

Integrated, Virtual Plant Design and Commissioning Methodology using Digital Manufacturing and Lean Principles

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ABSTRACT

New and unprecedented changes in customer demands, globalization, cost pressures, innovative product development strategies to shorten product development time, and changing external landscape with reduction of trade barriers, poses challenges and opportunities for the manufacturing industry. Customer demands and needs require modification and reconfiguration of existing manufacturing and assembly plants as well as creation and setup of new 'Greenfield' facilities in developing countries. Currently, the solutions provided by most service providers focuses on limited elements of the solution methodology. We have developed an integrated methodology to perform virtual plant commissioning using digital manufacturing, design for six sigma and lean manufacturing principles. Starting from product definition, the paper goes into the depth of macro and micro level plant layout, line layout and definition, line simulation, line balancing, optimization of line and process plans, tooling station detail, material flow, and kitting of modules. It integrates design at plant level, line level, station level and equipment level and as a result of this approach; multiple what-if scenarios are evaluated and visualized in 3D, early on in the product development process, before the need for investment in plant infrastructure. In addition, this methodology helps simulate the movement of a 3D digital prototype through a virtual plant; thereby helping reduce 'unpredicted' product launch costs and corrective tear-up of physical infrastructure.

INTRODUCTION

Greenfield projects are new factories, power plants, airports, facilities, assembly and manufacturing plants which are built from scratchⁱ. The advantage is that one is not faced with issues of legacy systems on one hand; while on the other hand the challenges in designing a new manufacturing facility are: getting government permits, procurement of real estate, flexibility and agility to meet desired takt time and jobs per hour (JPH), optimization of processes for optimal resource utilization at minimum cost of operation, optimal utilization of available space for layout, and availability of equipment and material handling systems to meet the design requirements. Based on our research, there are elements of the approach that are discussed in research papers and journals, in isolation. "The manufacturers are also reluctant to publish their successful design models due to competitive nature of their business."ⁱⁱ

Saifallah Benjaafar and Mehdi Sheikhzadeh in their paper entitled "Design of Flexible Layouts for Manufacturing Systems" mention the issues faced in designing flexible plant layouts where product demand and product mix fluctuates; and discuss stochastic nature of product demand, allowing for multiple processing departments and simultaneous flow of material between multiple processing departments simultaneously to decide the layout as a function of the demand.ⁱⁱⁱ

There is significant literature on manufacturing flexibility with relationship to resources, material handling equipment, machines, routing of parts, sequencing of parts, and mix of products; but the existing approaches and methodologies focus on some design challenges, in isolation.^{iv & v} To face the competitive markets, and the changing customer demands, manufacturers tend to increase their product mix and product variants; which increases cost and significantly affects the complexity in designing manufacturing systems and plant layout.

“According to surveys presented by Nof et al.^{vi} assembly of manufactured goods account for over 50% of the total production time and for 20% of the total unit production cost; 30% to 50% of the labor costs are involved in assembly tasks.”^{vii}

The challenges faced during integration of the processes and the iterative steps in designing the plant layout, often result in reduction of overall performance. Based on our research, one prime reason identified for this is that the objective function and the constraints used for optimization differ widely when considering the holistic approach i.e. complete plant layout and design using lean manufacturing principles, starting from the product assembly structure, as opposed to the scope of optimizing independent and isolated operations. Another challenge is to visualize the progress of designing the plant layout, using concurrent engineering methodologies, in a 3D environment and incorporating changes in the design process.

This paper discusses the integrated solution framework, flowcharts, methods, and covers the gamut of tasks to be performed to address the above challenges, while reducing waste. Our approach can be utilized across discrete manufacturing industries and across manufacturing activities like: assembly, welding, painting, forging, machining, stamping, and fabrication. Plant design elements to be presented in a future publication are: architectural, civil engineering, and utility. An automotive case study is also discussed to highlight the concepts and their application in the real world.

CASE STUDY

Assume there is an existing assembly plant that produces vehicle model ‘alpha’ with a takt time of 270 seconds. Based on changing market requirements and increased demand for the vehicle, the OEM wants to increase the production volumes of ‘alpha,’ by creating a new ‘greenfield’ facility at a new geographical location, with a takt time of 108 seconds. The OEM wants to create an optimized layout and design of the new plant which has a balanced line. The focus of this case study will be on the automotive body shop for the body-in-white (BIW) assembly of ‘alpha.’

