Since the implementation of waste minimization measures were very effective in simulation results. With the visual management observations at the site while execution of FPS and implementing those change in the simulation model helps to assess the amount of waste before undergoing the process.

6. Acknowledgement

The authors would like to thank the Vice Chancellor of SASTRA UNIVERSITY for providing facilities to do this work and for the continuous support and encouragement given throughout this research work.

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