International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-1S2, May 2019

Digital Twin for Factory System Simulation

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Abstract*: In the early days, building a manufacturing facility requires a lot of people to work at that facility. With the advent of CAD/CAE/CAM Softwares and high power computers, facility layout can be planned and engineered from a remote location. Manufacturing facilities undergo a lot of changes due to change in customer requirements, government regulations, safety standards, the complexity of products and process improvisation. It becomes indispensable to keep manufacturing facility digitally updated for upfront simulations and to capture facility change requirements caused by product variations. In the current methodology, it takes a significant amount of time and cost to keep manufacturing facility digitally updated. Digital Twin is an emerging technology that nowadays almost all consumer goods, airplanes, manufacturing plants, oil refineries, transportation networks, and even entire cities are having the potential to have Digital Twin of its own. This paper suggesting a methodology to apply Digital Twin to a manufacturing facility for keeping the model updated and simulated in real time. Real Time Location Sensing (RTLS) technology with transmitter tags, receiver nodes, and gateways (IOT) deployed at the facility. Manage transformation matrix for each asset in the Digital manufacturing facility at PLM/CAD software. The Discrete Event Simulation tool is integrated into PLM to run model directly from PLM in real time. Tags attached to each physical asset sends a signal to the receiver when asset movement or orientation occurs at the physical facility, Tags attached to each asset sends a signal to the receiver. The receiver sends pre-processed information to a gateway which acts as an edge device to process and converts those signals as transformation matric which gets synced to PLM system. Now digital manufacturing facility is up-to-date. Any facility change requirement can do in this digital model and simulated in real time for the quickest decision. The time factor has been compared with this new digital twin methodology and conventional methodology and discussed the results.

***Index Terms*: Digital twin, Internet of things, Object linking and embedding, Real-time location sensing, Simulation**

I. INTRODUCTION

The manufacturing industry has gone into new challenges during the lost last years. The global market has brought global business decentralization and manufacturing operations outsourcing. Therefore, the companies need decentralized tools for factory, product and supply chain management that for teamed as remote cooperation. Every day more and more, engineering tasks such as product design, factory supervision, and control or resources maintenance need to be done with decentralized multi-agent tools Widespread deployment of embedded systems, actuators, sensors (wireless) has driven the rise of Industrial Internet of Things (IIoT).

According to Industry 4.0, every equipment or devices available in plant floor should interact with each for better collaboration and assigned tasks accomplishment [Jiafu Wan et al., 2016].

The idea of the virtual representation of the physical factory is as old as computer. These earlier models were focused only on specific or tailor-made industrial asset-related issues. This all comes to be a challenging task, with the internet providing an enormous capacity for putting together long-distance company resources and providing a mean for effective remote teams' collaboration [WANG 2010].

Companies have been moving for the last decade into the world of e-manufacturing. The goal is to build a distributed manufacturing environment and network that can provide fast, decentralized and real-time solutions for the everyday challenges of the engineering company activities [de Albuquerque & Lelièvre-Berna 1998].

II. COMPONENTS OF DIGITAL TWIN

A digital twin is to simplify the complexity involved in IoT infrastructure. A lot of data about the same devices are being logged into databases or enterprise systems for carrying out multiple activities or to measure KPIs in Quality, Maintenance, Production, scheduling, and Performance. The Fig. 1 shows the Digital Twin Evolution.

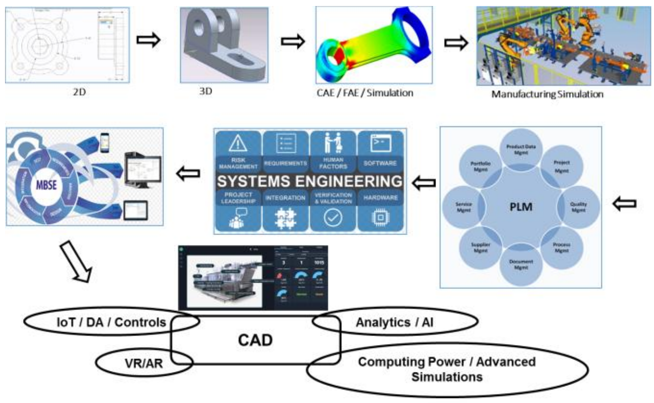

Fig. 1 Digital Twin Evolution

The digital twin model simplifies this and manages data in a more robust method for users to easily identify required reports, simulation results or historical performance of devices. Digital Twin is used to consolidating and analyzing datasets to replicate the factory production processes in the digital environment.

