AN ADAPTABLE AND SCALABLE CLOUD BASED KANBAN DECISION SUPPORT SYSTEM FOR OPERATIONS ENGINEERING

by

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DEDICATION

This thesis is dedicated to SriAadithya and PP. Thank you for providing the constant inspiration.

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For several decades, organizations in operations engineering and supply chain management have used lean manufacturing methodologies for enterprise-wide improvement. As these improvements evolve, so does the complexity and the size of data. With the ubiquity of data and the scale of machine automation, abilities for rapid decision making and handling of ever-increasing system complexity become necessary. Various applications in the literature infer Kanban as a tool to control inventory or to manage software user stories. In this research, we propose an EAT (Estimated-Actual-Total) *Kanban* framework that has practical use whenever dashboard-type monitoring of processes is desirable. The purpose of this investigation is to demonstrate how a cloud-based Decision Support System (DSS), combined with a robust continuous improvement methodology, can help operation managers to make efficacious decisions. The study addresses three research questions: (1) How can a robust Cloud-based Kanban Decision Support System (CKDSS) work for a service industry, particularly in scheduling and resource management? (2) How can an evolutionary algorithm, specifically Ant Colony Optimization (ACO), augment a CKDSS? (3) Can the proof of concept implementation in operations engineering be scalable to financial engineering?

Preliminary Web-based Kanban Decision Support System (WKDSS) implementation shows promising results in two action research studies (1) direct mail marketing and (2) education services industry. To address the first research question, the results from the first action research demonstrate that the WKDSS helped to reduce the scheduling time from 180 minutes to three minutes, and in the education services, an operations decision support system contributed to consolidate 175 excel files into one single database. The success of two implementations lays the groundwork to address the remaining two research questions via the enhancement of a web-based system to a cloud-based system – Cloud Kanban (CK). CK is developed and implemented for a generic Service Operations Management (SOM) organization, utilizing the power and innovative cloud platform Microsoft® Azure™. CK provides the following advantages: (1) flexibility to scale up the hardware resources, (2) subscription based capital-expenditure free pay-as-you-go model, (3) automatic software updates minimizing system down-time, (4) enterprise class technology for lower Total Cost of Ownership (TCO), (5) built-in meta-heuristics for augmenting human decision support , (6) higher mobility for accesses from any internet connected device, (7) reliable business continuity with built-in backups resilient to natural disasters and power failures, (8) robust security of data, (9) strategic value with competitive advantage with the nimble management of organization's resource demands, and (10) collaborative decision making.

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LIST OF ABBREVIATIONS

3DS – Diagnose, Design, Deliver and Sustain

3M – Muda (Waste), Mura (Variation), Muri (Overburden)

5S – Sort, Set in Order, Shine, Standardize, Sustain

7QC – Histograms, Cause & Effect, Check Sheets, Pareto Diagrams, Graphs, Control Charts, Scatter Diagrams

8D – D0: Plan the project, D1: Establish a team, D2: Define the problem including who, what, when, where, why, how, and how many (5W2H) for the problem, D3: Develop interim containment plan, D4: Determine, identify, and verify root-causes, D5: Choose and verify permanent corrections, D6: Define, implement and validate best corrective actions, D7: Take preventive actions for minimizing recurrence, D8: Congratulate team

8Waste (DOWNTIME) – Defects, Overproduction, Waiting, Non-utilized talent, Transportation, Inventory, Motion, Extra Processing

ACO – Ant Colony Optimization

ACS – Ant Colony Systems

AD – Active Directory

AR – Action Research

CAPA – Corrective and Preventive Action

CI – Continuous Improvement or Continuous Process Improvement

CK – Cloud Kanban

CKDSS – Cloud-based Kanban Decision Support System

CMMS – Computerized Maintenance Management System

CSR – Customer Service Representatives

DSS – Decision Support System

EAT Kanban – Estimated-Total-Actual Kanban

ERP – Enterprise Resource Planning

FLS – Front Line Supervisors

FMD – First Mail Date

GMP – Good Manufacturing Practices

IoT – Internet of Things

ISO – International Standards Organization

IT – Information Technology

JIT – Just in Time

Kaizen – Continuous Improvement

Kanban* Traditional Definition – Production flow signals / Visual display

Lean – Reduce 3 M and 8 Waste

LMD – Last Mail Date

NP – Non-deterministic polynomial-time

ODSS – Operations Decision Support System

OEE – Overall Equipment Effectiveness

PACE – Performance Aligned to Customer Satisfaction

PM – Preventive Maintenance

Poka Yoke – Mistake-proofing with behavior-shaping constraints

PSPL – Project Scheduling Problem Library

QMS – Quality Management System

QoS – Quality of Service

RCA – Root Cause Analysis

RCSP – Resource Constrained Scheduling Problem

RIA – Rapid Improvement Activity

RPH – Rate Per Hour (Within a timeframe, the ratio of quantity produced / production hours consumed)

Six Sigma – Reduce Variation by using Define, Measure, Analyze, Improve/Develop and Control/Verify or its variation

SLA – Service Level Agreement

SMED – Single Minute Exchange of Dies used for quick changeover

SOP – Standard Operating Procedures

SRPH – Standard Rate Per Hour (Based on historical run rate, calculated as the ratio of quantity produced / production hours consumed)

TCO – Total Cost of Ownership

TCT – Total Completion Time

TOM – Target Operating Model

VSM – Value Stream Mapping

WACSA – Web-based Ant Colony System Algorithm

WIP – Work in Progress

WKDSS – Web-based Kanban Decision Support System

WO – Work Order

CHAPTER ONE: INTRODUCTION

This chapter introduces the research. It covers cloud-based decision support systems, and continuous improvement methodology called "Kanban." The chapter describes a portrayal of the conditions that are prevalent in the current digital age that raises the need for a CKDSS system in operations engineering, and the importance of developing efficient and effective decision systems. Next, the introduction covers the definition of Kanban and the significance of the research in addressing the challenges and opportunities in CKDSS. The next section of the chapter covers formulation of the research objective and research questions followed by the delimitations of the study. Finally, the chapter summarizes the research framework.

1.1 Background and Motivation

There is a great race taking place to monetize "data" and to be "digital first." In this "race of the generation," the line between material flow and information flow is shrinking, facilitating a niftier creation and delivery of product, processes, and services. This shrinkage is a by-product of rapid decision making at various stages of product development, and the provision of services by capturing, computing, communicating and collaborating with different data systems. These decisions require curation of data. For instance, using Exabyte (one billion gigabytes) scale data stores, companies attempt to accurately predict what, when, and how much to produce and sell. Dealing with data at scale referred to as "Big Data," which is characterized by its volume, velocity, variety, value, and veracity (certainty of data), has become the new reality [1, 2]. With the advent of a Big Data, there is a need to design innovative DSS to incorporate the changing data dimensions. DSS helps to generate insights from the data gathered for effective decision making. One such area rich with data is operations engineering. In this process, the dimension of the data collected varies from the contextual data. For instance, the sentiment of the content (actual words used to describe/resolve queries) can vary relative to the time, volume, and language of the interactions. This Big Data presents an exciting challenge for application lean methods and deployment of a DSS.

1.2 Kanban Definition

In manufacturing engineering, the use of Kanban is limited to the operations and specifically to controlling the WIP inventory. In software engineering, Kanban is used to manage user stories or software requirements. While these are useful for specific assembly line or product development, Kanban application fails to address an enterprise-wide view of resource management. In this research, we provide an enhanced definition of Kanban that provides a holistic view of operations management. Kanban is an end-to-end visualization tool across the enterprise value chain to monitor and control the production and consumption of resources.

1.3 Significance of Research

The research aims to advance the investigation on Kanban, primarily focusing on how a robust CKDSS can support operations engineering. Furthermore, deployment of such a Kanban system varies based on industry-specific complexities and takes a significant amount of time, money and resources. These complexities become a barrier to effective and efficient operations. Mainly, small-scale enterprises that do not have access to substantial capital are susceptible to less-efficient operations. Our novel EAT Kanban model, which is cloud-based, would help to overcome these barriers by leveraging the TCO of cloud-based systems.

As part of the national network for manufacturing innovation [3], manufacturing at scale involves scaling up from startup to on-going operations. This growth involves various vital operations engineering decisions during the process that include scheduling and resource management. This research aims to enhance this innovation cycle by utilizing cloud-based technologies and providing a high fidelity, ready-to-use methodology, and tool for making quality decisions. It will help to quantify way up-front in the design state the need for DSS to enhance the delivery of product and services. The proposed research will significantly contribute to enhancing the use of DSS, especially for small and medium-sized enterprises. The cloud-based system developed will be ready for implementation at a lesser cost than conventional ERP based DSS. A valuable outcome will be to apply the concepts not only to operations engineering but also in service and non-manufacturing environments, including finance, software development, and quality management.

1.4 Problem Statement

Current research applications of Kanban are limited to control of the WIP inventory. The scope within an organization ranges from single-stage to multi-stage (two or three bin) constant order quantity or constant order cycle systems. Furthermore, many applications of Kanban are paper-based, or card-based systems that run in parallel to existing ERP systems. To date, research for deploying a Kanban system has been focused only on a department, or on a product, or at a project level. Scaling to the enterprise-wide level has been a challenge due to system intricacies, lack of standardized processes, and other industry-specific factors. It produces sub-optimized enterprise level processes, thus creating a need for a cloud-based system that can leverage easy to use, scalable, turn-key solutions.

1.5 Research Objective

This research aims to develop and implement lean methodologies that can be efficacious for operations engineering. Parts of the objective are:

1. Identifying operations system decisions: Combining the concepts of Kanban and DSS, operations engineering needs a novel, cloud-based DSS fortified by a continuous improvement methodology. This system will address *how can a robust cloud-based Kanban decision support system work for a service industry, particularly in scheduling and resource management?*
2. Developing an efficient framework: enterprise-wide scheduling systems require a combinatorial optimization belonging to a class non-polynomial (NP) hard problem. Metaheuristics must be drawn up to provide a practical solution. What are the critical elements of an efficient cloud-based decision support system to support such a framework? *How can an evolutionary algorithm, specifically Ant Colony Optimization, augment a cloud-based Kanban decision support system?*
3. Implementing scalable model: enterprise systems transcend multiple organizational units, including Human Resources, Quality Management, Customer Service, and Warehouse. *Can the pilot model in operations engineering be implemented in financial engineering?*

1.6 Delimitations

This research focuses on the service industry. The research presents a scalable framework, but there could be a situation where this approach might not work. Because the optimization techniques used to fall into a class of NP-hard problem, there could be circumstances that require fine-tuning of the heuristics parameters. These depend on the scope, complexity, and nature of the business operations in addition to the computational resource availability and the security of the cloud infrastructure. Furthermore, this research does not strive to propose a better performance for an existing algorithm.

1.7 The Framework of the Research

Figure 1 provides the organization of the research in a graphical view. Chapters are developed to present the components of the framework that align with various research activities.

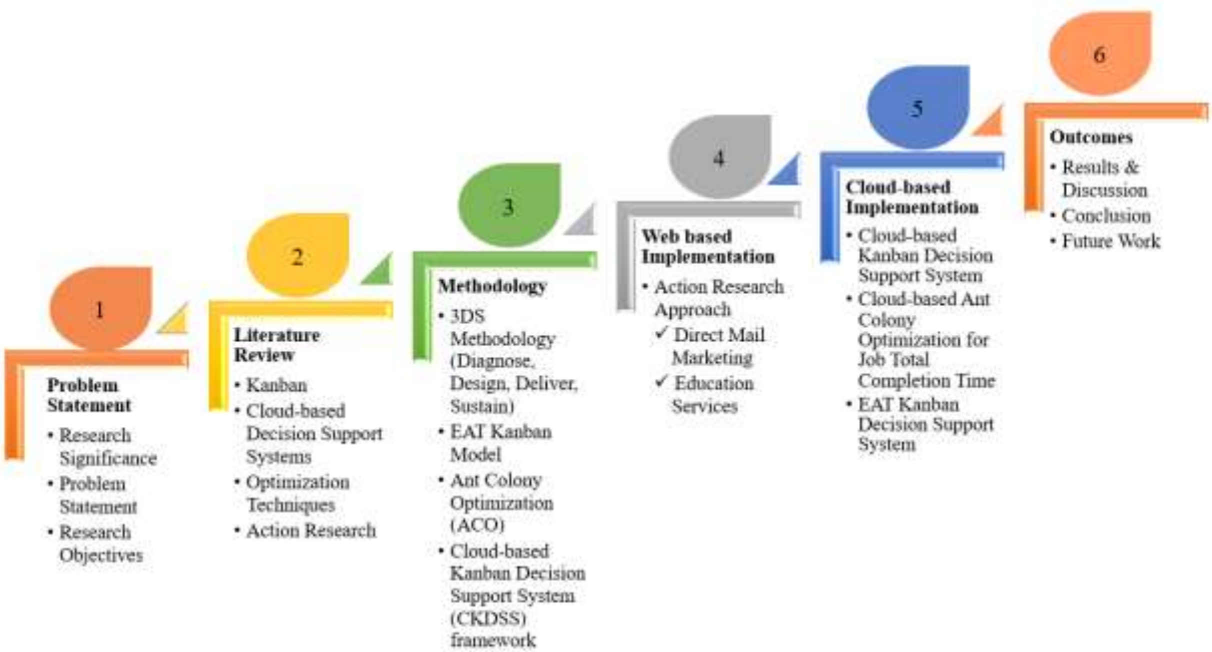


Figure 1 Research Framework

The elements of this research are listed as follows,

1. Problem Statement (Chapter 1): covers background information, motivation, the significance of the research, research objectives, delimitations, and a research plan.

