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Planning and Scheduling of a Corrugated Cardboard Manufacturing Process in IoT

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ABSTRACT
The automation has revolutionized the traditional product development scheme by using advanced design and manufacturing technologies such as computer-aided design, process planning, and scheduling. However, research in this field was still based mostly on experimentation, as most manufacturing companies did not use simulation techniques in the implementation of their manufacturing planning and scheduling process. In order to address this problem, software developers have put simulation software tools in the market such as Enterprise Resource Planning (ERP), Advanced Planning and Scheduling (APS), and Risk-based Planning and Scheduling (RPS) systems. In this paper, a methodology to model high degree of accuracy for the production floor, the planning and scheduling of corrugated cardboard manufacturing process through RPS simulation in Internet of Things (IoT) environment is established. The RPS model is able to generate a deterministic schedule without randomness, create a risk analysis of the planning and scheduling, and handle the uncertainty.

KEYWORDS: *IoT, manufacturing process, planning, scheduling ERP, APS, RPS*

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I. INTRODUCTION

In this competitive global economy, the manufacturing sector is transitioning into a smart manufacturing in sense that it is using advanced technologies and internet to develop new line of products, and delivered them as soon as possible; and the challenge for organizations is to respond quickly to any cost and efficiency perspectives related unpredictability and to make the right organizational business decisions, but also to generate feasible operational solutions [1].

Furthermore, the usage of simulated models during the early phase of the manufacturing process it is a reality now [2].

And a risk-based approach to planning, scheduling and ordering production in manufacturing systems is developed as framework for evaluating real options on production capacity [3].

But we are confronted with two types of constraints while finding a solution to a production scheduling issue. Those constraints are (a) allocating limited resources in order to perform each task, and (b) a particular time frame to optimally perform each task [4].

In this paper we have adopted a simulation-based expert production scheduling model that will provide a realistic factory modeling, unexpected event handling, human expertise on rule making; and improved production schedules in real time. We present a practical model with simulation results to characterize a typical planning and scheduling of a corrugated cardboard manufacturing process in IoT. A distinctive aspect of our work is that it combines both queuing and scheduling theories to provide a reliable risk-based planning and scheduling of our presented model. This paper is organized as follows. In Section II, we present and describe our queuing and scheduling modeling theories. In Section III, we give an overview and comparison of the ERP and the APS simulation software tools. In Section IV, we describe the simulation approach adopted in this paper. In Section V, we present our results and observations. Then finally in Section IV, we conclude our work presented in this paper.

II. System model

A. Queuing Model

The queuing theory can be viewed as a special case of stochastic process theory. Telecommunications, computer networks traffic studies, traffic flow studies; are all domains of the application of queuing theory. The stochastic queuing model is powerful tool for the analysis of the efficiency of access points where materials are frequently process by servers for manufacturing process purposes. The results obtained through this analysis are practical depending on selection of the mathematical model; and this model is based on the probability density functions such as times between two successive incoming materials and service times like process time in the server, which are all random variables. The server access point's characteristics are known if precise and full data about its operation are available [5]. The main problem of queuing models is its focus on time averages and the limitation of the system under fixed rules such as FIFO (First In, First Out FIFO) [6].

The Single Server Queuing (M/M/1) Approach:

Given an M/M/1 queue, there exists a stationary distribution π for the J-queue length if and only if $\lambda < \mu$, and π is given by:

$$\pi_j = \left(\frac{\lambda}{\mu}\right)^j \frac{\mu-\lambda}{\mu}, \text{ j = 0, 1, 2, ...,} \quad (1)$$

i.e.: the stationary distribution is geometric with parameter $\mu^{-1}(\mu - \lambda)$

B. Scheduling Model

The Stochastic Scheduling Mode: l

The stochastic scheduling theory is about scheduling problems that involve random attributes, such as random processing time, random due dates, random weights, and stochastic machine breakdowns. Scheduling problems are classified as either deterministic or stochastic based on the task processing times and its environment. In a deterministic model, job-processing times are fixed and known with certainty and the machines are continuously available. A stochastic model uses probability distributions or the machines are subject to breakdowns. Objective functions are classified as either regular or non-regular [7].Scheduling models are useful in finding operating rules that optimize given objective functions, and an objective function is said to be regular when it is a non-decreasing function of job completion times and its value is minimized; the average completion time is most used regular objective function [8].

