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Process Optimization and NVA Reduction by Network Analysis and Resequencing

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ABSTRACT

The article discusses a methodology to reduce cycle times through an algorithmic, analytical framework for sequential process flows. Studying process flow flexibility for reducing bottlenecks has always continued to open new research avenues. This methodology has been formulated keeping in view of sequential manually executed assembly processes, where a single operator is involved, the process steps are entirely manual or semi-automated. The concept can also be extended to other scenarios by computing a process flexibility measure in terms of time, resources and methods. Essentially this article talks about the use of an algorithm for effective scheduling on assembly lines, computing the most optimal path that that the process flow could have taken given how the process has proceeded. Current activity scheduling methods tally the progress against a plan, which is ideal and does not account for unforeseen wait times. The output of the algorithm which is the most optimal approach as computed for a given scenario will help achieve rhythm and reduce wasted time in places where it's possible to avoid them. A standard tool to measure the exact amount of compressible wait time or Muda Type of waste is chosen, the overall equipment efficiency was adopted for gauging this approach. This discusses the generalization of the principle used and its formulation as an algorithm and a flow chart.

KEYWORDS

Algorithm, C-Code, Mapping, Network Mapping, OEE, Optimization

1. INTRODUCTION

Assembly lines across various segments face delays or wait times which turn into bottlenecks. Many methods have been devised to eliminate or reduce their effects. But a system or algorithm that can calculate the best possible sequence of operations that could have been followed is of interest to any industry. A decision to procure additional resources especially of high value requires a robust estimate of plant or machinery capacity.

Time and motion study data gives some insight to the impact of delays on the process, but a tool to evaluate whether a better choice could have been made under the same circumstances was of need. Network formulations of processes are used as tools to analyze sequence constraints.

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Keeping in view of sequence constraints and scope of delay reduction available within a process flow, a step by step approach to reduce idle times was necessary. Generalized formulations were constructed based on permitted process flow sequences, that are more optimal than the original process.

Current scheduling methods using MS project is a purely tracking tool, some intelligence is required to be built into them, by using the algorithm discussed later in this paper, we factory to progressively reach the zero delay stage.

Use of simulation for process flows can only show how these delays effect the entire assembly line flow, but an unanswered question remains could it have been better.

2. NEED FOR THE STUDY

Optimized process flows with minimum delay is the desire of any manufacturing activity. Particularly in aircraft assembly plants where most of the work is manual, the need for standardization and benchmarking is of utmost importance.

A structured approach to compute process flow time with the least delay time was always needed. This need thus evolved later to an algorithm for re-computing an optimal process flow sequence with minimum delay or wait time.

Clarity in setting reasonable benchmarks based on the environment in which the study is conducted, complete understanding of the limitations and constraints under which an activity is carried out was required. Until the constraints could be formulated as a network or mathematical formulation, generating an approach for optimization under conditions of uncertainty is impossible.

The need of this study is thus justified in the context of better decision making in typical management problems of meeting and setting deadlines, benchmarks and targets.

Unavailability of time to look at such problems in greater detail and analyzing the same makes us overlook the rationale behind troubleshooting problems, increasing the tendency to take up rash, deleterious approach.

3. JUSTIFICATION OF THE STUDY

A scientific approach or tool to compute and benchmark the best possible sequence or flow steps in an assembly line was always needed for management to take clearer decisions and formulate better improvement ideas for productivity. Thus a computer compatible approach to calculate minimum possible delay was called for.

For assembly line processes which are repetitive use of mnemonics to classify activity into compressible, incompressible types was a prerequisite.

The need to thus classify an activity correctly as avoidable, avoidable, value added or non-value added was irreplaceable.

Also, a representation of conventional time and motion study data as a network makes it easier for visualizing serial, parallel activities.

Activities that happen in the background when measured against ones in the critical path, help visualize the actual processes better.

This thus reinforced a need to conduct a study of this kind.

4. OBJECTIVES

Objective of our paper is to demonstrate the algorithm with primary focus on delay reduction for effective activity scheduling. The emphasis is on demonstrating the least possible waste d time that could have been achieved given a process flow and its constraint. Emphasis is primarily to reduce delays from the learning from unnecessary wait or wasted time, as to how it could have been replaced by a productive activity. Learnings from live process flows and integrating it with the algorithm will serve as a learning tool, with which future process flows will be benchmarked to. Figure 1 shows the objective flow chart.

5. METHODOLOGY AND DATA

The implementation of concept is step by step process. Implementation steps are explained in the flowchart as shown in the Figure 2.

This work deals with the end to end perspective of reducing waste at an assembly line's sub-assembly of an aircraft- structures manufacturing company. Processes involved in an aircraft assembly plant are largely man dependent. Such processes involving human effort involve large amount of uncertainities/delays. A sub-assembly is where smaller assemblies required to assemble the aircraft are made on bench. The processes in sub-assembly generally involve a single operator, processes