2. Literature Review (Chapter 2): provides a review of relevant, previous research in Kanban, cloud-based decision support systems, optimization techniques, and AR.
3. Methodology (Chapter 3): highlights the use of AR, development of the 3DS methodology, the EAT Kanban model, the use of cloud-based ant colony optimization and the CKDSS.
4. Web-based Implementation (Chapter 4): includes the development of an AR approach for the implementation of WKDSS to two cases (1) direct mail marketing, and (2) education services. This chapter also covers the interdependencies of AR, 3DS, EAT Kanban model and its adaptations to the two cases.
5. Cloud-based Implementation (Chapter 5): comprises the development of a robust CKDSS framework. It also highlights a practical implementation of EAT Kanban for service operations management and the use of ACO to minimize the job TMT and to enhance decision support capabilities.
6. Outcomes (Chapter 6): summarizes the results and discussion of the implementation, followed by conclusions and recommendations for future work.

CHAPTER TWO: LITERATURE REVIEW

Significant portions of this dissertation have appeared in International Journal of Computer Integrated Manufacturing, Robotics, and Computer-Integrated Manufacturing.[4, 5]

During the literature research, it became evident that the term Kanban is described differently by various researchers and practitioners. Furthermore, the terms metaheuristics optimization techniques, DSS and AR have been used extensively in prior research. This chapter presents definitions of the terms and theories that underpin this research. First, it covers the definition of the terms Lean and Kanban, followed by the review of DSS and its cloud-based applications. A brief overview of evolutionary-based metaheuristics is presented, followed by the application of AR. Finally, gaps in the literature are summarized, proving a link to the research objectives.

2.1 Kanban

The term *lean* refers to the methodologies and tools that were made prominent by the Toyota Production System (TPS). Lean relates to the methods and tools used by the Toyota Motor Corporation [6]. There are two categories of Lean methodology in a service organization. They are (1) research done via case study and (2) theoretical models [7]. Various applications of lean manufacturing process measures have been widely researched, such as healthcare [8-15], information management [16], energy [17], engineering processes [18, 19], and food processing [20, 21]. Under the lean umbrella, Value Stream Mapping (VSM) is one of the most effective lean tools [22, 23]. The basis of VSM is the materials flow mapping process used by Toyota [24-26]. It is deployed to visualize the 3M's "Muda" (waste), "Muri" (overburden) and "Mura" (variation). One of the key tools that form the foundation of VSM is Kanban. In Japanese, the word “Kanban” means a visual board or visual display. It is used to control WIP inventory levels. In the production and operations world, there exist various types of Kanban and optimization approaches. Junior and Filho [27] presented a broad classification of the different adaptations of Kanban along with their relative strengths and weaknesses [27]. The original concept of Kanban has four components: (1) use of two communication signals (dual card Kanban system), (2) pulled production, (3) decentralized control, and (4) limited WIP [27]. Silva et al. [28] provide a DMAIC (Define, Measure, Analyze, Improve, Control) implementation for a constant order-cycle system, also known as milk run Kanban system [28]. In their DMAIC based approach, they highlight that a successful design of a Kanban system is dependent on various factors (such as route time, number of boxes that are beyond the production workstations), and therefore requires continuous system enhancements [28]. Figure 2 represents a typical Kanban system, where there is a decoupling point to separate the inventory supermarket from the workstation. The transfer of inventory happens via the signals to withdraw or to produce parts.

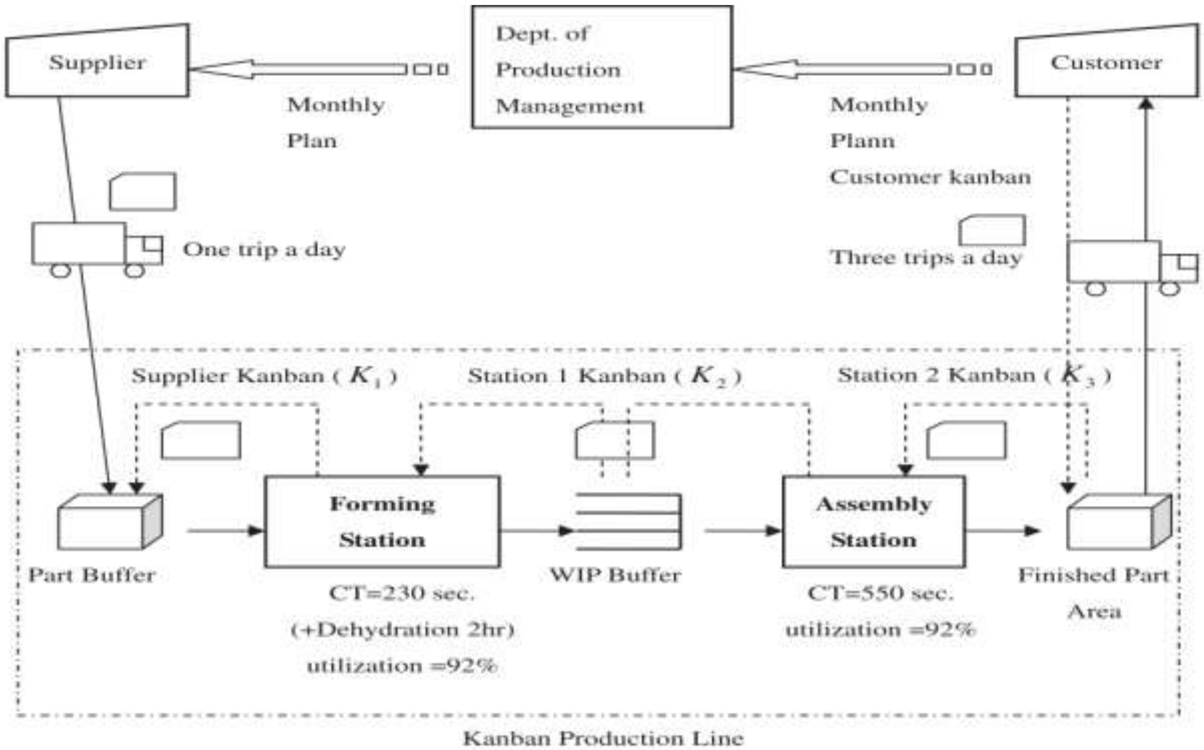


Figure 2 A Typical Kanban System

Recent research on the Kanban supermarkets considers a typical Kanban card system [29]. Lolli et al. [30] propose a Matlab™ based simulation approach to reducing the total daily cost (inventory cost added to the operating cost for line) along with providing 100% service in a multi-part feeder Kanban supermarket. The supermarket loads two inline feeders with dead freight. The simulation helps to pick the best scenarios with least total cost [30]. A condition-based preventative maintenance process uses a Kanban system with a continuous-time Markov chain model [31]. Based on a different inspecting schedule, an augmented Lagrangian genetic algorithm and a brute-force procedure were used to solve the model that strives to optimize the Kanban policy and the preventative maintenance policy [31]. Figure 3 shows a typical 2-stage Kanban system with two-card Kanban system for finished parts and one card to control the WIP.

The Kanban system helps to translate the monthly plan from the customer into a daily plan for a supplier, who delivers the materials once a day to meet the client's demand [32].

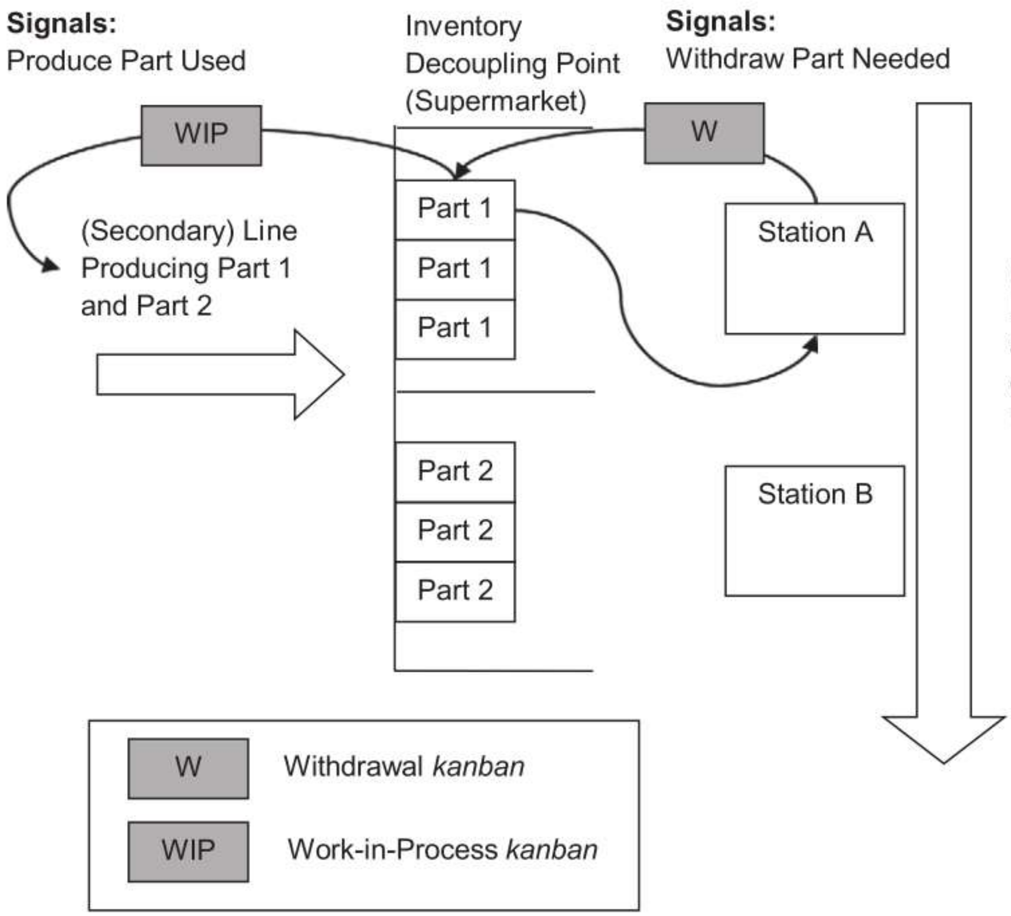


Figure 3 A Two-Card Kanban for Finished Parts & One Card Kanban for WIP [32]

There are various models of Kanban used in operations engineering. A Petri net to integrate purchasing, production and packaging were developed using LINGO software [33]. In campaign manufacturing environments where the setup time varies drastically between products, a discrete event simulation based Kanban model is proposed that has been successfully implemented in a self-medication mid volume pharmaceutical production process [34]. A Kanban system was used to minimize the total inventory cost in a hypothetical Just-in-Time (JIT) multistage production system [35]. A multi-objective genetic algorithm was proposed to optimize the Kanban number and size in the JIT system, hence minimizing the total WIP inventory [32]. Various performance measures, such as a number of cards or throughput, are used to determine the efficiency of a Kanban-based production process [36]. The deadlock issues in a Kanban can be analyzed using Petri net theory [37]. A knowledge Kanban model is proposed to improve the knowledge flow efficiency of a virtual enterprise research and development process [38].