Operation Scheduling:

In this paper-scheduling model, resources are called servers and tasks are called jobs. A job may consist of a number of operations. All machining parameters are known in advance. Each operation is to be processed by at least one machine at a time. Each operation after the initial one has exactly one direct predecessor and each operation before the last has exactly one direct successor. Therefore, each job requires a specific sequence of operations to be carried out for the job to be complete. The shop contains m different machines, and n different operations, each of which requires a different machine. The machines can thus be numbered 1, 2,...,m; and the operations of job j can be numbered (1, j), (2, j), ... , (m, j), n = m, with the corresponding machine number.

Basic Earliness / Tardiness Approach

Let n be the number of jobs to be processed on a single machine, where job j is described by a processing time p_j and a due-date δ_j. Let C_j, E_j and T_j denote the completion time, the earliness, and the tardiness ofjob j, respectively. Then,

$$E_j = \max(0, \delta_j - C_j) \text{ and } T_j = \max(0, C_j - \delta_j). \quad (2)$$

Associated with each job is a unit earliness penalty $\alpha > 0$, a unit tardiness penalty $\beta > 0$, and a unit cost 7 for due date. The problem is to find an optimal job sequence S to minimize certain objective function. A basic earliness/tardiness objective function is

$$J(S) = \sum_{j=1}^{n}(\alpha_j E_j + \beta_j T_j + \gamma_j \delta_j). \quad (3)$$

In some formulations of the E/T problem the due dates are given, while in others the problems are to optimize jointly the due date and the job sequence. If the due date is given and fixed, the problem is called constrained. If the due date is a decision variable, the problem is called unconstrained.

The Due-date Assignment Approach:

With respect to the unconstrained scheduling problem, the scheduler assigns a due date to each job. In this paper, we can use two different due-date-assignment methods.

Common/constant (CON) due-date assignment method:

All jobs are given exactly the same flow allowance, that is,

$$\delta_j = \delta, \text{ j = 1, 2, ...n.} \quad (4)$$

Here, the common due-date is set internally and is announced upon arrival of the jobs. It is a fixed attribute of a job. This method entirely ignores any information about the arriving jobs, jobs already in the system, future jobs, and/or the structure of the shop itself. It is representative of common practice where salesmen quote a uniform delivery date on all orders regardless of the order processing times.

Slack (SLK) due-date-assignment method:

All jobs are given flow allowances that reflect equal waiting times that is,

$$\delta_j = p_j + k, \text{ j=l, 2, ...n.} \quad (5)$$

In this method, the due-dates are set internally by the scheduler as each job arrives on the basis of job processing times. As defined in this method, jobs are given equal slacks, which represent the practice in which customers are treated equally with regard to their waiting times.

C. The Shop Model

The production floor of this plant is formed by eight sections: one section of phase, one section of glue unit, one section of bag unit, one section of chisel, one section of slice, one section of cut, one section of stack, one finish section. These sections are composed by two workstations, respectively. This is a fixe manufacturing line that produces two different types of corrugated cardboards. A total number of 8 transfer nodes or sections, and 16 servers; these eight sections are where servers perform the different operations. The Work In Progress (WIP) is moved by conveyors through the whole system. Inside the sections, the buffer capacity is defined as zero, which means that the workstations will be blocked if the workstation doing the next operation is still processing WIP. Six buffers are defined after each section. Failures of equipment and times to repair it are considered in the simulation model.

Fig. 1 represent the shop set up model used in this project, this floor plan shows how machines or server set up and how scalable they can be. The materials ordered are fed to the phasor, then to the bagger, then to the slicer, then to the cutter, then to the stacker, and finished before being shipped. Fig. 2 shows how the job flows from the beginning to the end.