CRITICAL TO QUALITY (CTQ) CHARACTERISTICS:
Following key characteristics were identified to meet customer satisfaction and to design the new BIW shop:

- Nominal takt time of 108 sec
- Throughput (average of 33 jobs per hour over a period of 150 working days)
- Balanced line (Capacity Utilization> 90%, waiting time <10%, blocked time <5%, fluctuation in capacity utilization amongst stations should be < 10%)
- Optimize Lead Time (19.5 minutes < Lead time < 21 minutes)
- 3D model of the plant (number of Stations, Process Plan, Manufacturing Bill Of Material, Bill Of Resources, Material handling Concepts and 3D Layout)
- Optimized cost of manufacturing with the use of robotics and level of automation

INPUTS FROM THE OEM OR THE ASSEMBLY PLANT:

- Existing layout of sheet metal body shop for ‘alpha’
- Production schedule
- Engineering and manufacturing bill of materials (E/MBOM)
- Process sheets
- Mean time to recovery (MTTR) and mean time between failures (MTBF)
- Shift calendar
- Rejection rate data
- Safety standards
- Production chart for past 6 months
- Cycle time data and distribution, loading and unloading time, clamping and unclamping time, and transfer time
- Motion and time study
- Manufacturing cost sheet
- CAD data and part geometry
- CAD of existing jigs and fixtures
- Spot weld data (coordinates for geometric welds and respot welds)
- Space constraints
- Defects definition and measuring strategies
- Quality gate definition

ASSUMPTIONS

It was assumed for the case study that MTBF, MTTR usage would be based on observations of semi automated plant and based on interviews. The level of automation is in line with the cost of manufacturing; and parts are always available at the BIW logistics store. Standard tugger speed and standard container loading and unloading time would be used.

TECHNICAL APPROACH

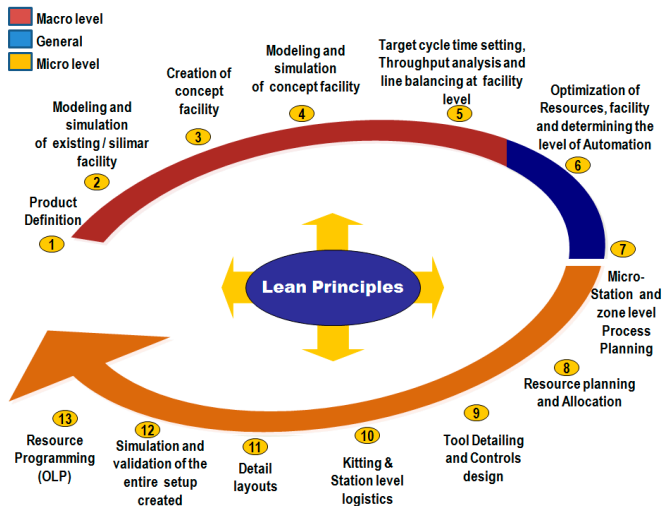


FIG 1: Plant Design Framework using lean principles

Fig 1 shows the iterative steps to be taken when designing the layout of a Greenfield plant using lean principles. It is broken down into three iterative segments, namely, macro-level, general level, and micro-level. The case study will be used to convey and emphasize some of the concepts and the approach.

MACRO LEVEL - PLANT LAYOUT DESIGN, OPTIMIZATION AND LINE BALANCING

Macro level plant layout design phase starts with conceptual designs of the line. Typical inputs required are: product data (CAD geometry, engineering bill of material, and assembly sequence process), design and process Failure Mode and Effects Analysis (DFMEA, PFMEA), lean principles, available real estate, standard operation sheets, vehicle and/or product quality history data, historical test and adjust data, annual production requirements, shift and work schedule, system efficiency, operation cap times, time studies along with plant and corporate test requirements are gathered from the manufacturer.

If there are similar products being manufactured by the OEM in other geographies, line observations and interviews are conducted to help define the macro level "Main Line and Secondary line" content. Flowchart in Fig 2a, 2b and 2c has been provided for guidance to create process at macro level based on this approach.