One of the disadvantages of a Kanban system, when used to control inventory, is the lack of load balancing capabilities [39]. In a vintage flow shop where there is high variety and significant time variability in the job, an alternative system called control of balance by card-based navigation can be used to control the work [39]. In production situations where there is significant variation in demand and has multiple products, a shared Kanban allocation policy is proposed [40]. There are many disadvantages of using paper-based Kanban, including unfriendliness to the information system, maintenance complexities for small production runs, and the absence of real-time value [41]. E-Kanban systems store information that is transmitted between suppliers to reduce cost and control WIP [42, 43]. They are developed to overcome the challenges of managing paper/card-based systems, where there is a situation of lost cards and manual errors [42-47]. An eight-step implementation framework with critical successes factors at each stage is provided to address the operational issues of implementation [48]. The chief benefits of the E-Kanban are its ability to (1) integrate with the existing ERP system, and (2) provide a visual interface [41].

One of the most recent adaptations of Kanban is in the field of software development [49-52]. Nakazawa and Tanaka [53] recommended the use of Kanban as task boards for agile software development to track "issues," "backlog," "to-do," "doing," "review," and "done" activities for small projects. A survey on the effectiveness of their web-based single page application Kanban reported a 20% increase in the motivation for software developers to complete their task. Another type of Kanban used in the software industry is the Open Kanban, based on six principles of "respect for people, courage, focus on value, communication, and collaboration, holistic or systemic approach to change" [54]. Przybylek and Olszewski [55] developed various games to increase the adoption of the Open Kanban. Faria de Souza et al., [56] combined Kanban and business process modeling notation to monitor the software developers progress in the developmental of distributed software. A conceptual Kanban scheduling system for the system of systems is proposed to manage work queues across large enterprise-wide projects [57]. It also introduces a concept of classes of service, a JAVA based prioritization algorithm to simulate and schedule the work across various stakeholders [57]. Heidenberg and Porres [58] proposed a theoretical process metrics-based approach called Kanban guards that acts as a decision support system to enhance the software quality. Hui [51] used an enterprise Kanban model based on Kotter's eight principles and the minimum viable changes for managing agile teams. Utilizing ServiceNow ™ software, a Kanban-based approach was implemented to reduce the backlog and improve Service Level Agreement (SLA) of security risk assessment in an e-commerce business [59].

2.2 Cloud-based Decision Support Systems

DSS has been in existence since the proliferation of computers and is an enabler for business decision-making [60]. Table 1 summarizes a few different areas of application of DSS and the methodology employed. When factors are different from specifying in advance, a DSS helps the management, operations, and planning levels of an organization to make decisions in rapidly changing environments [61-63]. Shim et al., [64] provided a comprehensive overview of DSS technology. Wan [65] developed an adaptive DSS for lean practitioners enabling them to make better decisions for CI journey, challenges such as roadmap status updates, appropriate tool selection, and stakeholder communications. Kokshenev et al., [66] suggested a decision-support center for planning and management of various processes for energy companies. Miranda et al., [67] highlighted how DSS could be used to schedule course timetables and classroom assignments. Giannoulis and Ishizaka [68] demonstrated ranking of universities in the United Kingdom, using the ELECTRE III multi-criteria decision system. Key variables that underpin these DSS are (1) the number of criteria involved in the decision-making process, (2) the number of stakeholders involved, (3) the decision algorithm, and (3) the output format or representation needs of the business. DSS has evolved from simple models to complex multi-criteria systems [69]. Next generation DSS are mainly web-enabled and thus could be delivered to any device that can access the web [70, 71]. Renu et al.,[72] utilized the latest trend of big data to create backbone methods-time measurement tables for consistent product planning of assembly time. DSS performance is evaluated and optimized for a positive outcome considering various factors, including scalability, data security, and web performance [73, 74].

Table 1 Application of Decision Support System

Area of Application	Methodology Used	Reference
Electrical energy	X-R model (X-Set of feasible solutions and R -Set of fuzzy preference relations)	[66]
Course and classroom scheduling	udpSkeduler based on mathematical programming models	[67]
University ranking	Data Envelopment Analysis (DEA) Multi-criteria decision method ELECTRE III	[68]
Supply chain management - Collaborative Planning, Forecasting, and Replenishment	Service-oriented framework (resources, location, lifecycle and time)	[75]
Service delivery	Big-data cloud-based service-oriented architecture	[76]
Cybersecurity risk planning	The genetic algorithm determines the risk to assets and cost of the assets in the portfolio	[77]
Information security planning	Multi-criteria decision framework based on decision theory.	[78]
Investment evaluation high-tech business	System dynamics and non-linear behavior	[79]
Mold industry	A genetic algorithm-based hybrid system supporting process planning	[80]
Blood center platelet production	Linear programming model	[81]
Bank rating	PROMETHEE II to determine bank's stability, performance, and risk	[82]
Vehicle routing	Ant colony combined with Google maps	[83]
Asset allocation	Simulation and stochastic programming	[84]
Inventory management	Spreadsheet-based simulation	[85]

A recent development in the application of DSS is to leverage cloud-based resources. An overview of various cloud-based helpdesk systems with an example of the FreeNest, a Finish software industry cloud-based project development platform [86]. An e-learning cloud architecture enumerates the focus on combining cloud architecture and e-learning features [87]. A cloud-based human cooperative behavioral library is proposed to improve the co-operation of agents in a construction project [88].The term "cloud computing" refers to the "as-a-service" approach to creating and managing resources that IT depends on [89-93]. Some of these services are referred to the fifth utility [94]. These services are classified into (1) platform, (2) infrastructure, and (3) software [95]. These services are provided by a third-party provider that helps the organization to deploy a technology-based solution at a low TCO efficiently. Another essential parameter considered for the selection of cloud services is the QoS [96, 97]. Many challenges need to be evaluated in selecting the right cloud service provider from the view of security of the system [98] to cost of provisioning the system [99-103]. Table 2 summarizes application of cloud-based DSS to various domains.

Table 2 Application of Cloud-based Decision Support System

Application Area	Approach / Algorithm used	Cloud Platform	Reference
Energy evaluation and management	General framework –Building automation system	General framework	[104]
Context-aware information services	General framework	General framework	[105]
Water distribution system	Particle swarm optimization	Microsoft Windows Azure	[106]
Community management	Cloud-based web services for financial, facilities, and energy	SmartCom-munity.in	[107]
Aquifer management	MODFLOW, ArcGIS		[108]
Emergency department-nuclear crisis	Resource description framework with matching SPARQL-based event pattern language	Event cloud - PLAY platform	[109]
Software testing	Hybrid particle swarm optimization and genetic algorithm	Hadoop cluster	[110]
Computing infrastructure provisioning	Starvation-removal and advanced reservation to best effort conversation	Haizea resource lease manager	[111]
Home system automation	General framework	Google cloud platform & Google app engine	[112]
Material tracking system	General framework with RFID technology	Microsoft Windows Azure	[113]
Cloud manufacturing	General framework – Interoperable cloud-based manufacturing system	General framework	[93, 114]
Mobile healthcare-diabetes management	Insulin Titration - PREDICTIVE 303 protocols	CollaboRhythm	[115]

2.3 Optimization Techniques

The use of metaheuristics as optimization techniques for resource scheduling is not a new field [116-119]. Tsai and Rodrigues [117] did an extensive survey of metaheuristics algorithms to schedule tasks and utilization of computing resources in the clouds based on three factors (1) modifying the operators, (2) amending the fitness function, and (3) hybrid algorithms that leverage two or more algorithms to improve performance. Due to the complexity of the scheduling problem, the literature is ripe with opportunities to balance between the searchability and the decision-making ability [117, 118]. There are various techniques, including ACO [120-123], genetic algorithm [124-127] , particle swarm optimization [128-130], league championship algorithm [131, 132], artificial bee colony [133-136], and bat algorithm [137, 138], that focus on scheduling optimization. These techniques consider a combination of makespan, response time, throughput, and utilization as performance measures for improvement.

James Patterson [139] introduced approaches for resource-constrained project scheduling. These are the class of NP-hard problem, used to minimize the project duration with resource restrictions, that has been of great interest to researchers [111, 116, 119, 140-157]. Sebt et al., [158] proposed an evolutionary programming approach to minimize the project duration. Utilizing a random key generation for the individual problems, and a successive generation scheme to decode and generate the project plan, they compared four different variants to find the best approach [158]. Balouka et al., proposed heuristics based on lean project management to maximize the project value of a satellite receiver development defined by many parameters, such as quality, profit, and performance. [159]. Bukata et al., [160] proposed a card-based parallel tabu search algorithm using the J120 dataset [161]. Chen et al., [162] proposed an ACS algorithm to schedule resources that are constrained by deadlines in a cloud platform. Kolisch and Sprecher [161] maintained a PSPL that has been extensively used to test various algorithms and its variations. Huang et al., [163] proposed an ACO that works best for small and large activities for PSPL [161] test problems. Quiaochu et al., [164] tested ant colony algorithms for managing the deployment of resources on a cloud platform. Rokou et al., [165] used a hybrid genetic algorithm and ACO for PSPL dataset [161]. Yan et al., [166] and Yan and Ding [167] developed an ACO algorithm based on the PSPL dataset [161].

2.3.1 Web-based Ant Colony System Algorithm

This section discusses the methodology and the implementation of the WACSA with ACS as the background heuristic [5]. WACSA harnesses the power of ant algorithms together with the flexibility of the Internet. Because WACSA runs on a web server, multiple clients having access to the Internet can access it simultaneously; its main advantage is flexibility. Based on user requirements, the algorithm's governing parameters can be easily modified to simulate different conditions. Figure 4 shows WACSA methodology, which has five phases: (1) input, (2) initialization, (3) ant generation, (4) ant walk, and (5) output.

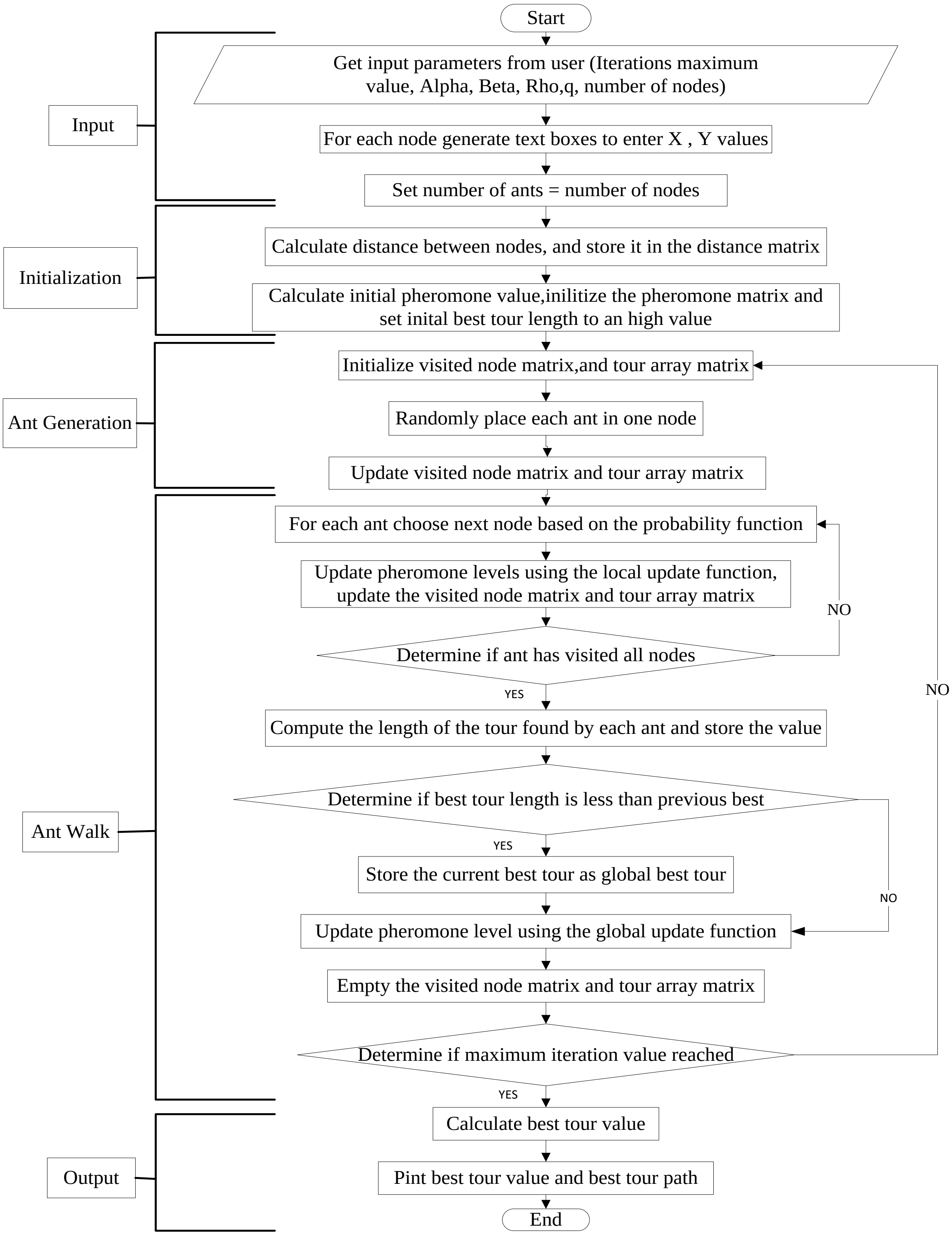


Figure 4 Web-based Ant Colony System Algorithm Methodology[5]

In the input phase, the user accesses the WACSA website and enters problem parameter values. In the first step, the user enters values for various parameters. They are: (1) α, β, (where α and β are control parameters that control the relative importance of the path), (2) the amount of pheromone intensity (ρ), (3) the initial pheromone value (q_o), (4) the number of nodes (n), and (5) the maximum iteration value. The values α and β are critical parameters that guide the ants to make progressive movements. In the second step, a web page containing text boxes equivalent to the number of nodes will appear to allow users to capture the Cartesian coordinates of nodes. Concerning best practices in the literature [168], the number of ants required for simulation is set to equal the number of nodes.