Figure 1. Objective flow chart

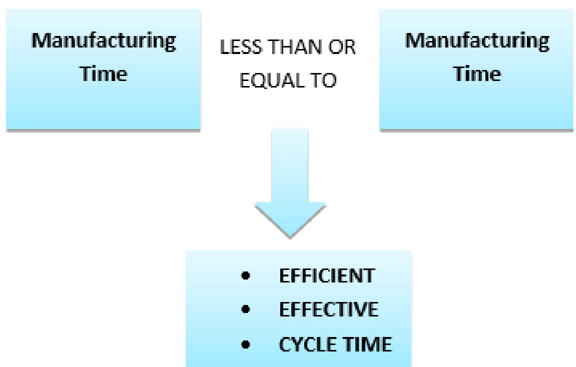
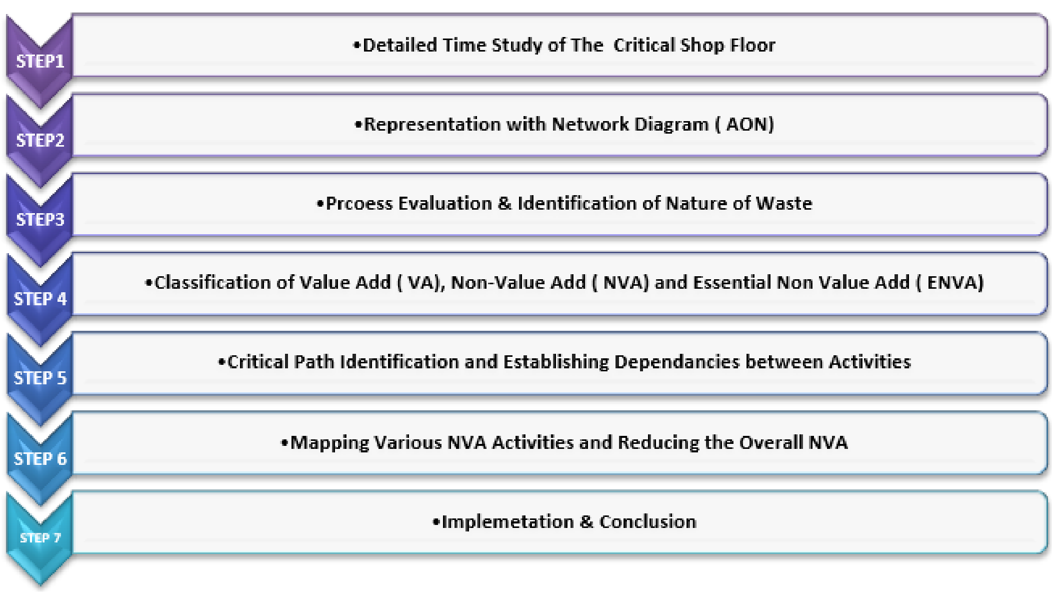


Figure 2. Methodology flow chart



are sequential, do not involve parallel activities. Delays are encountered prior to beginning of each step, i.e. at the preparation stage itself. Every sub assembly for the next engineering assembly needs to follow an Assembly Operation Procedure. Common delays in production are caused by waiting for fasteners, waiting for quality, collection of primer and sealant, stamping of the files per stage and preparation for next kit. The major tasks involved in a standard assembly operating procedure are as sketched in Figure 3. Table 1 shows the cycle times of operating processes.

5.1. O.E.E Before Implementation

Figure 4 shows the OEE diagram.

5.2. Activity Disaggregation and Analysis

The activities of each operating procedure are disaggregated into elements and studied. Each activity is analyzed and categorized into Value Add (VA), Non-Value add (NVA) and Essential Non-Value add (ENVA). Table 2 shows the activity disaggregation.

5.3. Network Re-MAP

- Activities 27 onwards have been considered for the case study only;
- Dotted Lines represent NVA activities being carried out simultaneously;
- (‘’)Activities are the activities which have been broken down into components with additional manpower;
- In cases 2 & 3 - activity 36 has been shown with a dotted line, as it prolongs post the NVA activity’s duration.

Figure 5 shows the network Re-MAP.

6. EMPERICAL RESULTS AND DISCUSSION

Table 3 displays the consolidated sheet. Figures 6 and 7 show the time trends.