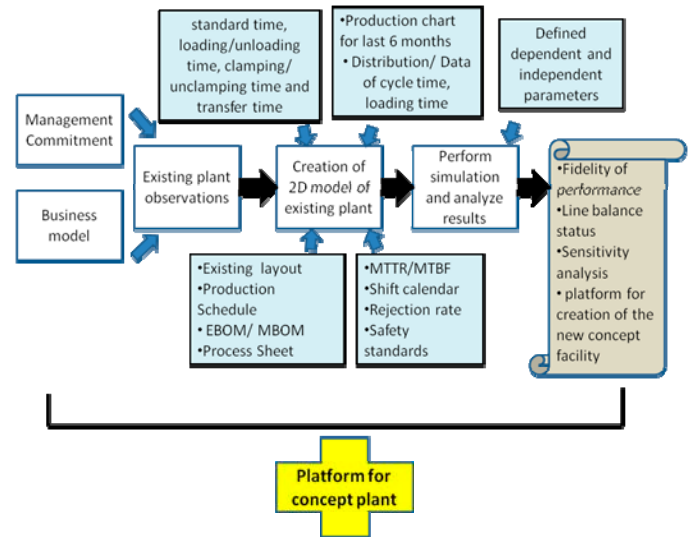


Fig 2a: Approach to model and simulate existing facility

Note: Facility is a setup, which can be a station, a zone, a line, a shop, or the entire plant.

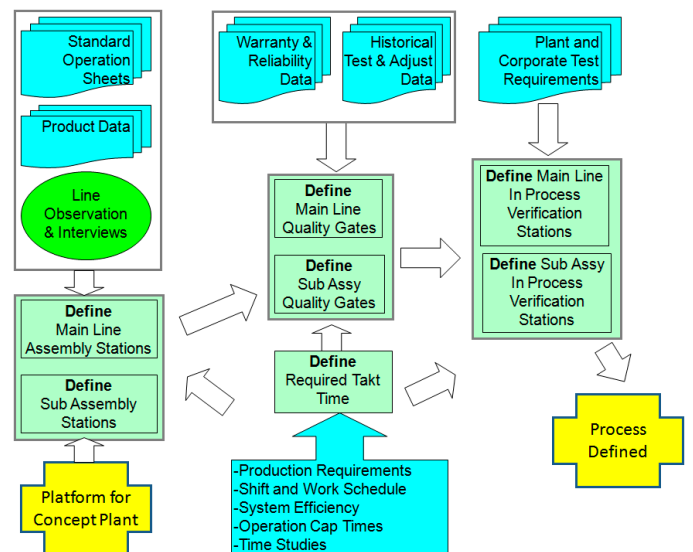


Fig 2b: Macro level process definition approach (Facility level)

Subsequent to defining the process (Fig 2a), the prime path of the system layout is defined as shown in Fig 2b. It is an iterative process, where modeling, simulation and validation using digital manufacturing tools is performed.

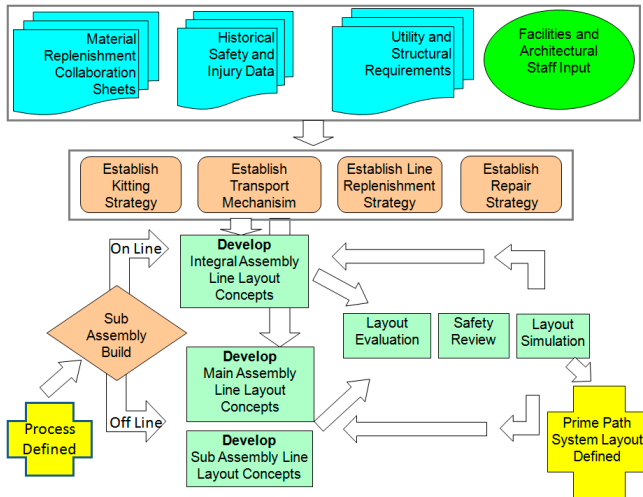


Fig 2c: Approach to create a Macro level prime system layout

This approach helps define the structure of the concept facility wherein the basic layout is defined based on the sequence of activities, fish bone sketch of primary & secondary line concepts, approximate area of available real estate and flow of material. Fig 3 shows a conceptual design of the plant layout for a discrete manufacturing industry.