Revised Manuscript Received on March 23, 2019.

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Historically 2D cad like the simple layout was used to plan factory production processes. Later on, 3D cad came into the light to provide better insights about in the third dimension to better understand about clash results. With the advent of a lot of simulation software, the reflection of physical effect made easier in a simulation environment. Till here data was stored specifically to tailor-made applications. Core activities like production planning & scheduling and plant monitoring become easier as enterprise level applications like ERP, SCADA, PLM, and MES got maturity. As product complexity is being increased and multiple systems are involved to manage any factory floors operations, it becomes a mandate to use Systems engineering principles to cope up the timing involved in bring product and doing its manufacturing feasibility. The Fig. 2 Shows the Digital Twin Data flow from Devices.

Though many components are involved for building this digital twin model, the following components are acting as the base,

1. 3D CAD Model
2. Virtual Reality / Augmented Reality
3. Industrial Internet of Things
4. Big Data
5. Data Analytics
6. Artificial Intelligence

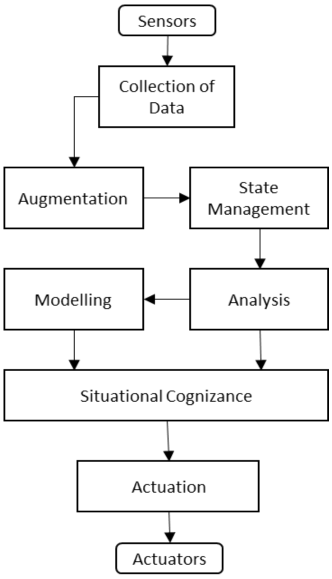

Fig. 2 Digital Twin Data flow from Device

The digital twin can be applied to any assets like machines in a factory or complete factory. Some logical assets like processes or services can have a digital twin model built. Digital Twin has multiple components to simulate states and future conditions of devices or assets. In current trends, sensors are available massively to gather any types of data.

In the emerging trends industrial internet of things playing a vital role in realizing the objective of industry 4.0. The intelligent software-based network has been devised and experimented to visualize physical factory in the digital environment. Networks are varied from various wired and wireless networks. Various components like physical layer, control layer, Application layer have been derived to support intelligent networks. Various services such as data collection service, data transmission service, and data processing service has been described and experimented with test results [1].

The real concept of Digital Twin emerged from product lifecycle management (PLM) before even new technologies like the Internet of Things, Smart manufacturing and Industry 4.0 got emerged. Digital Twin is a software model which is composed of 3D physical, mechanical and electrical data along with detailed information about its assembly process and instructions on production. It helps to simplify design, simulate, validate, optimize, streamline and debug the manufacturing process [2].

Digital Twin current trend has 3 main questions related to a user persona, value chain, its supporting data model, inputs, user interfaces, benefits and supporting business models. In industrial software and automation landscape, multiple systems are involved. Manufacturing Execution System (MES) / Manufacturing Operations Management (MOM) are acting as elements to contribute Digital Twin model. Manufacturing process management software like ERP/PLM naturally fits with Digital Twin to simulate discrete event simulations studies to find bottleneck stations and throughput of any system or manufacturing lines.