Figure 3. Major tasks in the assembly process

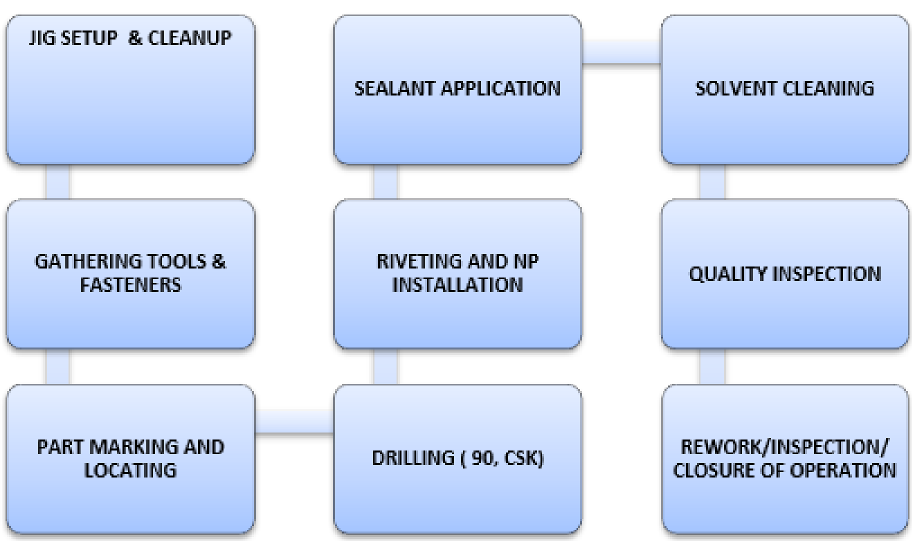


Table 1. Cycle times of operating processes

Process	Cycle Time
Unpacking Parts	0:05:53
Centre Marking - Holes	0:07:53
Hole Prep, Drilling Prep and Np Drilling	0:59:10
Np Drilling	1:18:37
Deburring	0:28:54
Simultaneous Primer Application	0:06:47
Procuring Fasteners	0:01:31
Setting Up Csk	0:07:33
Csk - Preperation	0:07:16
Cleaning	0:04:21
Csk - Operation	0:58:42
Csk- Operation Final	1:08:25
Solvent Clean Up	0:02:55
Q/A Inspection	0:01:42
Operation Sheet Closure	0:03:25
Riveting	1:01:00
Solvent Cleaning	0:03:12
Operation Sheet Closure	0:02:43
Part Labeling	0:09:05
Q/A Inspection	0:02:13
Part Numbering, Paper Work	0:07:59
Seal Tape on Kits	0:35:42

6.1. Process Evaluation (Using Network Diagrams)

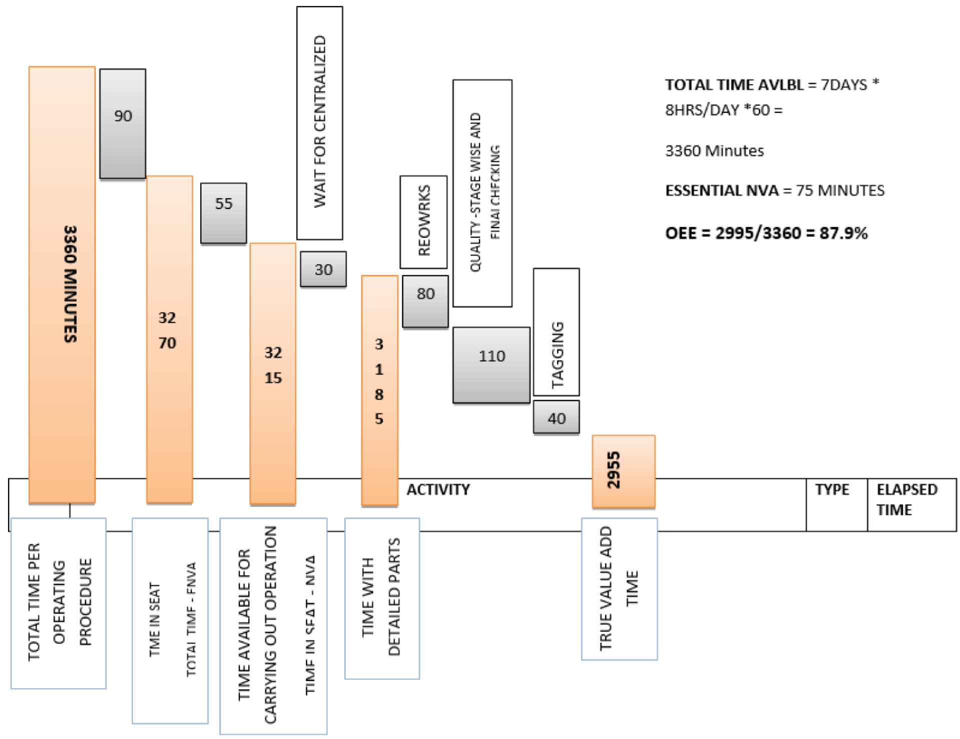
We constructed a model of the process which included a list of all activities required to complete the assembly, the time and duration of each individual activity, the dependencies between activities and the logical end points such as the deliverable items. Using this process we identified the critical processes and also the total float activities. We used an approach to problem solving, where every NVA activity was mapped with a VA activity and the impact on Cost of Man-Hours and total Cycle time were recorded.

It is important to take into consideration several constraints that are inescapable while re-networking the work flow. In our case the application time of the Sealant and the Primer were of key significance. In the process of decongesting the bottle necks and re-routing the work from bottle necks we have also taken into consideration pulling of manpower.

The generalization of the technique adopted to reduce the NVA by systematically by re-mapping the activities and re-networking work flow:

- As a Generic sequence an activity can be divided into n steps;
- Let the activities involved be divided into steps from $A_1 \dots A_n$;
- Let A_{x1}, A_{x2}, A_{xn} be intermediate steps that represent stage inspections/operations;

Figure 4. OEE diagram



- All activities involve corresponding preparation activities given by $P_1, P_2, \ldots, P_N$ Let Possible wait or Delay times corresponding to activities be $W_1, W_2, \ldots, W_k$ (here $k = 1, 2, \ldots, N$);
- Improvements over original sequences (Case with delays) are based on succeeding preparation activities that can be mapped to the wait duration.

7. FORMULATION

Let P_2 be mapped to W_1, for which there can be three different possibilities based on magnitude of these quantities (see Figures 8-10):

- Delay optimization with constraints on sequence and life of materials used;
- Activities where a certain activity must be followed only after a certain other activity has been completed, life of materials used is limited;
- Let A_{x1} represent an inspection activity for which Waiting is W_x and successor activity A_3 is to be done only after A_{x1} (see Figure 11);
- Let Life of the material used for activity A_3, while preparation P_3 is being done be L;
- Life L must be such that $L = W_{x1} + A_{x1} + A_3$ at least;
- W_{x1}, P_3 can have three different cases those being:

$Wx1 > P3$
$Wx1 = P3$
$Wx1 < P3$

Table 2. Activity disaggregation

	ACTIVITY	TYPE	ELAPSED TIME
1	Searching for bin , next procedure manual		0:06:36
2	Unpacking parts (critical parts)		0:01:02
3	personal work		0:04:51
4	Unpacking Kits		0:01:01
5	Hole marking and dimensioning		0:07:44
6	tea break		0:18:04
7	arranging hand tools and consumables		0:03:26
8	Operation performed based on procedure		0:33:55
9	Debris cleaning		0:04:48
10	Solvent cleaning		0:02:01
11	Operation performed based on procedure		0:08:04
12	Went to procure design template and tools		0:03:31
13	Operation performed based on procedure		0:06:57
14	Preparation - for Operation based on procedure		0:11:19
15	Unpacking components		0:01:19
16	Waiting for Centralized tool		0:07:18
17	Operation performed based on procedure		0:00:25
18	Operation performed based on procedure		0:06:05
19	Q/A Inspection		0:02:30
20	Rework- Operation performed based on procedure		0:04:55
21	Rework -Operation performed based on procedure		0:10:09
22	lunch		0:34:31
23	Waiting for Q/A		0:02:40
24	Q/A Inspection (after rework)		0:04:54
25	Deciding rework to be undertaken each kit		0:16:00
26	Rework - Operation performed based on procedure		0:50:05
27	Waiting for secondary tools		0:13:53
28	Waiting for centralized tool		0:09:24
29	Operation performed based on procedure		0:02:51
30	Operation performed based on procedure		0:04:33
31	tea break		0:17:36
32	Went to get consumable with limited life		0:04:05
33	Operation performed based on procedure		0:23:15
34	solvent cleaning		0:06:02
35	Checking for proper installation of detachable parts		0:15:48
36	Waiting for centralized tool		0:23:36
37	Operation performed based on procedure		0:06:43
38	Q/A Inspection		0:04:24
39	Went to get consumable with limited life		0:06:13
40	Operation performed based on procedure		0:11:11
41	Touch-ups		0:06:22

Figure 5. Network re-map

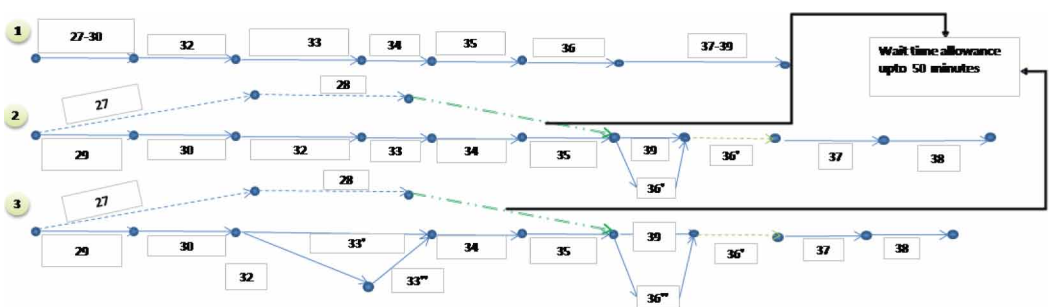
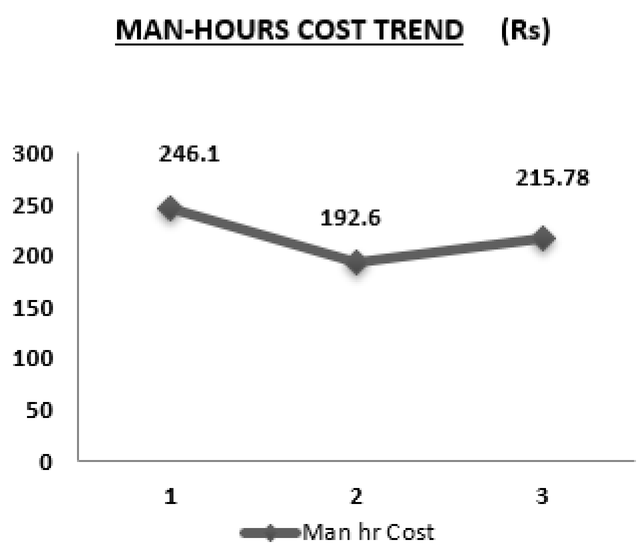


Table 3. Consolidated sheet

CONSOLIDATED SHEET OR TABLE					
Case	Description	Total time taken	Man hr. Cost	Time saved(min)	Cost savedRs.
Case1	Original sequence(27-39)	2:18:23	246.1	0	0
Case2	Mapped sequence(29-30-32-33-34-35-39-36'-37-38-39)	1:48:53	192.6	0:29:30	53.5
Case3	Mapped + Manpower(29-30-33'-34-35-39-36'-37-38-39)	1:39:18	215.78	**0:39:35**	30.31
	Wait time allowance in Cases 2&3	**0:50:53**	Cost/Hr. Undisclosed		

Figure 6. Man-hours cost trend



Each case has a unique implication on the constraint variable L which is of fixed value (see Figures 12-14).

8. DEVELOPMENT OF THE ALGORITHM

As a result of extensive network remaps carried out and from the formulations generated we formulate the algorithm for computing the least possible delays using mnemonics for wait time and preparatory activities. The algorithm is evolved after breaking down process flows and segregating activities as process activity, preparatory activity and wait times.