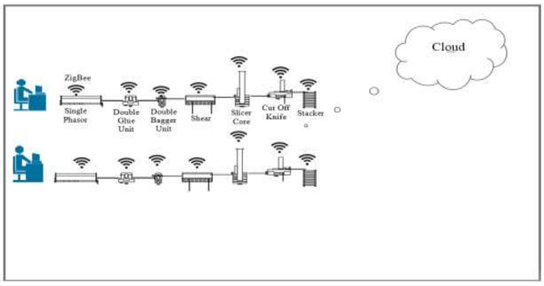

Fig.1. Shop model

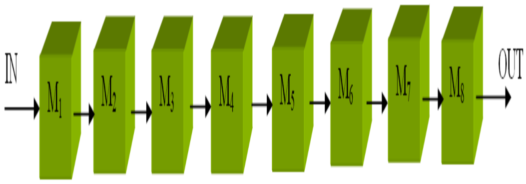

Fig.2. Flow shop model

D. The Wireless Networks Model

The Wireless Local Area Networks:

The wireless local area networks Wireless Local Area Networks (WLANs) Technologies have been subject to wide research in the domain such as mobile computing and other. The WLANs provide high-speed wireless connection where information can accessible easily. The WLANs [9-11] are found in many applications, such as web browsing, file transferring, etc. IEEE 802.15.4 is an important standard for WLAN, which is made of the standard 802 Logical Link Control (LLC) protocol that is divided into two sub layers: Physical Layer (PHY) and Medium Access Control (MAC) layer [12].

IoT Networking:

IoT stands for "Internet of Things" it is the way to link physical objects to the Internet so that data can be shared amongst those physical objects, monitored and controlled remotely. Every IoT device has three basic components: a digital sensor, processor, and Internet connection. The IoT will allow smart applications including manufacturing, transportation, home automation, and so on. Wi-Fi, ZigBee, and Bluetooth are basic technologies in IoT networking. For this project we will use the ZigBee radio communication technology, which is a low power technology adapted for battery operated machine-to-machine communication, such as thermostats, pressure detector sensors motion detector sensors. The ZigBee is the choice for this project for the WLAN. These wireless technologies work collaboratively to collect, forward, and process data to achieve manufacturing automation [13].

Table 1 represent the specifications of three wireless technologies, in terms of the frequency bandwidth, channel bandwidth, modulation, spreading, range, maximum data rate, energy consumption.

Table 1 Wireless Technology Specifications

	ZigBee (IEEE 802.15.4)	Bluetooth (IEEE 802.15.1)	WiFi (IEEE 802.11a/b/g/n)
Frequency bandwidth	2.4 GHz ISM	2.4 GHz ISM	2.4 & 5 GHz ISM
Channel bandwidth	2 MHz	1 MHz	20 / 40 / 22 MHz
Modulation	OQPSK	GFSK	BPSK, QPSK, M-QFDM
Spreading	DSSS	FHSS	DSSS, CCK, MIMO, OFDM
Range	10 – 100 m	10 m	100 m
Maximum data rate	250 kbps	1 Mbps	600 Mbps
Energy consumption	Very low	Low	High

The Wireless Sensors Networks (WSNs):

The leap forward in digital electronics, embedded systems, signal processing, and wireless communications brought about the development of very small, low-cost and low-power sensor devices, equipped with multiple parameter sensing, processing and communication [14]. A wireless sensor network is the deployment of a large number of sensors covering a given region. These sensors usually interact in order to monitor and data gather data, process the gathered data, and communicate the processed data over multiple points to the end-user located at the data sink. Various application schemes have been brought forward for wireless sensor networks, such as precision agriculture monitoring systems, battlefield surveillance, and industrial monitoring systems. Researchers in the field of wireless sensor networks have tended to focus on the issue of energy efficiency. This is due to the large number of nodes and their deployment in remote, unattended, and hostile environments, where it is usually difficult, if not impossible, to recharge or replace their batteries. Low power solutions are required in order to minimize energy consumption and extend the lifetime of the networks, without jeopardizing reliable and efficient communications in the networks.