III. CURRENT FACTORY SYSTEM SIMULATION

The Fig. 3 shows the Digital Factory Creation Workflow and the system level simulation was conducted in four stages

1. Machine states monitoring
2. Forklift movements
3. Constraint Management
4. Asset position and orientation

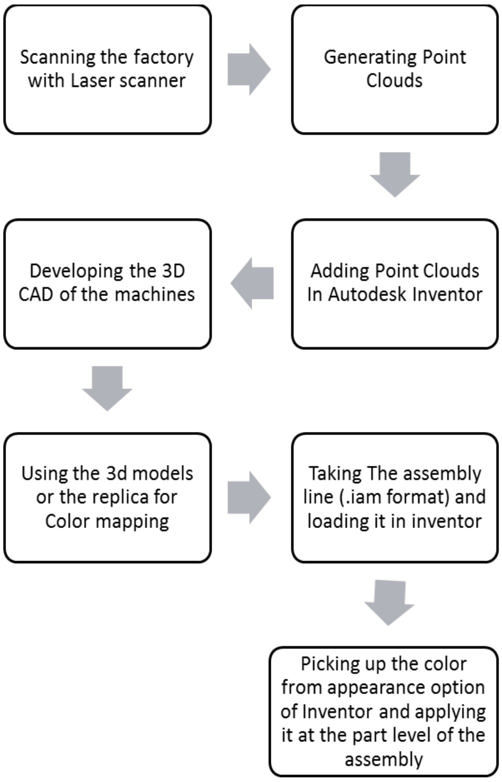

Fig. 3 Digital Factory Creation Workflow

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A. Layout Process

New facility development and retooling of existing facilities require layouts to be updated. The process of creating a layout for pre-planning and manufacturing engineering work is a very complex process. There is a requirement to execute digital factory workflow to create a layout for an existing facility or new Greenfield facility. It comprised of carrying out laser scanning of the entire facility of plant. It results out point cloud data of the facility. Cad modeler models or converts that point cloud data into a 3D Cad model to view the facility in 3D. This layout usually goes through a lot of approval as it matures. It will act as a reference for carrying out any modifications in the layout of machines or process improvement.

B. Constraint Management

Constraint management is carried out in factory floor operations to find out bottleneck stations or assets for meeting the throughput of the line. It collects a lot of information from shop floor systems to monitor assets performance, good parts, bad parts, states of the machine and so on. Multiple software like data acquisition protocols, data storage software, and data analytics software are being used to process the data from the shop floor to the reporting system. Another constraint in monitoring this production system is it is integrated into a lot of systems like quality systems, maintenance system, production system, and scheduling system.

C. Forklift Management

Material planning and logistics team usually make an extensive study to calculate the requirement for a number of vehicles required inside plants. Usually, paths of forklift movement from the assembly line to the storage area are optimized for efficiency gain of the plant. This estimated routes and effective utilization of indoor vehicles need to be monitored and managed properly to validate its results. Currently, the complex system has been developed to monitor this information which is logged in a different system which RFID has based tracking mechanism to send out location-based services.

D. Discrete Event Simulation

Tab. 3.1 Input data for Discrete Event Simulation

S. No	Daily	S.No	Weekly	S.No	Monthly
1	45.46	5	43.25	20	44.0
2	41.96	10	43.96	40	43.6
3	42.83	15	44.58	60	42.8
4	44.54	20	44.38	80	43.2
5	41.46	25	44.63	100	43.0
6	42.96	30	43.00	120	43.3
7	43.67	35	42.90	140	44.1
8	43.54	40	43.78	160	43.2
9	46.79	45	43.13	180	44.2
10	42.83	50	43.85	200	43.8
11	45.17	55	42.17	220	43.5
12	41.67	60	41.90	240	43.7
13	44.79	65	43.21	260	43.3
14	44.75	70	43.67	280	44.0
15	46.54	75	43.97	300	43.4

Number of vehicles required inside the plant floor and its pedestrian movement to predict constraints that occur for material movement while replenishment to that line sides. The current process is taking a significant amount of time to develop the DES models and run simulations. This is because data that is required as input to this model is coming and acquisition from different systems. Multiple people are involved in collecting and cleaning this information which caters to the need of DES model. Its reuse scope is also limited due to its complexity in channeling the required information as input file to DES model.

IV. DIGITAL TWIN ARCHITECTURE

A new process and architecture has been proposed and tested to reduce the time involved in carrying out these activities. Here data from plant floor system is acquisition through PLCs using data transfer protocols. Kepware software is used for the collected data from PLC. The Fig. 4 shows the Digital Factory Creation Workflow.