This method is adopted for simple sequential activities, which can be broken down as:

Figure 7. Time saved trend

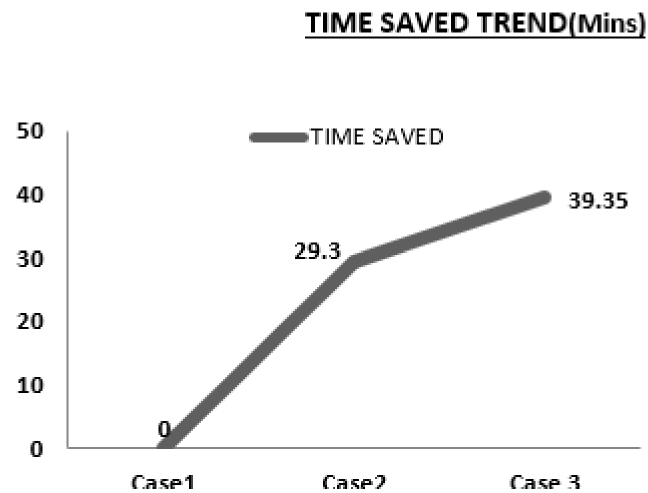


Figure 8. CASE 1 – $W_1 > P_2$: Wait time in the sequence reduces from W_1 to W_1

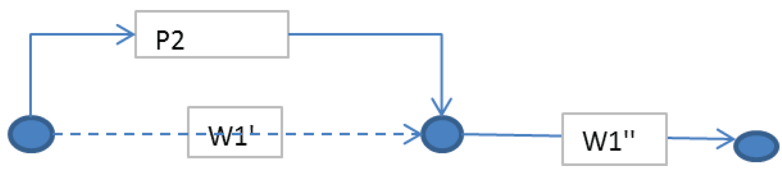


Figure 9. CASE 2 – $W_1 = P_2$: Wait time is reduced to 0

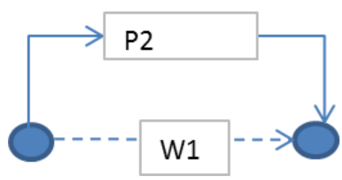


Figure 10. CASE 3- $W_1 < P_2$: Preparatory activities surpass the wait times

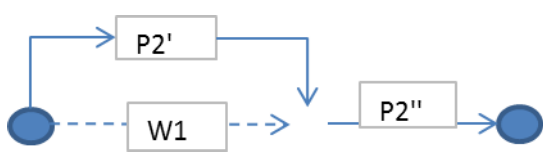


Figure 11. A_{x1} represents an inspection activity for which Waiting is W_x and successor activity A_3

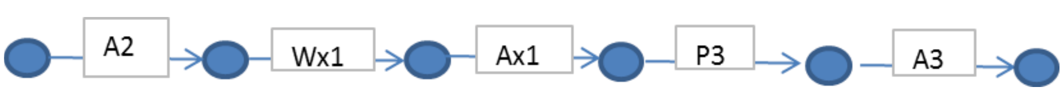


Figure 12. Wx1 > P3 - Life of the consumable left L' = L-($W_{x1"}$ + A_{x1} + A_3)

Figure 13. Wx1 = P3 - Life of the consumable left L' = L-(A3 + Ax1) > 0, wait time is consumed by preparation activity P3

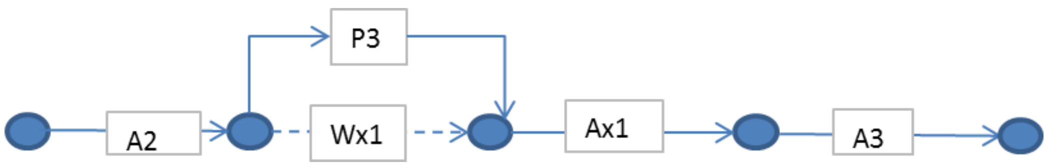
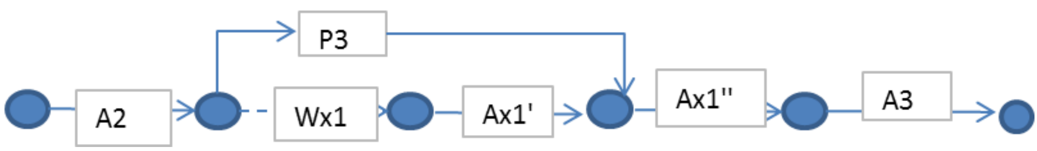


Figure 14. Wx1 < P3 - L' = L-(A3 + Ax1") > 0, wait time is entirely consumed, along with this some part of the activity Ax1 is also completed



1. Preparatory activities
2. Process activity
3. Wait times

Premise: All wait times happen prior to process activities.

Let A_i represent process activity where i = 1, 2,…, n (n steps in the process).

Preparatory activities be P_i i = 1, 2, …, n.

Wait times be represented by W_j j = 1, 2, …, m.

m <= n … (Implication of the premise).

Objective function: To minimize process delays in a flow process.

Let R be the objective function:

$$R = \sum_{i=1}^{n}(P_i + A_i) + \sum_{j=1}^{m} W_j \quad (m <= n)$$

$$R = \sum_{i=1}^{m}(P_i + A_i + W_i) + \sum_{i=m+1}^{n} P_i$$

R = P + A + W

Min R (P, A are constants more or less, W is a variable)

9. BREAKING DOWN UNCERTAINITIES IN WAIT TIME AT PROCESS AND SUB-PROCESS LEVEL

Figure 15 shows breaking down uncertainties in wait time at process and sub-process level.

Process Variable which can be minimized is W.

Uncertainty in W can morph as three possibilities against P:

W < P
W = P
W > P

Within the sequence there is a constraint on the ability to map wait times.