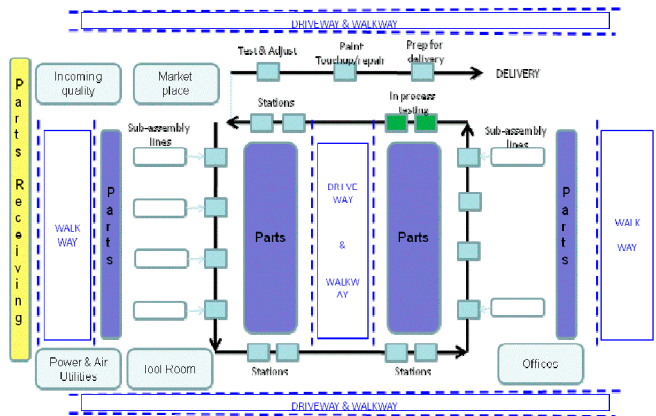


FIG 3: Conceptual Design of Plant Layout

The primary assembly line with stations is in the center of the plant (shown by dark thick lines and boxes). Material enters the plant from the left. Parts are received, incoming quality confirmed, and then moved to the marketplace. Based on production requirements, the parts are pulled next to the aisles connected to the sub-assembly lines and the main line. Stations for in-process testing and adjustments are identified based on the product and process requirements. Space for offices and other facilities are also accounted for at this level. At this level a macro level layout of the plant design is created.

CASE STUDY – STEP 1 – MODELING OF CURRENT BODY SHOP

- Create existing BIW shop layout for 'alpha' with takt time of 270 seconds using a digital manufacturing software (closures line is excluded)
- Perform simulation and sensitivity analysis to identify the effect of changes in **dependent parameters** (Takt time, Capacity utilization, waiting time, throughput and Lead time) as the **independent parameters** (buffer size, conveyors speed /length, cycle time of stations, distribution stream) are changed
- Determine the fidelity of performance (actual performance vs. performance of simulated body shop)

Case Study – Step 1 – Approach to model and simulate current plant

Historical distribution of the data set, like availability of parts at stations, MTBF/MTTR of stations, maintenance schedule and rejection rate are fed into the simulation software. The parameters defining the process planning (cycle time, set-up time, loading/unloading time, processing time, activity sequencing) are changed in the simulation software to meet the desired takt time. This helps define the macro level process. The layout obtained at this stage is a representation and is not scaled. The area of each of the elements along with the shape and size would be determined in the subsequent steps.

Case Study – Step 1 – Deliverables and Results

- Virtual 2D model of the 270 sec takt time shop as shown in Fig 4, using digital manufacturing software

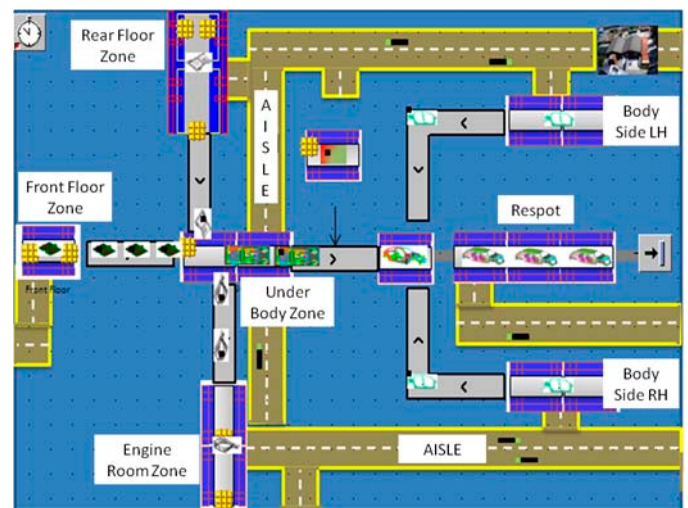


FIG 4: Modeling and Simulation of Existing Body Shop (270 sec takt time)

- There is, approximately, 15% difference between the actual performance and simulated results, which can be attributed to noise in the system and aberrations and simplifications in the simulation (example: power failure, safety data trends and safety performance) as shown in Fig 5 a, b, and c.