III. MANUFACTURING PLANNING AND SCHEDULING BY PREVIOUS METHODS

A. Advanced Planning and Scheduling (APS) Systems

An APS system can be an off-the-shelf software or customized software with algorithms to solve a specific planning problem. It can be deployed as a broad tool supporting planning processes at different planning levels or specialized tool supporting one particular planning process. It can be defined by many others differently.

It is a set of technologies, business processes and performance metrics that enable manufacturing companies to compete more effectively in the global market place. The technologies involved are computer software and hardware that enable organization to change the way they plan, schedule, forecast, distribute, and communicate with customer and suppliers. It is also defined as a system that sits like an umbrella over the entire chain, thus enabling it to extract real-time information from the chain, with which to calculate a feasible schedule, resulting in a fast, reliable response to the customer.It can also be described as a computer program that employs advanced mathematical algorithms or logic in performing planning, scheduling, forecasting in manufacturing during short, intermediate, and long-term time periods. Its simultaneously consider a range of constraints and business rules to provide real-time planning and scheduling, decision support, available-to-promise, and capable-to-promise capabilities. It often generates and evaluates multiple scenarios and management then selects one scenario to use as the adopted plan. It five main attributes are demand planning, production planning, production scheduling, distribution planning and transportation planning [15].

B. Enterprise Resource Planning (ERP) Systems

The ERP is centralized system that provides tight integration with all major enterprise functions such as Human Resource, planning, procurement, sales, customer relations, finance or analytics, and other connected application functions. Even though, there are risks associated with the implementation of ERP system, the ERP systems have carved a very important role in business operations among large organizations. The ERP systems do have some beneficial features and values, which have compelled many big companies to deploy them, but its adoption in small and medium size manufacturing companies is less wide spread as oppose to big companies. The complexity of its system, its huge cost from the pre-implementation to the post-implementation, irrelevancy of business operation and the lack of awareness towards it explained its low level of acceptance. Regarding some small and medium size manufacturing companies, which have implemented ERP system, all the sub-sectors of those manufacturing companies and their industries chose one of the forms of adopting ERP. A number of industries require different kind of ERP modules for their business operations, based on the type of industry; the ERP system has to be customized [16].

Table 2 shows a comparison between APS and ERP systems regarding the planning philosophy, business driver, industry scope, major business area supported, information flow, simulation capabilities, optimization abilities, manufacturing lead times, incremental planning, speed of re-planning, data storage and calculations.

Table 2 A comparisons of APS versus ERP systems

Area	ERP system	APS system
Planning philosophy	• Planning without considering the limited availability of key resources required for executing the plans • Goal: Feasible plans • Push • Sequential and top-down	• Planning provides feasible and reasonable plans based on the limited availability of key resources • Goal: Optimal plans • Pull • Integrated and simultaneous
Business driver	Manufacturing coordination	Satisfaction of customer demand
Industry scope	Primarily discrete manufacturing	All industries
Major business area supported	Transaction: Finance, Controlling, Manufacturing	Planning: Demand, Manufacturing, Logistics, Supply chain
Information flow	Top-down	Bi-directional
Simulation capabilities	Low	High
Ability to optimize cost, price, profit	Not available	Available
Manufacturing lead times	Fixed	Flexible
Incremental planning	Not available	Available
Speed of re-planning	Low	High
Data storage and calculations	Database	Memory-resident

IV. THE EXPERIMENTATION METHOD

The Simulation Approach

The software was chosen for this work as it offers the four discrete modeling paradigms developed for the Simulation of Queuing System (SQS) with a focus on intelligent objects. This software provides a new object based paradigm that has been successfully implemented in manufacturing systems. The simulation software offers two object options to simulate the physical workstations: server and workstation. In this paper, we opted for the server object to represent a machine. A total of 16 servers objects are used to phase, glue, bag, chisel, slice, cut, stack and deliver a finished product final. Each server object has three queues used to contain the units waiting to be processed (input buffer), the units being processed (processing buffer), and the units waiting to move to the next process (output buffer).