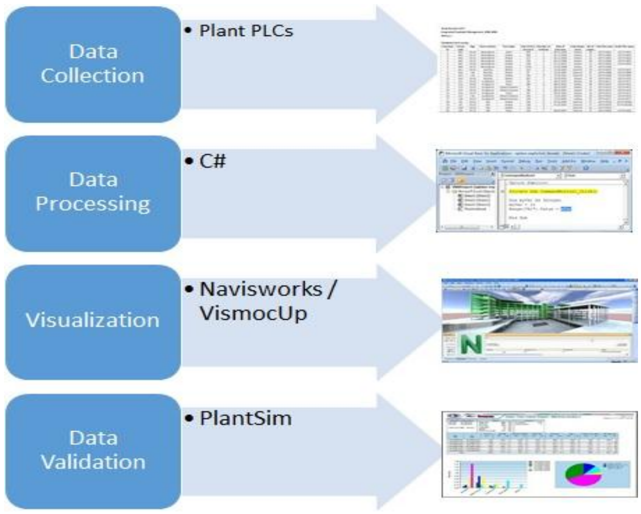

Fig. 4 Digital Factory Creation Workflow

In this work, two methodologies were proposed and explored architectures of them. First Architecture is to convert current visualization software into digital twin solution by integrating other multiple systems. Autodesk Navisworks is the visualization software to view and walk through the entire factory floor in digital mode.

A. Machine States Monitor

Machine states information are being collected for production monitoring system and available separately in a silo. The plugin was created to integrate this data from a production monitoring system to synchronize to the visualization tool.

Machine states like cycling, down, transfer, starved and the buffer is captured and assigned with different colors on cad models.

Leveraged automation plug-in's provided by Visualization tool and which is created in web services to post states change information from the plant monitoring system. Custom plugin developed inside visualization tool subscribed to web services created inside a production monitoring system. Red Green Blue (RGB) values of cad entities are updated in the visualization tool for every state change happening inside plant floor systems. An algorithm to update machine status is shown below. The Fig. 5 shows the algorithm to search and apply RGB values to cad entities

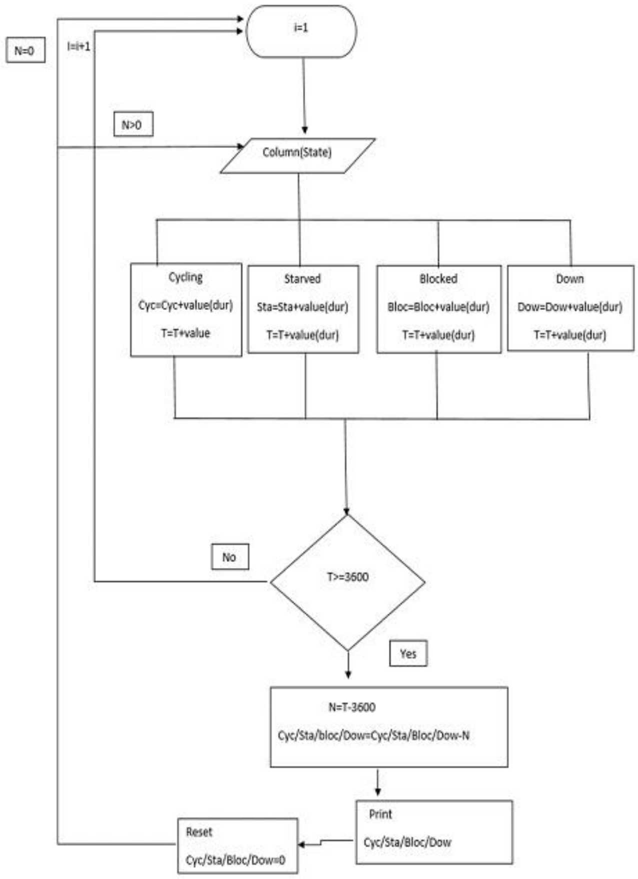

Fig. 5 Algorithm to search and apply RGB values to cad entities

The result that gets from this approach promising an alternative approach was tried and tested. It was to leverage timeline option which is limited simulation capability to simulate cad based on timeline information that load as CSV files into visualization. This approach was dropped off because didn't have much control on monitoring states information on this approach.