Mappable Set $S_{j,i} = \{ W_j ,\ P_i \}$ where(i = j + 1, j + 2, …, n) for given i:

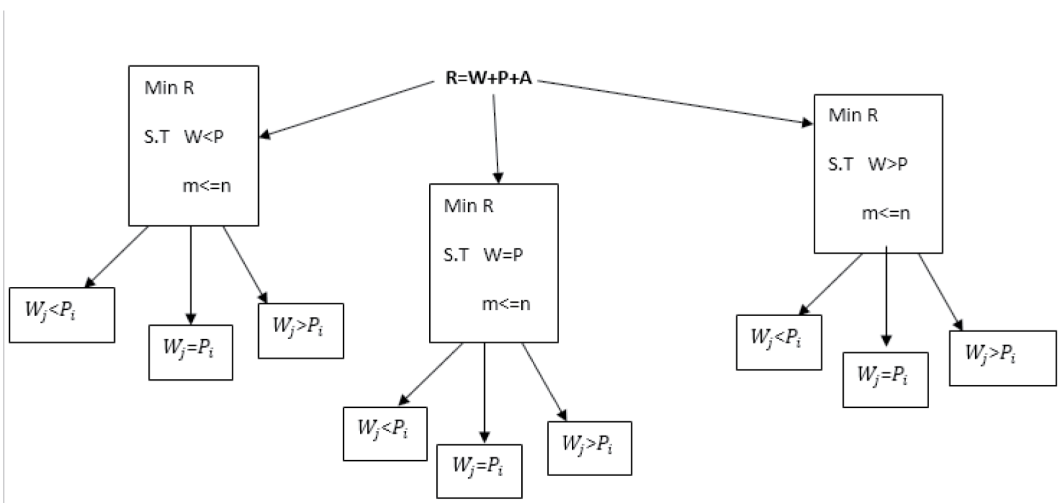
i.e, $S_{1,i} = \left\{ W_1, \left(P_2 / P_3 / \ldots P_n \right) \right\}$

$S_{2,i} = \left\{ W_2, \left(P_3 / P_4 / \ldots P_n \right) \right\}$

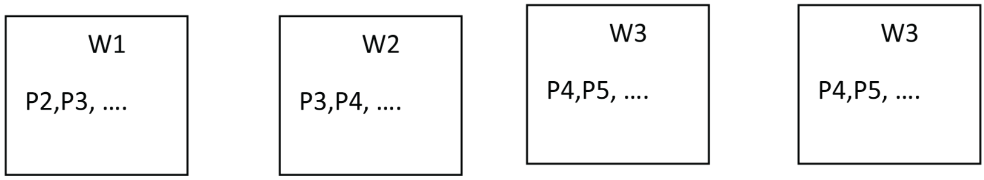
.
.
.
.
.

$S_{m,i} \left\{ W_m, \left(P_{m+1} / P_{m+2} / \ldots P_n \right) \right\}$

Figure 15. Breaking down uncertainties in wait time at process and sub-process level



W1 – W3



The sub activities can also can be further broken down into three cases:

1. $W_j < P_i$ --------> wait time reduced to zero
2. $W_j = P_i$ -----→ Zero wait time
3. $W_j > P_i$ ----→ Can be reduced to zero with aid of $P_{i+1}, P_{i+2,}$

After each wait time is reduced to zero in this manner the set of preparatory activities P available for mapping keeps reducing. The methodology is a piecewise algorithm that can be fed as a logic.

After ith wait time set of activities left P = P-{ P_i, P_{i+1} , $P_{i+2,}, ..$ }.

Thus, as we proceed ahead in a sequential process flow, the scope for reducing wait times also diminishes, after applying the method. Serial replacement of Wait times W_j happens with $P_i's$ in the process flow order.

After exhaustive replacement or minimization:

$$R = W' + P' + \sum_{i=1}^{n} A_i$$

W' is the reduced or redundant idle time left after exhaustive substitution.

P' is the redundant sum of preparation activity times left unmapped.

10. FLOWCHART

Figure 16 displays the flowchart.

In the above tree branch representation (Figure 17) replacement or elimination of wait times continues till set of preparatory activities are exhausted. Constraints on sequencing as shown in formulations can also be applied to the above technique.

The same exhaustive optimization technique can be applied to large networks (Figure18), wherein each parallel path can be treated as a sequential path, and each path can be condensed exhaustively.