The initial pheromone matrix and an initial best solution are assigned in the initialization phase. The distance matrix is populated with the Cartesian coordinates. For instance, if a problem has 13 nodes, then a matrix with dimensions 13 x 13 is generated. The distance formula generates the distance between any pairs of nodes. The distance "D" between any two points X_1, Y_1, and X_2, Y_2 is given by the following formula:

$$D = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2}$$ *Equation 1*

Using this distance matrix, the initial pheromone value (τ_0) is initialized and calculated based on the Equation 2, where "n" is the number of nodes and $D_{i,i+1}$ is the distance between nodes i and i+1.

$$\tau_0 = \frac{1}{(\sum_{i=1}^{n} D_{i,i+1}) * (n)}$$ *Equation 2*

In the first ACS proposed by Dorigo and Gambardella [168], the initial pheromone value depends on the nearest neighborhood heuristics value. The previously known best solution to a given problem is multiplied by the number of nodes to arrive at the initial pheromone value. In WACSA, the initial pheromone value is assigned based on Equation 1. It is one of WACSA's features that makes it flexible for a range of problems where the previous best-optimized solution is not known. The assessed initial pheromone value for every ant is stored in a matrix referred to as a "pheromone matrix." Finally, a significant positive integer value is assigned as the initial best solution. It is compared to the best solution of the first iteration and establishes the current best solution, which is then used for further comparison.

In the ant generation, a starting node matrix, a visited node matrix, and a tour matrix are created for each ant. Initially, the visited node matrix is populated with a value of "0." Once an ant visits a node, this value in that ant's visited city matrix is changed to "1." This matrix, called the "tabu list," holds information about visited and non-visited nodes for all ants. $Tabu_k$ in the visited matrix is defined as the list for the k^{th} ant that records those nodes that have already been visited. During iteration, this directs the ant to the next valid node, thereby preventing its movement to previously visited nodes and thus enforcing the TSP constraint of visiting all cities only once. At the beginning of the simulation, one ant is placed in each node. Time, t, is discrete, and $t = 0$ marks the start of the algorithm. A random number between zero and one is generated. For each ant, an initial node is randomly chosen by multiplying the random number by the number of nodes. This value is rounded up to the nearest integer. For each ant, this node is inserted into the initial starting node matrix and the tour matrix. Furthermore, the visited node matrix is updated with a value of 1.

Ant walk starts at time t = t+1; every ant will have moved to a new node, and the parameters controlling the algorithm is updated. The ant's selection of the next node is based on the distance to that node and the amount of trail (pheromone) intensity on the connecting edge. The factor "visibility," n_{ij} is defined as $\frac{1}{D_{ij}}$, where D_{ij} is the distance between nodes i and j. A random number "q" between zero and one is generated and compared with q_0. It allows the ants to explore different paths and avoid sub-optimal convergence. If q is less than q_0, ants choose the next node based on the action choice rule (L), generally referred to as the "pseudo-random-proportional action choice rule or state transition rule" [169] as shown in Equation 3 :

$$L = \begin{cases} arg\,max_{j \notin Tabu_k i \neq 1} \{ (\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta} \} & if\ q \leq q_0 \\ S & Otherwise \end{cases} \qquad Equation\ 3$$

If q is greater than q_0, then the next node is selected based on the probability transition rule (S) given by Equation 4.

$$S = P_{ij}^{k}(t) = \begin{cases} \frac{(\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta}}{\sum_{j \notin Tabu_k i \neq 1} (\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta}} & if\ S \in Tabu_k(i) \neq 1 \\ 0 & Otherwiese \end{cases} \qquad Equation\ 4$$

Tabu k(i) contains the set of nodes to be visited by ant k positioned on the node i. The next node to be visited by the ant is determined based on the values of these functions in the equation 3 and 4. The value q vs. q_0 determines the relative importance of exploration vs. exploitation. The smaller the q_0 value, the higher the probability that the ant will make a random choice of the next node. Once the ant moves to the next node, the tour matrix is updated with the new node number. The visited city matrix for that ant at the new node's location is updated with "1," which shows that this node has already been visited. After each ant has completed one movement, the pheromone trail intensity on each edge is updated using Equation 5 called the "local pheromone update." The evaporation mechanism suppresses the unbounded buildup of pheromone intensity. The amount of evaporation is (1−ρ), where ρ is a value between zero and one. The ants continue to move, and the local pheromone is updated until all ants visit all nodes once. This sequence constitutes a valid tour. By utilizing the tour and distance matrix, the length of tour for each ant is computed. These values are sorted in ascending order, and the lowest value is stored as $\frac{1}{L_{BestIteration}}$. The next step is the global pheromone updating process using the following Equation 6:

$$\tau_{ij} = \left((1-\rho) * \tau_{ij}\right) + \rho * \left(\frac{1}{L_{BestIteration}}\right) \qquad \textit{Equation 5}$$

$$\tau_{ij} = \left((1-\rho) * \tau_{ij}\right) + \rho * \tau_0 \qquad \textit{Equation 6}$$

At this point, each ant would have successfully performed one valid tour. The last step is the stopping criterion for the algorithm. The ant walk is repeated until the iteration counter reaches the maximum permissible iteration value. At the output stage, the best tour matrix for the entire iteration is printed. Based on this, the length between any two pairs of nodes is calculated from the distance matrix and added together to give the tour's length. Computation time for the entire process is also displayed.

2.4 Action Research (AR)

In 1946, Kurt Lewin applied the research method known as AR to the fields of social management or social engineering [170]. AR has become the epitome of qualitative research [171]. In the context of lean or CI, a general definition of AR is given as, “A general term to refer to research methodologies and projects where the researcher(s) tried to directly improve the participating organization(s) and, at the same time, to generate scientific knowledge [172, 173].” Coughlan and Coghlan [174] provided an extensive review of where AR can be applied, its characteristics and an implementation cycle.

Figure 5 shows a systematic approach that aids building of the AR practice. The first step is to set the context and purpose of the research, followed by data feedback and analysis. An action is then planned for implementation, and its success factors are evaluated. At all stages of this cycle, there is monitoring that connects the steps to minimize the threats to validity and serves as empirical justifications similar to consultants providing value by the use of their expertise [174]. AR’s adoption to operations management particularly in applying Six Sigma and lean principles is gaining acceptance. Baker and Jayaraman [175] elucidated process improvement using AR and process maps. The approach helps to identify failure modes in a nuclear reactor fuel processing site that resulted in 27% reduction in inventory.

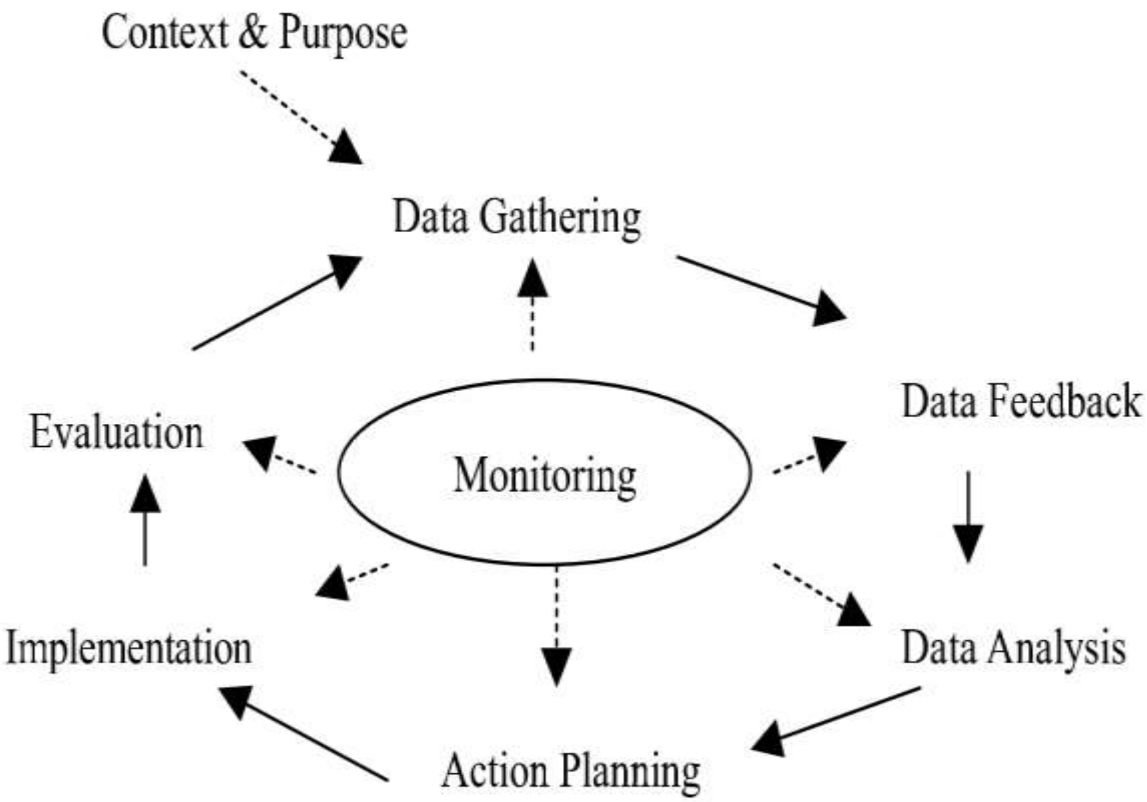


Figure 5 Action Research cycle [174]

Jang et al., [176] integrated lean construction with AR to explain a framework that resulted in doubling the productivity in a light-rail transit construction site. Khan and Tzortzopoulos [177] utilized a cyclical learning process AR to aid lean construction. Filho et al., [178] utilized AR and DMAIC method in the surgical department to improve health care that resulted in 94 % reduction in delay of surgery. Matos et al., [179] described the practical use of AR to implement lean practices in hospitals that resulted in 25 % reduction in space requirements and improved operating room. Nørgaard and Sørensen [180] provided a ten-step recommendation to implement AR in a clinical pharmacy that helped with ease of buy-in from various stakeholders. Thiollent and Toledo [181] presented a Participatory Action Research (PAR) approach to improve sanitary conditions in healthcare and to promote health through empowerment. The AR innovation cycle is argued to be a critical strategic lean implementation for leveraging organizational learning [182]. Prida and Grijalvo [183] enumerated AR approach for lean implementation in an aerospace industry that helped to identify high-cost areas.

2.5 The Gap in the Literature

In literature, the general notion of Kanban was to control inventory, particularly the WIP inventory. In operations, many approaches from the one-bin system to the multi-bin system are in use. In the software world, Kanban was used at monitor tasks and manage requirement queue for development and delivery of software systems/productions. The review indicates that there is a lack of substantial research in applying Kanban concepts as a general framework for enterprise-wide operations engineering. There is considerable overlap in understanding and definition of the term theories, model and framework in the implementation science [184]. For this research, we define a model as the simplified abstraction of problem and framework as steps to bridge and facilitate implementation of the model. Notably, the use of the cloud-based system for Kanban to reduce the TCO has been yet to explored. This research addresses the gap via the research objective, "*how can a robust cloud-based Kanban decision support system work for a service industry, particularly in scheduling and resource management?*"

The research area using metaheuristics-based scheduling algorithms and its performance in cloud-based systems is in its infancy. While various metaheuristics-based algorithms and its variations are used primarily based on the PSPL dataset, there is a lack of research in applying the ACO algorithm in the cloud for the RCSP. By combining the WACSA with the Kanban for the RCP problem, this research addresses the gap via the research objective, "*how can an evolutionary algorithm, specifically Ant Colony Optimization (ACO), augment a cloud-based Kanban decision support system?*"

AR is widely used in social engineering but is in the early stages of adoption for operations. This research contributes to the AR via the research objective "*can* the *pilot model in operations engineering be implemented in financial engineering?"*

CHAPTER THREE: METHODOLOGY

Significant portions of this dissertation have appeared in American Society Lean Six Sigma Conference, American Productivity and Quality Council ®, Robotics and Computer-Integrated Manufacturing [4, 45, 185].