B. Forklift movement

RTLS (Real Time Location Sensing) technology has been developed and deployed in the plant environment with beacon technology to monitor data from the transmitter. Estimate and Kontakt ibeacons are being attached to assets of interest. Then ESP32 nodes are available as anchors to receive positional information from ibeacons and pass it to the gateway. In this IOT2040 Siemens used as a gateway to acquits ion data from microcontrollers that are attached at the point of interest. Here The trilateration method is used to harvest radio wave signal into location data and transfer it to the AEP system using Siemens gateway. AEP module will send that data to the PLM system to update position information of forklift. Alternatively, in real time it can be sending that data to visualization tool to monitor real-time movement of forklift in a digital environment.

C. Assets Position and Orientation

RTLS technology is replicated and that was used in the forklift movement in assets monitoring for digital twin. The developed an architecture shown below to permanently monitor assets movement and update in the digital factory environment. The Fig. 6 shows the High-level architecture for Digital Twin System.

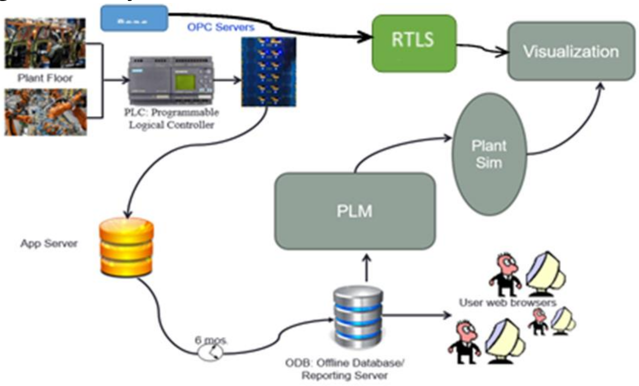

Fig. 6 High-level architecture for Digital Twin System

Here it could be connected to the factory floor application like MES to ERP application and then converged that information to the PLM system to update the digital factory transformational matrix. In emerging trends, IoT technologies are available to easily deploy in a scalable environment. It can be easily leveraged AEP application like Thingworx and analyze data from plant floor system and send location-based information to existing PLM system to manage the information. The Fig. 7 shows the Digital Twin Architecture.

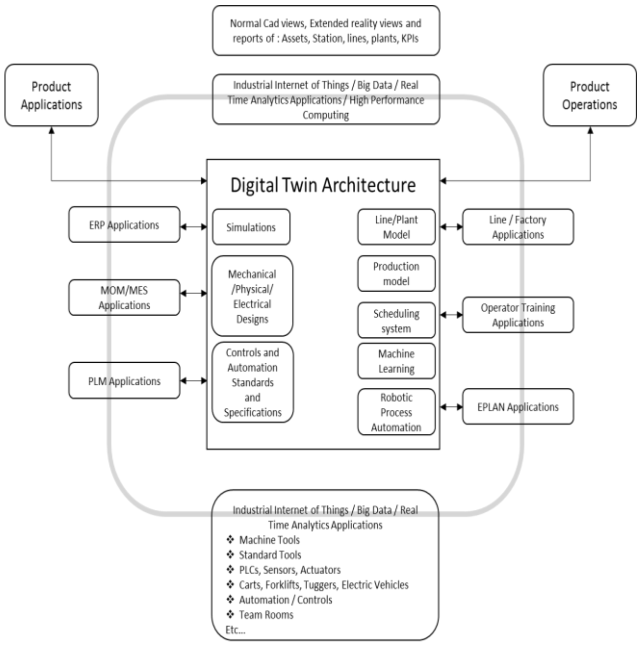

Fig. 7 Digital Twin Architecture

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PLM based system engineering has been leveraged and anchored as a centralized system since it has all product and its manufacturing process information managed effectively. Missing information is shop floor operations information not integrated to make this PLM information so dynamic and change in real time to update downstream engineers to make use of data effectively. PLM is integrated with all other systems like ERP, MOM/MES, and CRM systems.