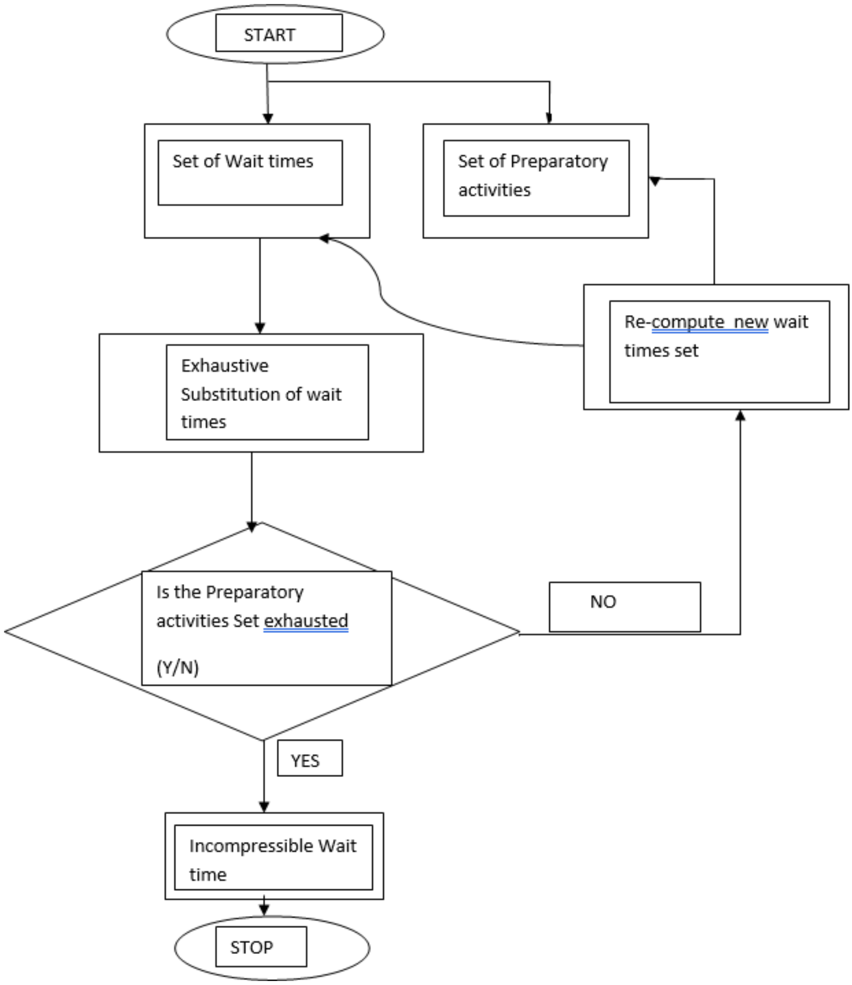
A network as shown above has multiple paths.

Each activity can be broken down into smaller. The same technique holds good.

OUTPUT OF THE PILOT ALGORITHM:

```
Enter the no of preparation times: 5
Enter Preparation times: 12 12 13 14 13
Enter wait times: 2 3 4 5 6 7
Reduced wait times are: 0 0 0 0 6
ORIGINAL CYCLE TIME: 91 sec
REDUCED CYCLE TIME:  70 sec
```

Figure 16. Flowchart



11. RESULTS

Figure 19 shows the comparison graph.

11.1. O.E.E After Implementation

Figure 20 shows the networks re-map.

12. SUGGESTIONS AND CONCLUSION

From this paper it was inferred that a combination of network analysis, piecewise minimization is a suitable tool to expose the unnecessary waste. In this paper the effectiveness of lean principle is substantiated in a systematic manner. Process evaluation can help estimate critical activity times and also significantly reduce NVA time. The NVA was reduced by 55.3% and cost of man-hours was significantly reduced. Man-hours cost is reduced by 22% and 50% wait-time allowance are provisioned for. The OEE was improved to 88.88% and the calculation was projected only for a limited number of activities. The implementation of the formulation is planned to be extended to all