This chapter describes and discusses the research methodology adopted. The first part of the chapter describes the detailed steps involved in developing the 3DS (Diagnose, Design, Deliver, and Sustain) methodology. Next section of the chapter highlights the enterprise-wide view of EAT (Estimated-Actual-Total) Kanban for operations engineering is discussed. Furthermore, it covers the development of a mathematical model of cloud-based EAT Kanban with ACO for the RCSP with project due date. Lastly, it summarizes the general steps to implement the cloud-based model.

3.1 Diagnose Design Deliver Sustain Model

Utilizing the general AR implementation model by Coughlan and Coghlan [174] this research uses AR cycles. The approach is modified to accommodate the type, and the extent of data gathering, the data quality, the data analysis, and the data visualization needs of the organizational context. Figure 6 encompasses four high-level stages of the 3DS methodology. At the “diagnose” stage, the team gathers information on the current problem or opportunity and tries to determine how to make changes that will add value to the business or customer. In the “design” stage, the project lead captures the process mapping method and metrics needed to monitor for successful implementation. A process mapping methodology in a collaborative workshop is used to: (1) assess the current state of the processes, (2) create and agree on a TOM process map that aids implementation, and (3) create a plan that includes a list of action items with owners and due dates. The focus of the “deliver” stage is in implementing the project and communicating changes. For example, the business team would apply the new processes by executing the action items that result from the process mapping workshop. To ensure project completion, during the “sustain” stage the team monitors successful implementation of the action items. At this point, the team works with the sponsors and the project managers to track implementation, the benefits, and return on investment of the new processes. In the 3DS methodology, there are three impact areas: (1) project, (2) process and tools, (3) and people. For example, the design phase directly impacts the process and tools used by the customer, and the delivery phase affects the people. Three principal capability owners of the 3DS methodology at various stages of the method are (1) project management, (2) process engineering, and (3) change management. For example, change management is accountable for the “deliver” and “sustain” stages.

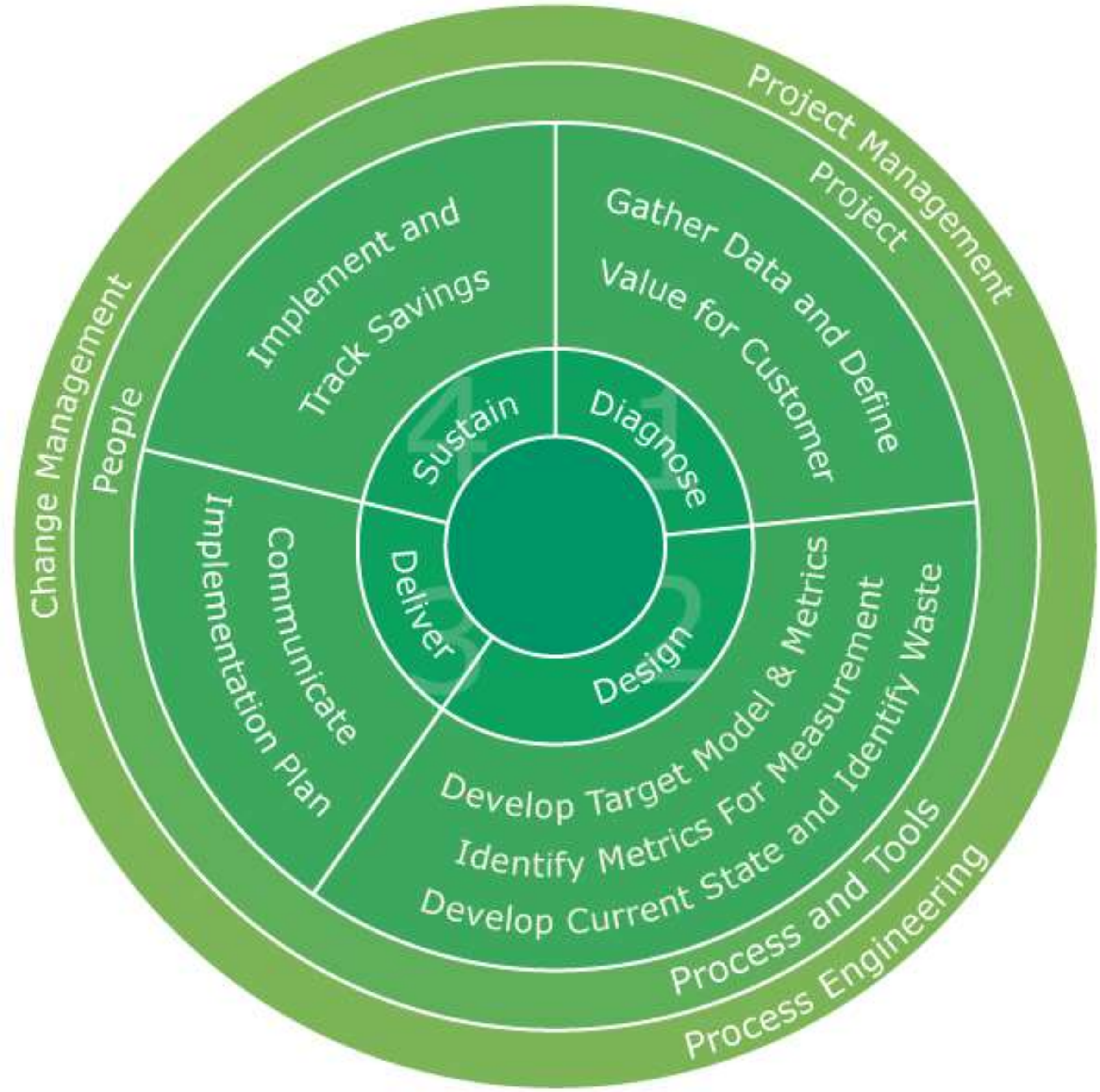


Figure 6 3DS Model [185]

3.2 Estimated-Actual-Total Kanban Model

For a given period under consideration, the EAT Kanban model provides a visual display of activity, product or service status. In this model, there are three parameters: (1) Estimated → defined as the value known ahead of time for that instance, (2) Actual → defined as the value known at the instance of time, and (3) Total → defined as the value at the end of the time. The sequence of how they line up constitutes different scenarios.

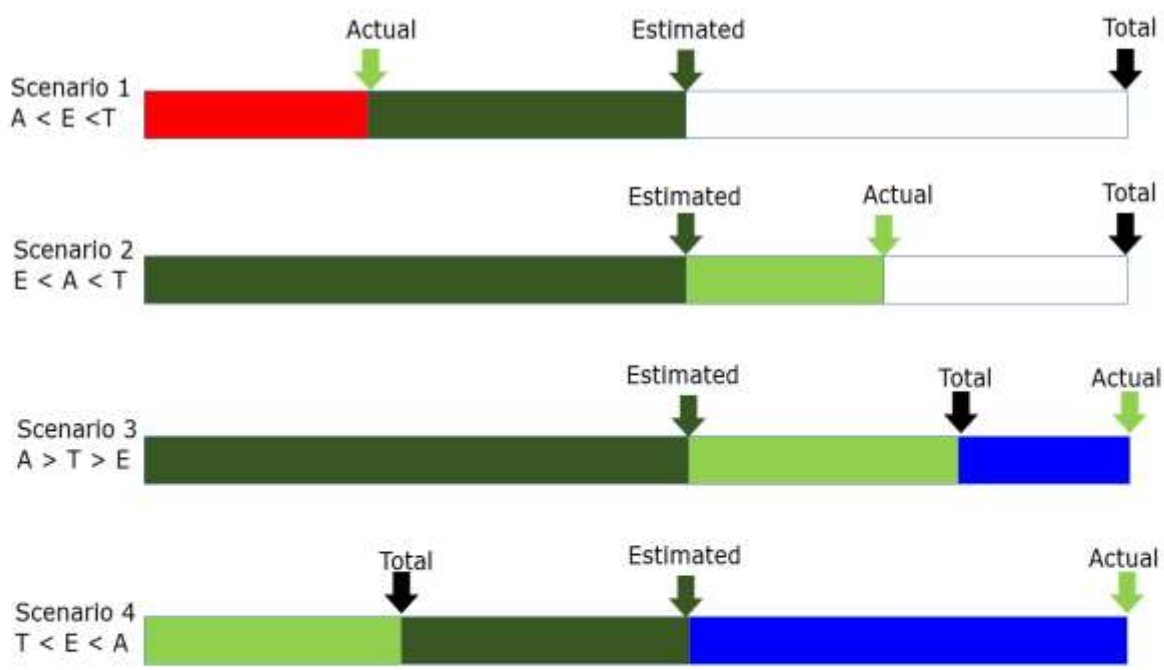


Figure 7 EAT Kanban Model

Figure 7 shows the four different scenarios of the EAT Kanban model. Scenario 1, occurs when the "Estimated" is higher than the "Actual" but is less than the "Total." In this case, the portion of the bar up to the "Actual" is color coded "red," and the part of the bar from "Actual" to "Estimated" is color coded "dark green." The "red" and "dark green" signifies that the activity or service is lagging the estimate and needs attention. Scenario 2, occurs when the "Estimated" is higher than the "Actual" but is less than the "Total." In this case, the portion of the bar up to "Estimated" is color coded "dark green," and the part of the bar from "Estimated" to "Actual" is "light green." The "dark green" and "light green" combination infer that the process or service is performing ahead of the rate at which it was "Estimated" to perform. Scenario 3, occurs when the "Estimated" is less than the "Total" which is less than the "Actual." In this case, the portion of the bar up to "Estimated" is color coded "dark green," portion up to "Total" is color coded "light green" and the portion up to "Actual" is color coded "blue." The combination of "dark green," "light green" and "blue" colored bar shows that the process or service has one of the deadly sins of eight wastes, "overproduction," represented in the "blue." Scenario 4 occurs when the "Estimated" is more than the "Total" but less than the "Actual." In this case, the portion up to "Total" is color coded "light green," the portion up to "Estimated" is color coded "dark green," and the portion up to "Actual" is color coded "blue." The "light green," "dark green" and "blue" color case shows over-production but also highlights the forecast errors. This generic model can be used to monitor any enterprise-wide initiatives that have volumetric and time-bound data. One of the principal advantages of this type of representation is that it helps to adapt various metrics, for instance, volume, cost, and count, not only by products or services but also across the whole enterprise.

The other possible scenarios for EAT model are: scenario 5 → T < A < E, where the "Total" is less than the "Actual" which is less than "Estimated", is a variation of scenario 4 and will follow it color coding of scenario 4 where the operations are "overproducing" than the scheduled. scenario 6 → E < T < A will follow scenario 3. Other variations where the "less than" becomes "equal to" will adopt the nearest applicable scenario. For example, scenario 7 T = A < E will follow scenario 4 T < E < A and scenario 8 A < T = E will follow scenario 1 A < E < T.

3.3 Ant Colony Optimization for Resource Constrained Scheduling Problem

As described in section 2.3 of the literature review chapter, in operations engineering, RCSP is one of the classic problem faced by the operations managers. Especially in an open job where there is no restriction on the order in which the job is processed on the machine. The objective is to minimize the makespan defined as the total time the order stays in the operations from the time it is released to operations until is it shipped out the door. The time outside the operations, such as transit time to the customer, is not considered. The modified RCSP problem for SOM can be formally described as follows: There is a finite set of job orders $J = (1,2,3, \dots . N)$, each job has a defined subset of activities that are to be performed using a pre-defined sequence on a finite set of machines $L = (1,2,3, \dots . M)$. Some of the activities completion times vary based on the number of human resources utilized. The objective is to find a schedule of minimum duration to complete the job and without violating the following constraints:

1. The preemption of tasks is not allowed. It means other available machines cannot finish any started tasks.
2. The setup time is independent of the operation time as the setup tasks can be done as soon as a machine is available.
3. Each machine can process only one task at a time.
4. All the machines are always available during the scheduled period.
5. All the jobs are released to the operations based on the high-level start dates dictated by the ERP systems which are determined by customer’s due dates requirements.