V. RESULTS AND BENEFITS

Time taken to conduct manufacturing feasibility and validation study is a very critical process in industrialization. This paper proposed and deployed a methodology to reduce time significantly to conduct the following engineering studies during the industrialization process.

Tab. 5.1 Time reduction for engineering study using Digital Twin Model

S. No	Functionalities Implemented	Old Method (Mins)	Current Method (Mins)	% of Time Reduction
1	Machine States	30	1	96.6%
2	Forklift location	60	2	96.6%
3	Constraint Management	120	2	98.33%
4	Asset Location	960	2	99.79%

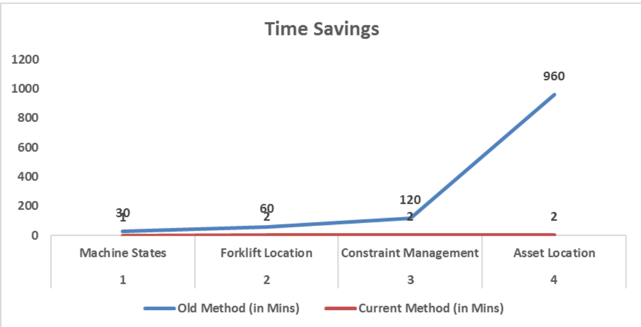

Fig. 8 Time Comparison of Old and Current Methods

Time has been reduced significantly in machine states monitoring task. 96.6% of the time has been reduced for machine states monitoring process. 96.6% of time reduced for forklift location monitoring process. 98.3% of the time has been reduced in the constraint management process. 99.8% of the time has been reduced in Asset location and monitoring process. The Fig. 8 shows the Time Comparison of Old and Current Methods and this process in two visualization tools and compared its performance to evaluate its viability for digital twin model. Here both Navisworks and Vismockup & Plantsim solution were used to reflect this scenario.

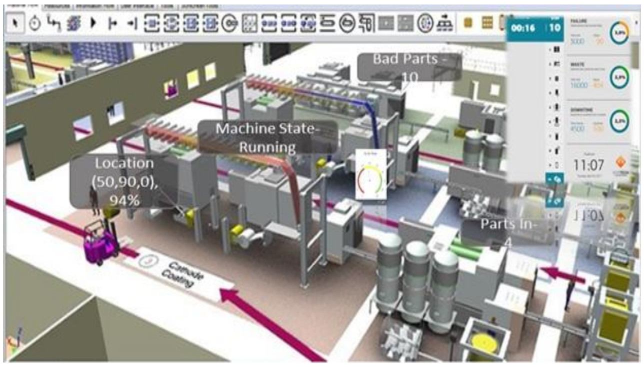

Fig. 9 Digital Twin Architecture

The latter solution has a slight edge over the former solution in terms of simulation and visualization capability.

VI. CONCLUSION

This proposed approach has a significant benefit in terms of time and cost. Performance of RTLS has been evaluated in terms of bit rates, range, and battery power. This technology is optimized for range and battery power because of its ruggedness and maintenance work involved. Passive tags vs active tags studied and deployed the optimized ones. Various technologies like UWB, RFID, Bluetooth, and GPS has been referenced through literature study and arrived at optimal technology in terms of range and accuracy. This Gateway technology has minimal processing power for doing analytics on interpreting transformation matrix from analog signals. PLM software integration APIs established to receive coordinates information from IOT gateway technology. The Discrete Event Simulation model has been developed by providing all critical parameters. The plant simulation tool used to integrate into PLM software. In these days, the DES model is available as a disconnected model and manually all parameters or input variables updated to execute simulation for future changes. This causes a huge delay in understanding the facility change requirement and impact of a product change in the facility on the throughput and bottlenecks. Industrial Engineers in manufacturing facility have to manually collect all this information and fed this information into the system.

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