The RPS simulation was used in this project in order to simulate the planning and scheduling of a corrugated cardboard manufacturing process in an IoT environment. The RPS simulation tool generates a detailed resource constrained deterministic schedule and a probability-based risk analysis of that schedule with variation in the system; it is useful in generating schedules which minimize risks and reduce costs caused by uncertainty. This manufacturing plant is a job shop that produces finished goods. We wish to generate a 30-day production schedule for this factory that fully accounts for the limited resources in the system. This factory consists of functionally grouped machine groups named Phase, Glue, Bag, Chisel, Slice, Cut, Stack, and Finish, with two machines within each machine group. Each of these machines is modeled using a Server, with a Transfer Node that is named for the machine group (e.g. Phase) and is used to dynamically route based on a scheduling rule to the selected machine (Phase1 or Phase2) within the group. The Phase Servers have a sequence dependent setup time where the setup time is specified in a changeover matrix based on material color. Possible material colors are defined in a string list named Material Color with values Other, Red, Green, and Blue.

There are two finished goods (Finished Good A and Finished Good B) that are produced in this factory, and each has its own routing and unique setup and processing time and material requirements at each Server within its routing. Even though we are modeling the material consumption at each Server, in this project we are not explicitly modeling the material resupply logic. Our model was created using a global scheduling rule that can be easily changed in the model properties. By default, orders are processed first-in-first-out; however, this global rule can be easily changed to any of the standard dispatching rules supported by simulation tool.

The ranking rule, processing time, buffer logic, failure types, uptime between failures, and time to repair options of the server object are defined accordingly. In this case, the ranking rule is used to prioritize the entities with the smallest value. The processing time defines the time that takes to process the entity at a specific server. Buffer logic defines the capacity of the three queues of each server. Failure type is a tool used to select the method to define the time between failures (i.e. calendar time based, event count based, no failures, processing count based and processing time based). The uptime between failures is used to define the time between failures and time to repair is an option used to define the time required to repair a failure when it occurs.

The WIP produced by the server is moved using conveyor objects. The travel capacity, entity-ranking rule and the desired speed of the conveyor objects were defined accordingly. The travel capacity defines the maximum number of entities allowed to be moved by the conveyor at the same time. Entity ranking rule is used to prioritize entities with the smallest value, and the desired speed is used to define the speed of the entities being move by the conveyor.

A source object was defined to create the entities that represent the orders of corrugated cardboards being produced by production floor. Since it is intended to simulate two different types of corrugated cardboards, two different entities were defined: corrugated cardboard model one and corrugated cardboard model two. This means that this source produces two types of entity objects. The flow through floor of these two corrugated cardboard models is different. Because of that, a sequence table was defined for each entity type. These sequence tables were specified at the entity level. In order to avoid jumps between orders of the different models, a specific priority value was assigned to the different orders. A total of seven buffers are defined to store the WIP. These buffers are located between the different sections forming the assembly plant. No buffers are defined inside of the different servers. As an example imagine two internal servers of a section, if the first server finishes its task but the next server is still performing its task, the conveyor will not move and the server will be blocked until the second server releases its WIP [17].

V. RESULTS AND DISCUSSION

1. Entity Workflow

The Entity Workflow in fig.4 provides a detailed view of the progress of each entity through the factory. The rows correspond to orders, and the time bars going across represent resource usages by that entity. This figure shows any date-time based milestones and upper/lower target values for those milestones, along with the color code probabilities of meeting each target.