The RCSP for this research is modeled from the adaptation of open shop scheduling problem from Ciro et al., [186].

$J = \{1,2,3, \dots . N\}$, a finite set of jobs (work orders) that has a finite set of activities

$L = \{1,2,3, \dots . M\}$, a finite set of machines

3.3.1 Decision Making Variables

C_i → Completion time of job $i = \min_{m \in L} C_{im}$

3.3.2 Binary Variables

$$X_{ijm} = \begin{cases} 1 \text{ if job i proceeds job j on machine m} \\ 0 \text{ Otherwise} \end{cases}$$

(i, j) → Job Index $i, j = \{1,2,3, \dots . N\}$

m, m' → Machine index, $m, m' = \{1,2,3, \dots . M\}$

P_{im} → Processing time job (i) on machine (m)

D_i → Due date of job (i)

r_i→ $\textit{Release date of job i}$

C_i → Completion time of job $i = \max_{m \in L} C_{im}$

G → Large number

3.3.3 Objective Function

To minimize the Total Completion Time C_i of the job i

3.3.4 Problem Formulation

$$minimize = \sum_{i=1}^{N} (C_i - r_i)$$ Equation 7

Where

$$C_i \geq C_{im} \; \forall \, i \in J; \; \forall \, m \in L$$ Equation 8

$$C_{im} - G(1 - X_{ijm}) \leq C_{jm} - S_{jm} - P_{jm} \; \forall \, i,j \in J, i \neq j; \forall \, m \in L$$ Equation 9

$$C_{im} - G(1 - Z_{imm'}) \leq C_{im'} - P_{im'} \; \forall \, i \in J, \forall \, m, m' \in L, m = m'$$ Equation 10

$$X_{ijm} + X_{jim} = 1 \; \forall \, i,j \in J, i \neq j; \forall \, m \in L$$ Equation 11

$$Z_{imm'} + Z_{im'm} = 1 \; \forall \, i \in J, \forall \, m, m' \in L, m \neq m'$$ Equation 12

$$C_{im} - P_{im} \geq r_i \; \forall \, i \in J; \forall \, m \in L$$ Equation 13

$$X_{ijm}, Z_{imm'}, \in \{0,1\} \; \forall \, i,j \in J; \forall \, m, m' \in L$$ Equation 14

Equation 7, infers to the minimization of the flow time where the completion time is greater than the release date and validates a positive flow time. Equation 8 defines the completion time. Equation 9 defines the setup time constraints indicating the next job cannot be processed until the setup is complete. Equation 10 indicates starting time for processing operation $O_{im'}$ is greater or equal to the completion time of the operation O_{im}. Equation 11 and Equation 12 refer to the sequence of any operations pair in same machime m and any two operations of job i . Equation 13 establishes the release date constraint and Equation 14 denotes the binary decision variables.

3.4 Cloud-based Kanban Decision Support System Framework

Figure 8 provides activities involved in implementing a CKDSS. The first step is to identify the organization’s needs for the cloud services and its acceptable requirements, for example, speed to value, the total cost of ownership, and quality of data. The requirement gathering helps to identify a service provider and to set SLA. The initial system is configured based on the organization’s information technology security needs. The next step is to determine the enterprise parameters to be tracked. For example, in operations, it may be expedient to track the volume of products at each activity of the production. In finance, it may be advantageous to track the cost of each activity, and in the quality, it may be critical to track the quality issues. The frequency at which the data will be tracked and various production parameters should be then established, for instance, cost per hour for machine production rates. The inputs may come from different sources, and they are formatted into a structured database. The organization will have some high-level data from its ERP/planning systems. Any additional data inputs are developed utilizing the ERP/planning system and formatted to get the "Estimated," "Actual," and "Total" values for the EAT Kanban model. Based on the organization's needs, using metaheuristics, a first-cut schedule is developed. An EAT Kanban model is generated depending on the sensibleness of the output formats. At this stage, the practitioner performs a practicality test, and any changes that simplify the algorithm are made, resulting in a DSS. Finally, the reporting features are incorporated and force multipliers and gaps are identified to make an informed decision for enhancing the deployment.

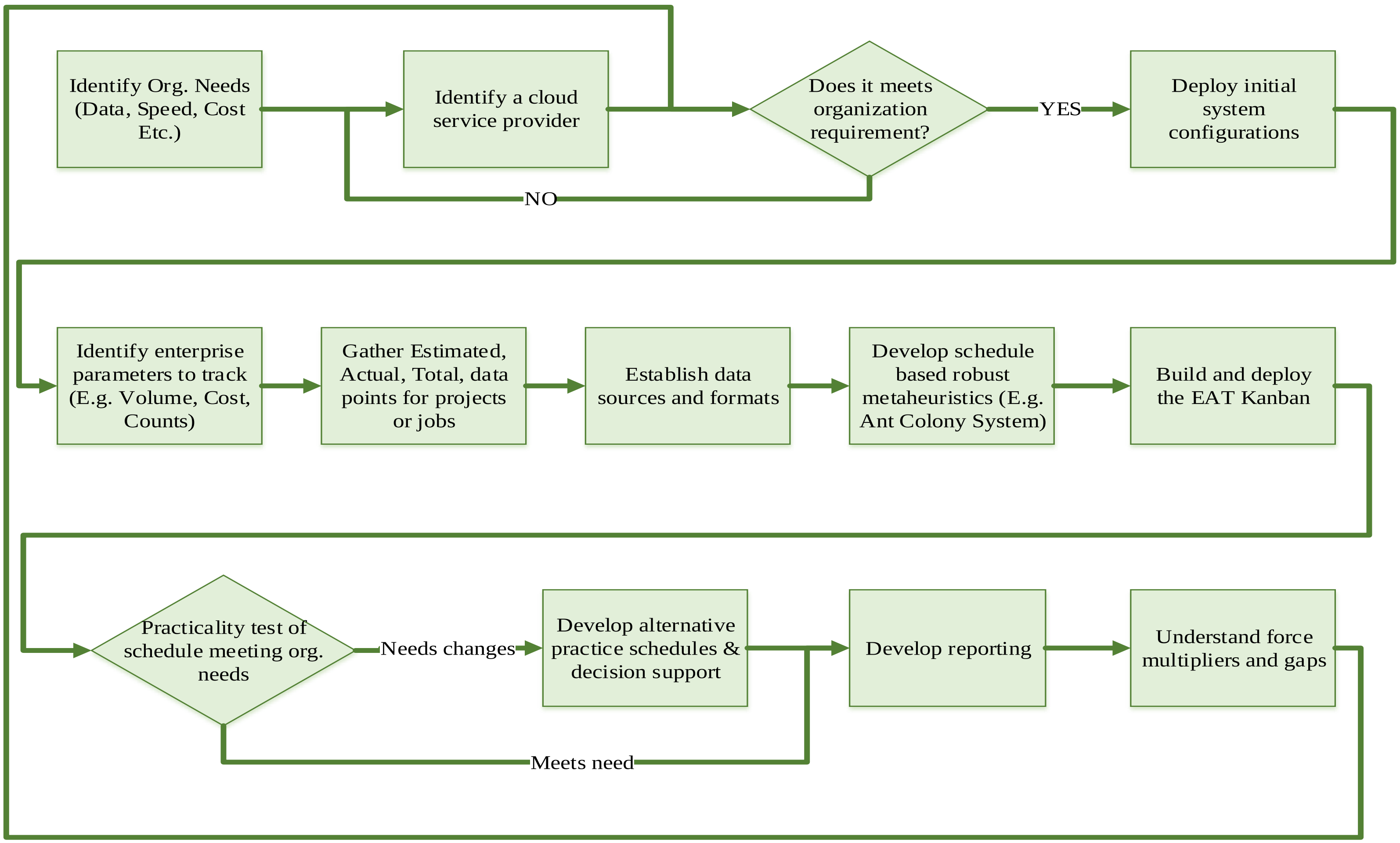


Figure 8 Cloud-based Kanban Decision Support System

CHAPTER FOUR: WEB-BASED KANBAN IMPLEMENTATION

Significant portions of this dissertation have appeared in American Society Lean Six Sigma Conference, Flexible Automation and Intelligent Manufacturing Conference, and Robotics and Computer-Integrated Manufacturing[4, 45, 187].

This chapter describes the two variations of web-based practical application of the EAT Kanban DSS: (1) direct mail letter shop, and (2) educational service provider. Each sub-section covers, business overview, AR for implementation, web-based DSS deployment framework and features.

4.1 Case 1: Overview - Direct Mail Marketing Letter Shop

Scheduling in a letter shop is a complex process due to the volume and high variety of products that must be fulfilled within a client specified due date. Figure 9 shows a high-level overview of the letter shop process. There are various processes, communication and documentation steps involved in executing a "typical" direct mail letter shop job. The foundation process is varied based on the individual requirements of the clients. Within the process are numerous points where the dedicated account team customizes specifications, proofing, quality controls, and reporting to match the unique needs of each client. In this way, the organization works in locked step with each customer while avoiding the risks of countering proven machine configurations and process controls. A project starts after a successful bid to deliver services. The client sends job instruction to the CSR and the raw material to the warehouse. Typically, a large campaign there are various "drop dates" defined as the date by which it should be ready for transportation so that it can meet an "in-house" date. The scheduling team manually develops high-level schedules of all the jobs based on plant production capacity, labor limits, and drop dates. It allows the CS team to create the WO. The customer address data file is clustered into drops and is optimized based on various zip codes by a process called “pre-sorting.” Pre-sorting helps to split the production into packs, enables the production team to prepare the WO by using various machines configurations and constraints. The manufacturing process has four stages. In stage 1, using the address file and blank paper rolls, a high-speed printer prints personalized materials, such as statements and letters. In stage 2, depending on the length of printed personalized material, sheets are cut from these rolls and folded. In stage 3, personalized materials, along with other generic materials, are assembled and inserted into an envelope by a process called “inserting.” In some cases, there is an additional step, printing the address to match the personalized material. Finally, in stage 4, with the actual production count, a mailing statement is created to ship the materials via USPS. These steps can be performed by one single machine or by four different machines, depending on machine capability. Furthermore, the number of people used at these machines can vary the machine configuration. At various production stages, the quality team audits the WO to make sure that the completed job will meet client specifications. The warehouse ships the final product with the final mailing statement through the optimized distribution channel. Due to the economics of scale on prints, the number of generic materials received per project can fluctuate. Most of the time, the quantity of generic materials provided will exceed the required quantity due to various factors, such as the production volume, the setup cost, the number of colors, and the client project/promotion campaign schedule. The scheduling team evaluates about 60 jobs daily with four to seven activities across five to ten different client campaigns. It is an intense and time-consuming process to coordinate resources for all jobs.