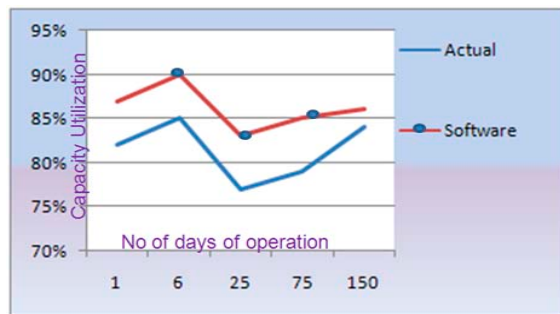


FIG 5a: Capacity Utilization vs. Number of Days of Operation

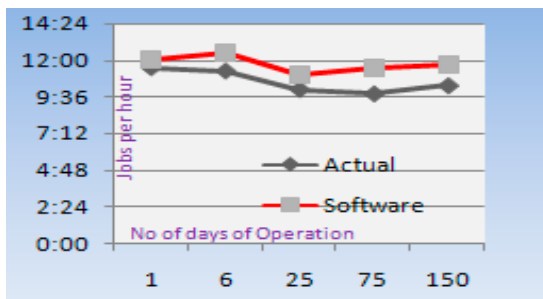


FIG 5b: Jobs per hour vs. Number of Days of Operation

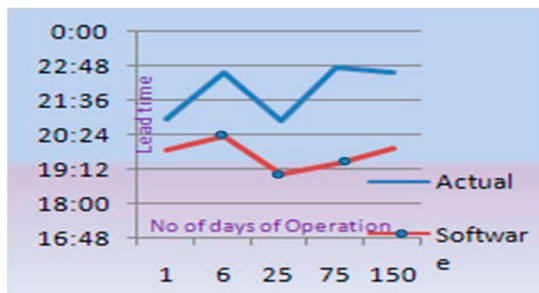


FIG 5c: Lead Time vs. Number of Days of Operation

- Sensitivity analysis performed to evaluate the effect of changing the independent parameters, on the dependent parameters, is used for designing the new body shop with takt time of 108 seconds
- The line is not balanced based on simulation as the difference in % capacity utilization of all the stations varies from 5% to 35% at different times during the simulation (exceeds the < 10% threshold, for fluctuation in capacity utilization)
- Based on interviews with line personnel, the sealant station, which was dispensing sealant into the BIW

had consumption that was significantly higher than the design parameters (nominal: 125mg/Body)

- Macro level layout at plant level and line level (main line and secondary line getting into the main line)
- Macro level station/zones layout and scope of work to be performed at each station
- Process definition (Macro level cycle time, set-up time, loading/unloading time, processing time, transfer time and activity sequencing)
- Material flow diagram at plant level
- Buffer size at line level
- Tugger movement charts at plant level
- Macro level balanced line at line and plant level
- Approximate space requirements

INCORPORATION OF LEAN MANUFACTURING PRINCIPLES

During design of plant layout at the macro-level, the objective is to reduce waste. Eight causes of waste have been categorized in Fig 6 based on lean principles and industry standards, namely: Defects, Transportation, Motion, Underutilized People, Over-production, Inventory, Waiting time, and Over Processing.

When performing 'value stream mapping' and identifying causes of waste, it is essential to ask the fundamental question at each step: Does this process add value to the customer? Many manufacturing operations are built to produce large batches of products to ensure the facility is kept operational. The products are then pushed through the system. Lean principles require creating products based on the 'pull' generated by customer demands.

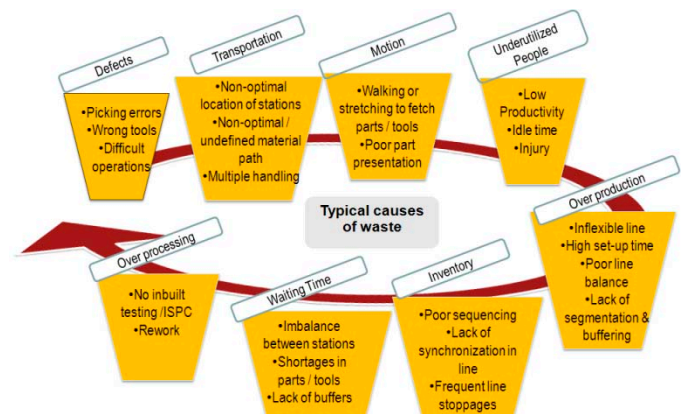


FIG 6: Typical Causes of Waste