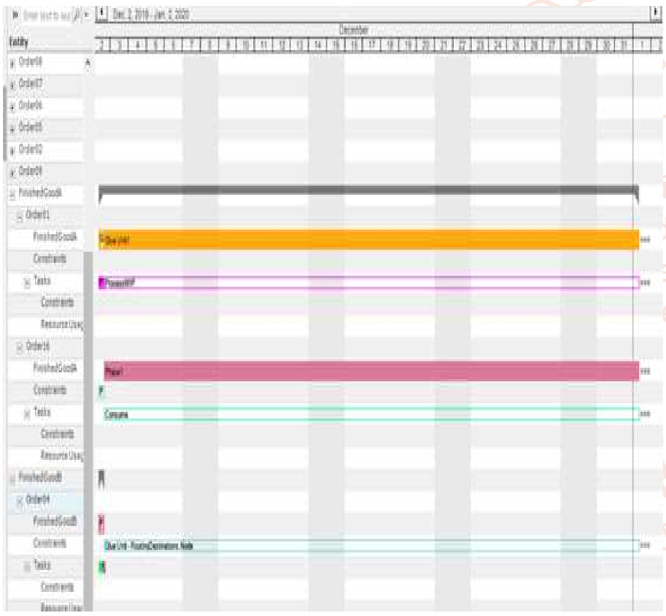

Fig.4. Entity workflow

2. Resource capacity logs

The Resource capacity log provides details of all changes in resource capacity, including shift changes and breakdowns.

3. The Constraint Log

The constraint log includes the entity that waited, the cause of the wait, and the duration; and is useful for finding and correcting problems in the schedule caused by unnecessary waiting for materials, resources, or other constraints in the system.

4. Manufacturing Orders

Fig. 7 contains a target ship date, and displays additional columns for the expected ship date and on time probability based on the risk analysis that has been performed by RPS simulation. The risks are color coded as gray (low risk), yellow (moderate risk) or red (high risk), based on the performance classification slider settings in the table ribbon.

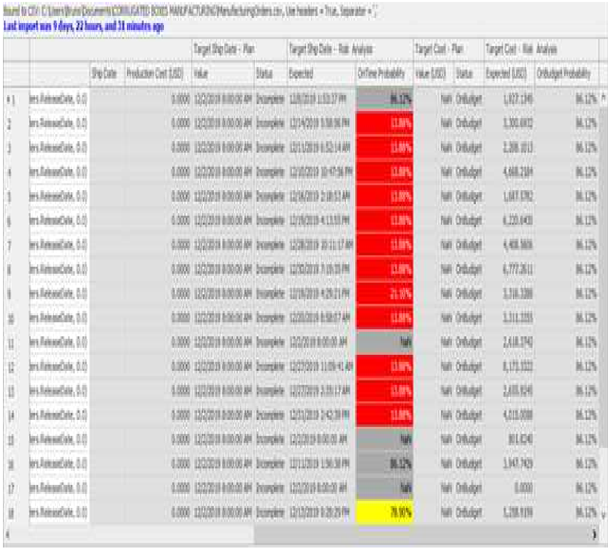

Fig.7. Manufacturing orders

5. Materials list

Fig.8 shows the material named Finished Goods A

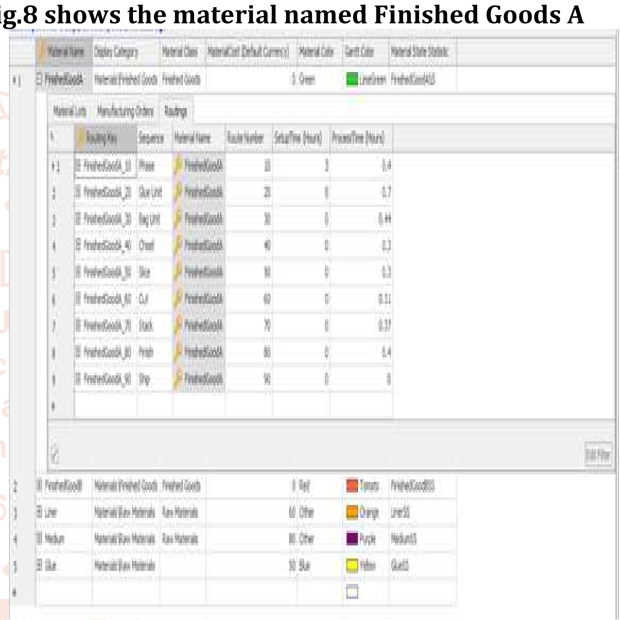

Fig.8. Materials list

6. Dispatch list report

Fig. 9 shows the dispatch list for resource bag unit1, it contained in the relational data tables for the model.