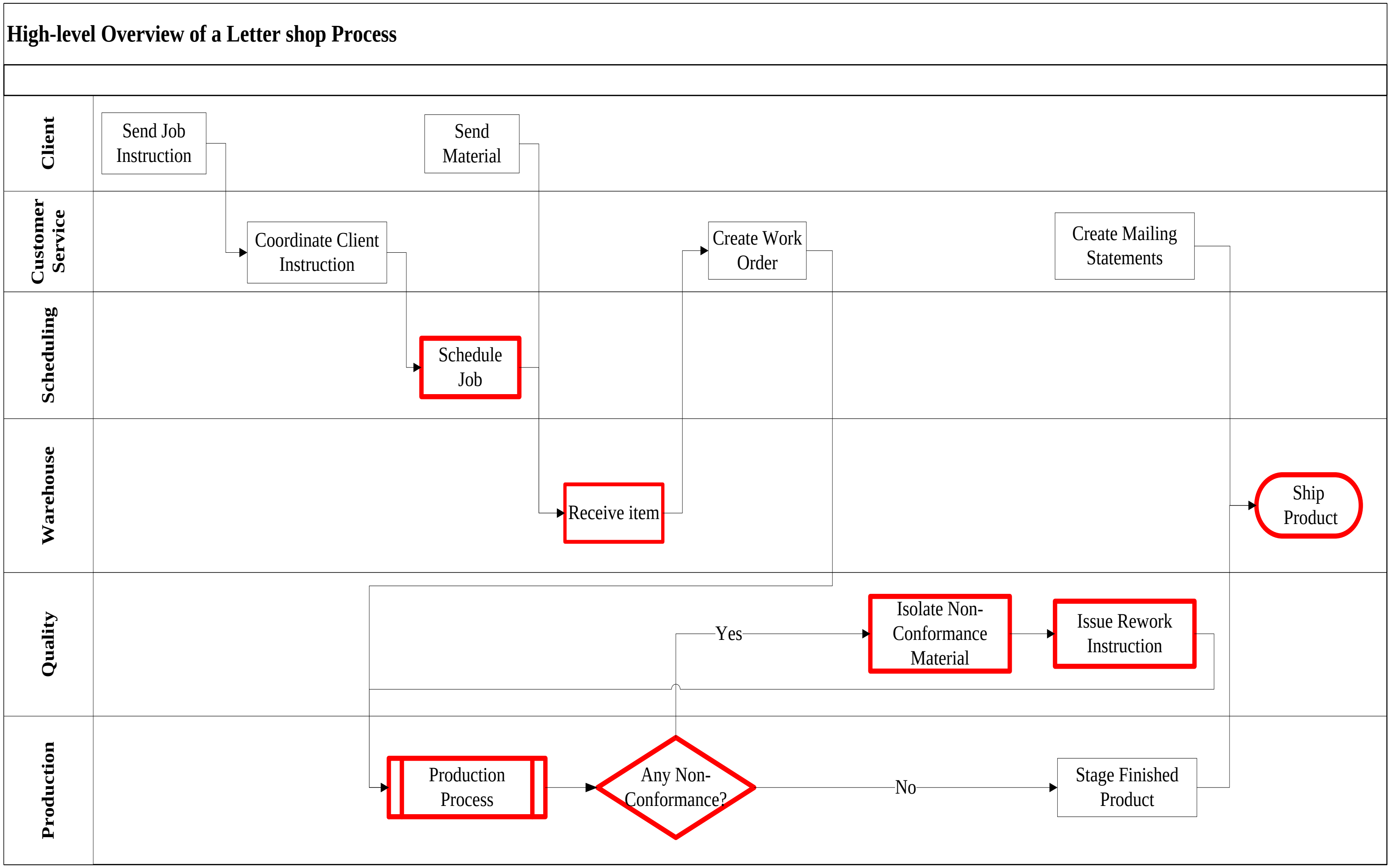


Figure 9 High-level Overview of Letter Shop Process

A vital component of the letter shop's CI program is CI maturity levels that were developed by the AR practitioner as a roadmap to world-class manufacturing. Refer to Figure 10 for the various CI maturity levels. The CI process is tightly integrated with all processes of the organization. The CI focuses on productivity and technological advances that allow the letter shop to provide the reliability required by its clients while maintaining consistent and competitive pricing year to year. CIP encompasses elements of ISO, 5S, and Six Sigma. The letter shop's ISO-based process centers on an examination of standard operating procedures, identifying those factors critical to quality, and then calculating standards. Every production and support process has been subjected to workflow and procedures analysis by a cross-functional team of experts.

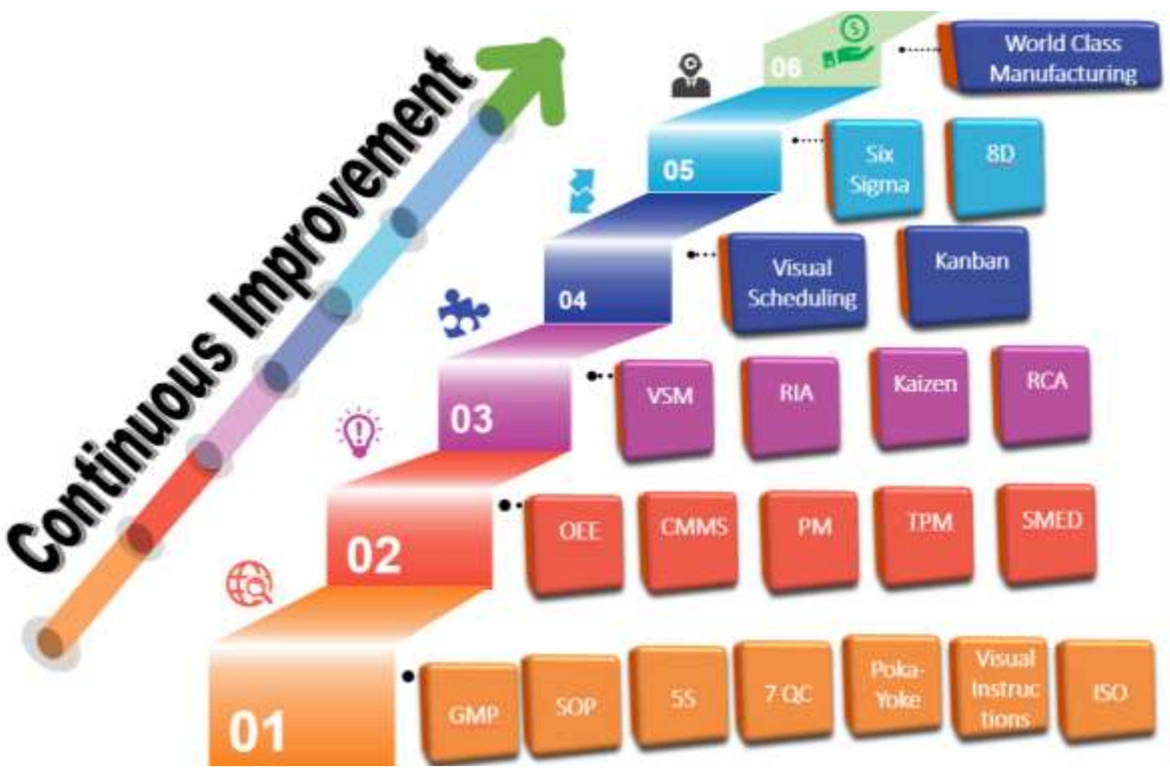


Figure 10 Continuous Improvement Maturity Level for Letter Shop

4.1.1 Case 1: Action Research for Letter Shop Implementation

Utilizing the principles of AR, Figure 11 represents the AR cycles adopted for developing and implementing a web-based Kanban. The first step of the AR cycle is to understand the organization's strategic purpose. After obtaining management approval, the practitioner understands the needs and gaps in the current processes. In the second AR cycle, a CI survey is administered to determine the culture and target area of implementation. The survey results showed that the nervous system of the operations was scheduling. Management realized that by strengthening scheduling, they could increase their competitive advantage. In the third cycle, after alignment of three-year strategies, a pilot deployment with customer service and the operations department was performed. Reflecting on the lessons learned the fourth AR cycle, a decision was made by management to strengthen the quality department. The pilot was enhanced to incorporate the quality module. Continuing the AR cycles, the organization implemented the system in other departments such as shipping, human resources, and finance.

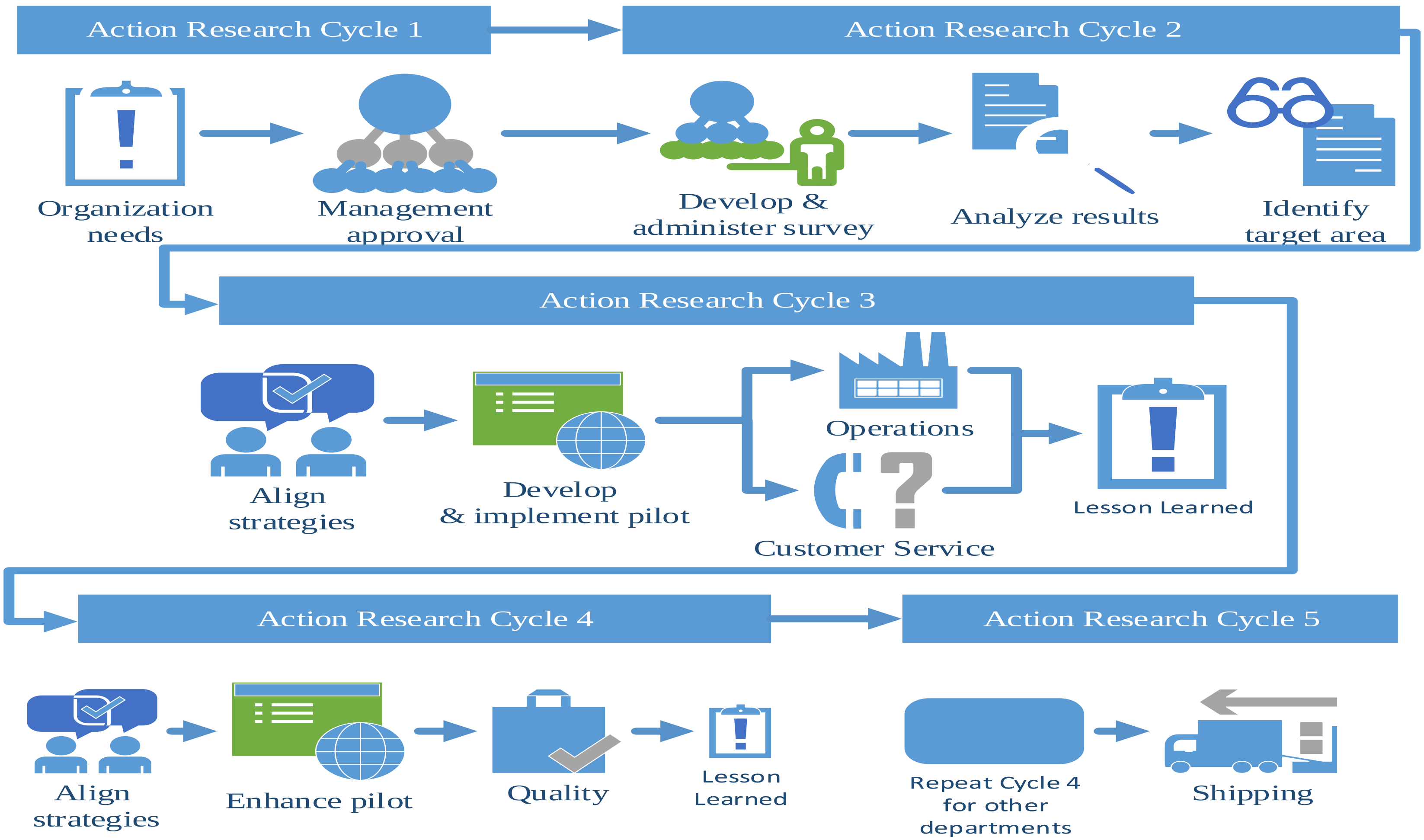


Figure 11 Action Research Approach for Letter Shop Implementation

4.1.1.1 Baseline Survey

As part of AR cycle 2 (shown in Figure 11), a pilot study via a 25-question survey was used to establish baseline CI culture. The survey was developed using the five-point Likert scale with (0-representing no need for CI and 5- representing the high need for CI). The survey was made available in the English, Spanish and Vietnamese languages. Appendix A: Continuous Improvement Survey presents the full list of questions. Employees received the CI survey along with their paychecks. The study addressed eight categories that were important to the organization, for instance, training, CI, quality, performance, finance, communication, troubleshooting, and standard work. Four CI focused questions in the survey were: (1) Is continuous improvement of the process is needed to ensure highest customer satisfaction and meet our mail dates, (2) awarness of lean manufacturing tools and concepts for example 5S, Setup Reduction, Standard Work, Value Stream Mapping, and Just-in-Time, (3) improvement of the current OEE / 5S, and other improvement activities or process, and (4) mindfulness of lean manufacturing tools and concepts (for example, 5S, Setup Reduction, Standard Work, VSM,JIT).

A total of 188 surveys responses were received. The participation represented about 37.60 % of the total employees. Figure 12 shows the summary, indicating the consensus among all levels of organization for the need of CI to satisfy the customer requirements. The minuscule difference (0.6) between the various job position indicates that the total workforce is willing to undertake the CI journey, a very positive and favorable factor for implementing new CI initiatives. The survey also highlighted the need to strengthen scheduling and resource management practices for the organization. The mitigation strategies were addressed in AR cycle 3 to develop a DSS.