Figure 17. Tree branch representation

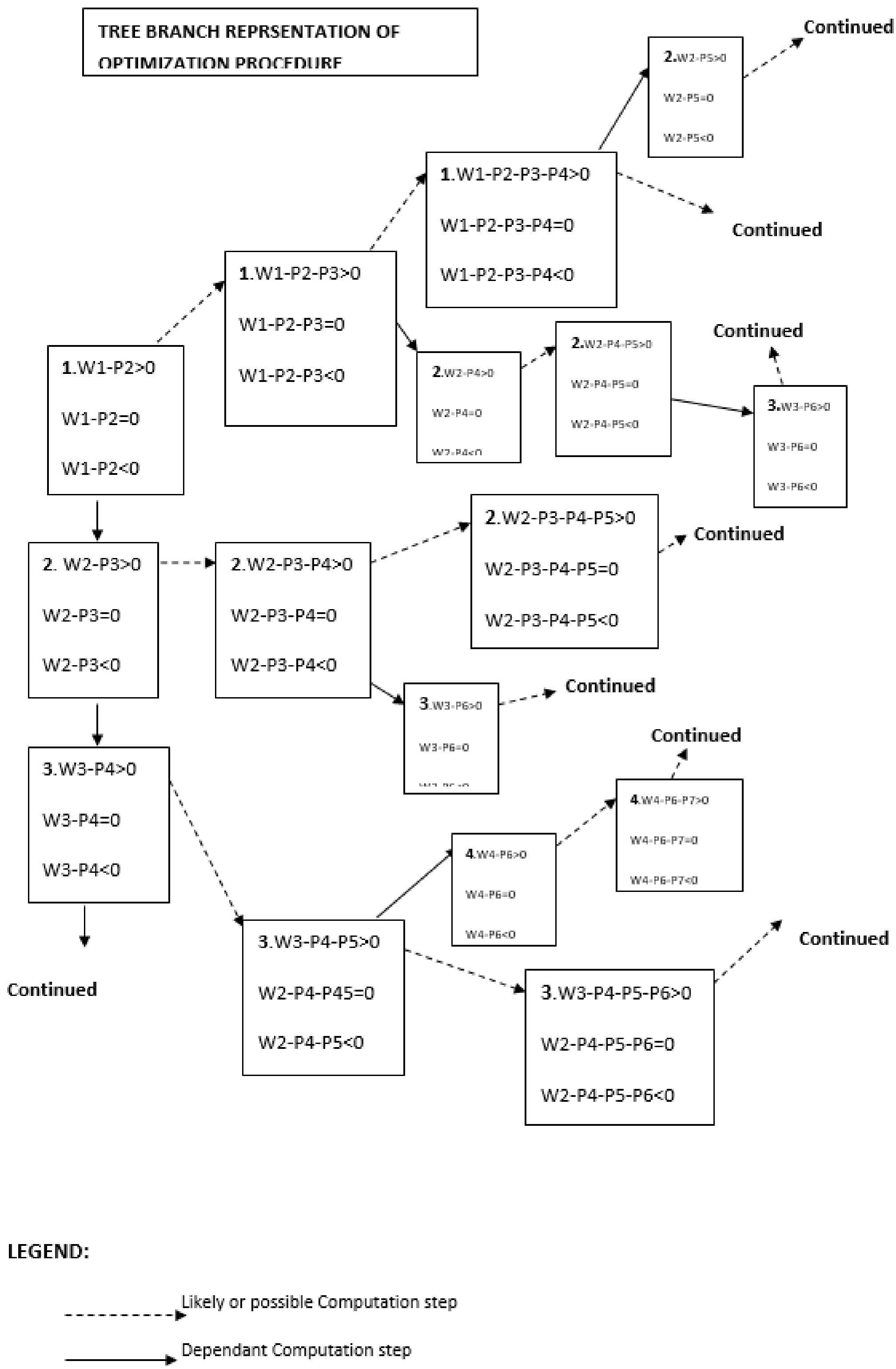


Figure 18. A network with multiple paths

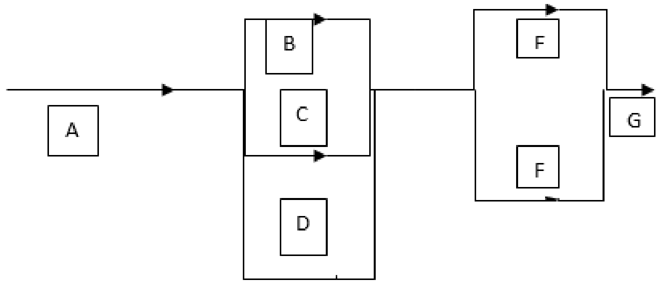
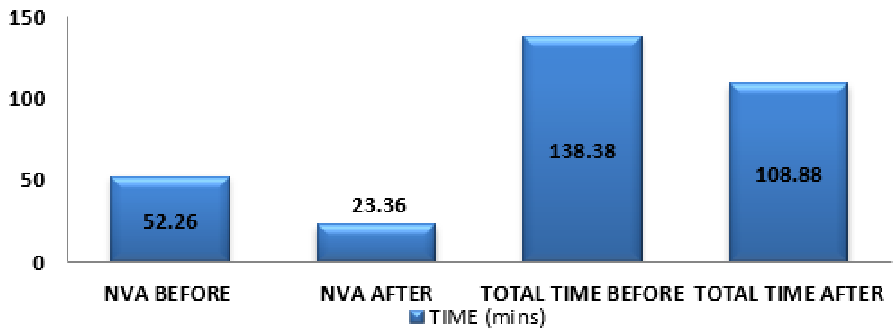
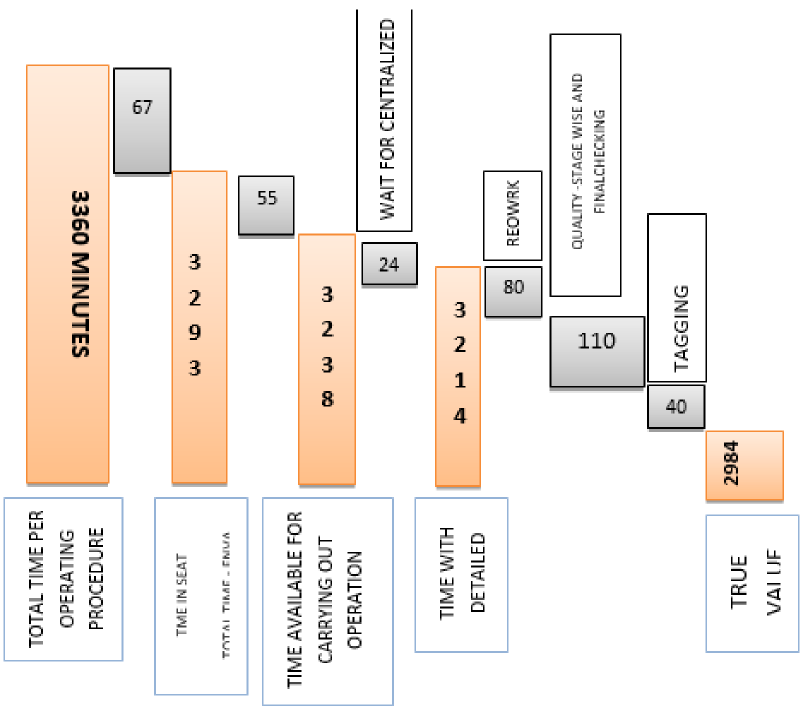


Figure 19. Comparison graph



- 55.3% NVA REDUCTION

Figure 20. Networks re-map



the processes, with the aim of improving TAKT. The method when adopted in a computer can yield the best possible sequence.

The approach can be extended to analyze material consumption, flow, cost analysis and modified as and when situation demands, the need for a new generation industry to build robust data capturing mechanisms and devise techniques to measure, evaluate and establish process flexibility measures in order that alternate methods of manufacturing can be easily singled out. Depending on the type of manufacturing, the workaround on cutting cycle times would take various forms.

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