Dispatch List Report

Scheduled Resource

Bag Unit1

Order Id	Scheduled Quantity	Scheduled Start Time	Scheduled End Time
Order01	15	12/2/2019 4:23:53 PM	12/3/2019 4:14:43 PM
Order03	20	12/4/2019 8:38:49 AM	12/5/2019 8:26:00 AM
Order04	9	12/5/2019 8:26:02 AM	12/5/2019 1:13:16 PM
Order16	12	12/5/2019 3:37:02 PM	

Fig. 9. Dispatch list report

7. Target Detail

The fig. 10 shows a detailed summary of target performance for each entity. This includes the target value, status, expected value, and on time probability of being within bounds for the order targeted. This table shows results with two targets: one for cost and one for ship date

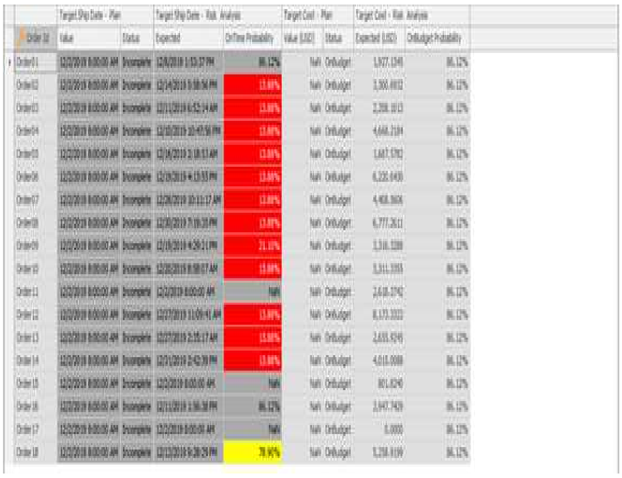

Fig.10. Target detail

8. Risk plots

The fig. 11 provides a detailed summary of each of our targets that we have defined for the model, and it is useful for analyzing the risk associated with an entity at a detailed statistical view. This figure shows a risk plot for the manufacturing orders target ship date. The plot consists of the mean value (gold circle), confidence intervals (brown/blue bands), range (horizontal line), and median and upper/lower percentiles (black vertical lines). The upper and lower bounds are shaded in red.

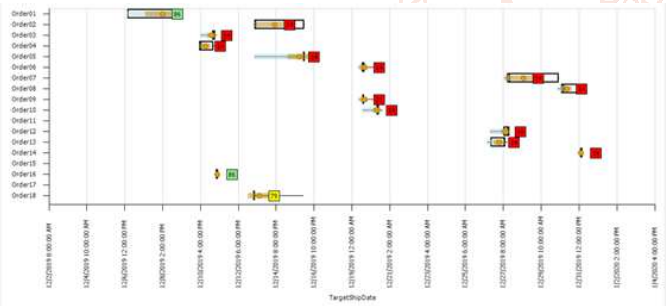

Fig.11. Risk plots

9. Detailed results

The fig. 12 provides both charted and graphical reports detailing information about the schedule based on the data recorded in the logs.

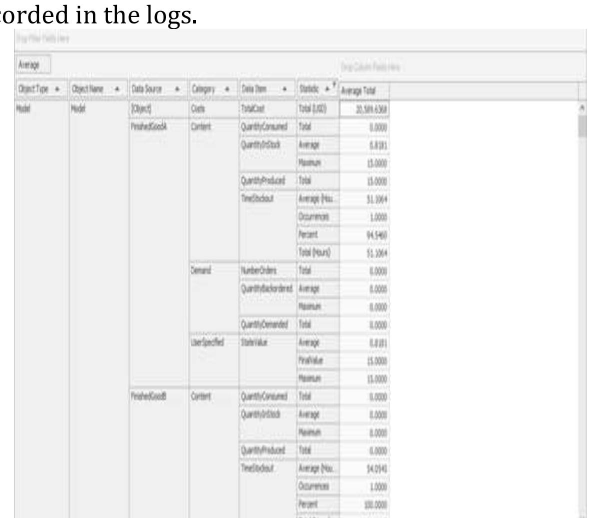

Fig.12. Detailed results

10. Resource dispatch list report

The fig. 13 is a portion of the Resource Dispatch List report for the Bag Unit1 workstation resource.

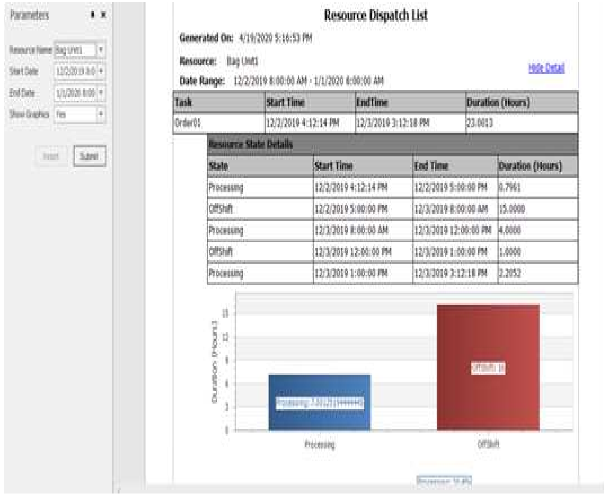

Fig.13. Resource dispatch list report

11. Dashboard reports

In this fig. 14 the resource Bag Unit1 has been selected on the card set, the resource states for Bag Unit1 are displayed by the pie chart, and the list of orders processed by Bag Unit1, Chisel1, Glue Unit1, Phase1, Slice1, and Worker[1] is listed in the tabular grid.

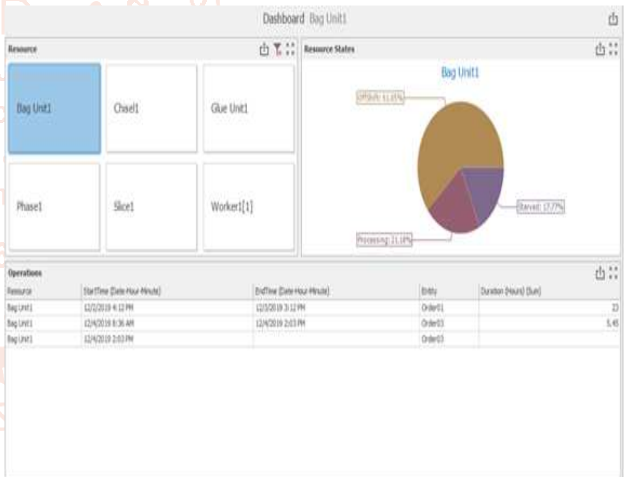

Fig.14. Dashboard reports

VI. CONCLUSION

We have performed a Risk-based Planning and Scheduling simulation to model with a high degree of confidence level, a smart corrugated cardboard manufacturing plant in IoT environment, including the production floor system through simulation software. We demonstrated how the presented model could be implemented by the corrugate cardboard manufacturing industry, as a helpful tool when taking decisions related with the production planning and scheduling. This risk-based Planning and Scheduling provides detailed and realistic plans/schedules along with the associated risks. The flexibility of the underlying facility model and the flexibility of the in-memory relational data set for providing the necessary data to drive the scheduling model; are two important advantages of the scheduling solution.With this Risk-based Planning and Scheduling models, we can quickly access the quality of the resulting schedule, and automatically generate the data schema and model using the provided add-ins, as well as using standard

Dashboard Reports and Table Reports for displaying the simulation results.

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