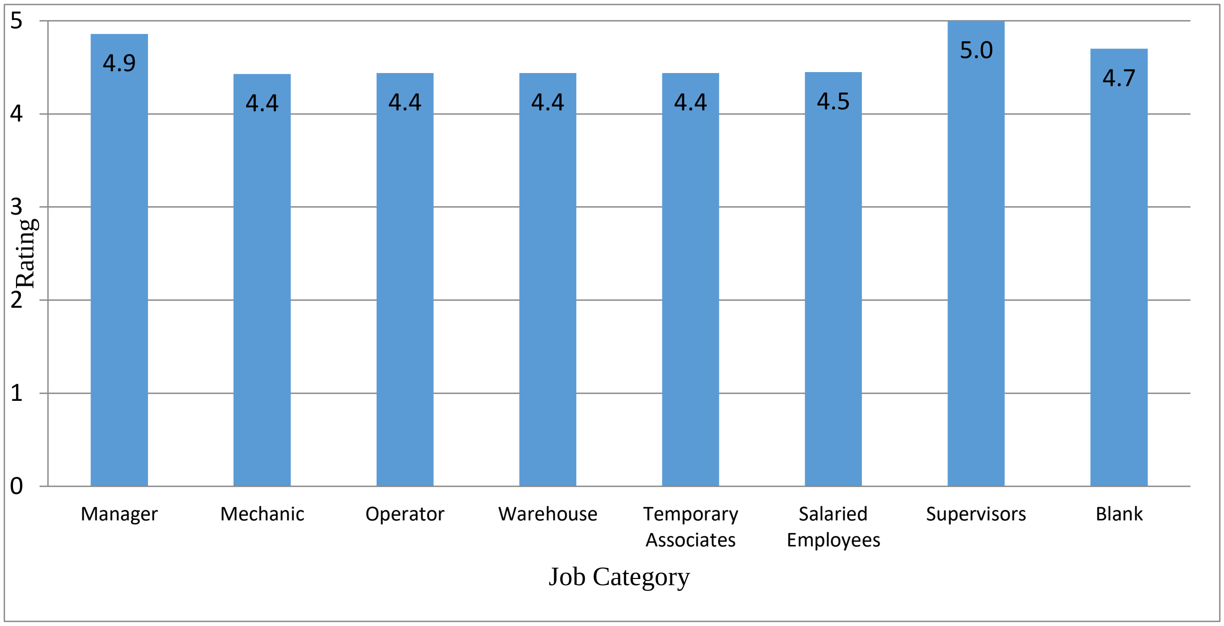


Figure 12 Continuous Improvement Survey Results by Job Classification

4.1.2 Case 1: Web-based Kanban Decision Support System (WKDSS)

Figure 13 shows the integrated model of the web-based DSS. The model has six distinct modules that are interconnected to deliver the WKDSS. The rectangle boxes indicate process flow that are tagged with individual numbers such as A010. The "red" thunderbolt line depict the electronic flow. Underpinned by an EAT Kanban model, these features of the DSS helped the operations to be effective and efficient in managing the day to day enterprise functions.

4.1.2.1 Production Module

In this module, the actual production quantities are captured. The FLS enters the production data daily based on the project due date, and by a number of tasks to be performed. The CSR enters all job-related comments into the system. The comments help the production team to see the status and execute the WO as per the schedule.

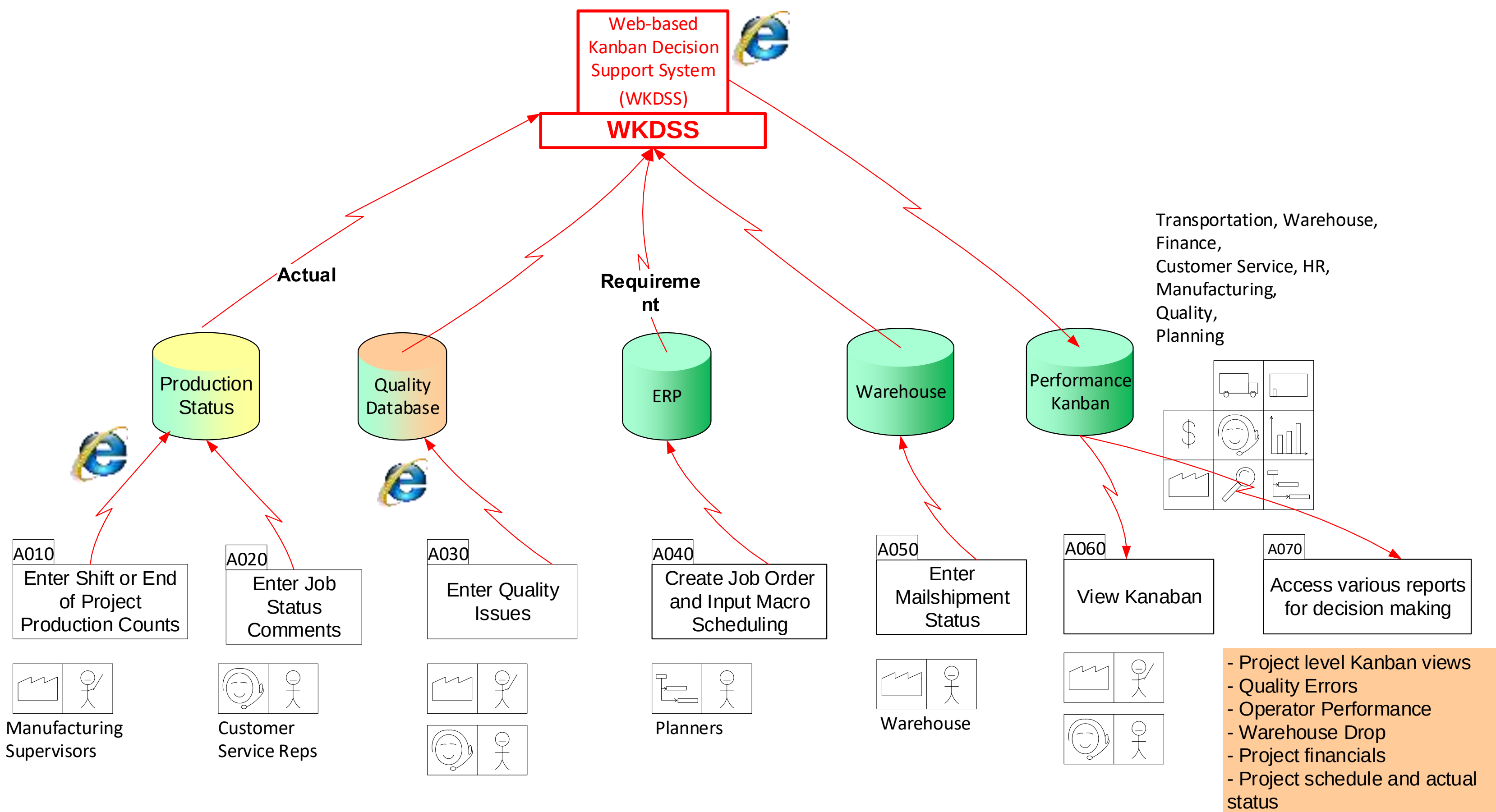


Figure 13 Web-based Kanban Decision Support System Framework

4.1.2.2 Resource Planning Module

This module interfaces with the existing ERP and obtains the "Estimated" quantities. The scheduling team enters quantities to be produced and sequence of activities to be performed to complete the project. The ERP also holds all the standard machine rates, cost per hour, customer master data, and pricing information of the job.

4.1.2.3 Quality Module

This module houses the error reporting function that supports the CAPA for the ISO 9000:2001 QMS. It is used during the quality audit performed in the production process. The information about the job and the relevant production metrics are pulled from the first two modules and allows the CSR and the FLS to enter any first pass setup or physical quality issues. It acts as the trigger for the quality team to follow up and resolve the issues. Periodic audits are conducted, and the non-conforming finished products are isolated. The error that caused the non-conformance is identified and entered. The quality team routinely checks this report and take necessary quality assurance activities.

4.1.2.4 Warehouse-Shipping Module

This module utilizes the production due date and provides a data-entry interface to the warehouse operator on the various mail drops. As the production is completed, the status of each pallet shipped is entered. It enables the production and scheduling team to manage their capacity and machine schedules.

4.1.2.5 Project Performance Kanban

A key module of the DSS is the project performance Kanban that caters to a broader audience and enables departments to be effective and efficient in executing their tasks. One of the focuses of this research was to reduce scheduling complexity and improve the quality assurance of the process. The web-based Kanban is a key feature of this module, it sorts Kanban by job and then by FMD (a critical customer requirement,) and constitutes the schedule adherence metrics. The Kanban provides an actual view of project progress and visually depicts the status. The capabilities of the Kanban to drill down to a task level provides options for the production and scheduling team to make informed decisions. Each activity is represented as a "*Kanban*."

4.1.2.6 Reporting Module

This module has eight different reports: (1) production performance → has various reports that gauge the efficiency of the process and machines, (2) scheduling → has Kanban with choice of decisions either increasing the number of machines that can be run in parallel or increasing number of people on a machine for that activity, (3) open capacity → that informs the sales team how much more they can bid for open jobs from the market, and plan for weekly temporary worker needs, (4) customer service → provides a job-drop calendar and comments about jobs for communication, (5) warehouse → receiving material entry and daily efficiency, (6) quality → quality error reports and overall quality performance, (7) human resources → reports employee overall performance efficiency, and (8) metrics → financial performance of job for various clients and invoice status.

4.1.3 Case 1: Deployment of WKDSS

Figure 14 shows the main screen of the web-based system deployed for an authorized user of the organization network. The users can log into the system using a web browser and the network password. The system has a second level of user access to allow visibility based on their permissions to access various modules. The data for the Kanban comes from two sources: (a) production counts entered directly into the Kanban database by FLS, and (b) job and production information from the ERP system. The links on the screen are displayed based on the user security roles. For example, the FLS may have access to production history, but the overall job summary will only be available to the customer service representative and top management. Appendix B: Case 1: Web-based Kanban features provide various screens of the system.

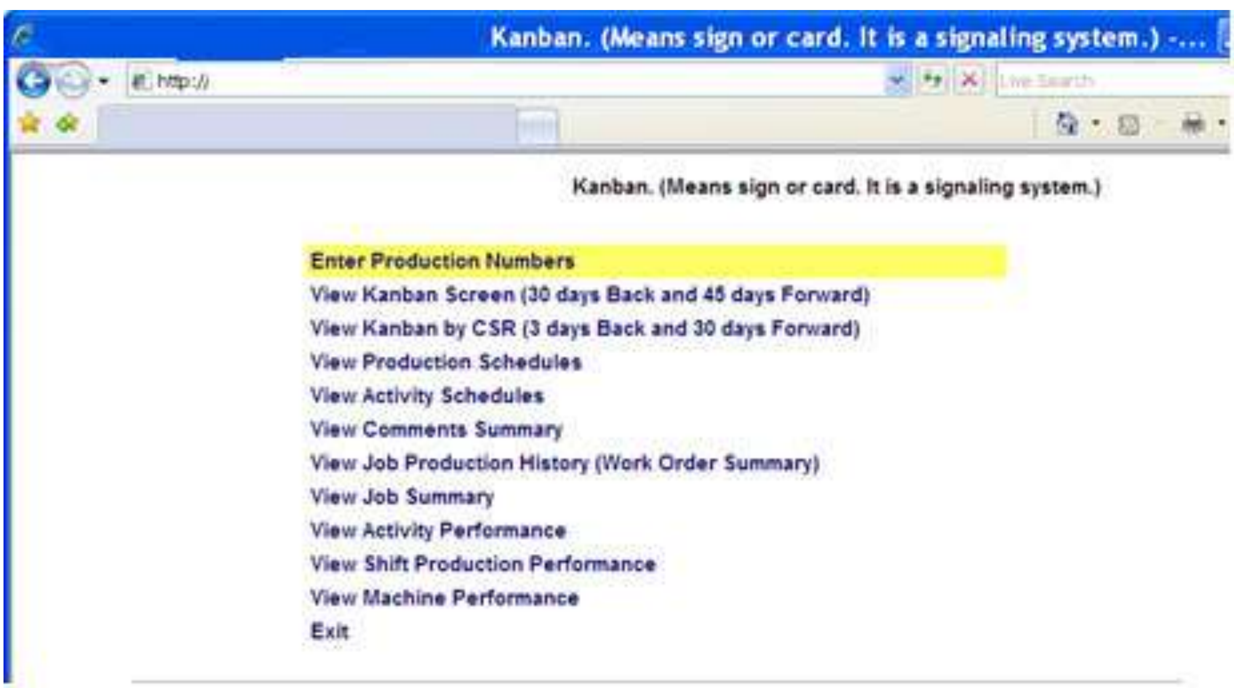


Figure 14 WKDSS - Main Screen

4.1.3.1 Gather Production Data

As shown in Figure 15, FLS enters the production count by selecting various drop-down menus on the production entry screen. First, the selection is the “Date” and “Shift” from the corresponding drop-down menu. The default value of the “Date” and “Shift” drop-down is automatically set based on the date and time of the server. The next selection is the group lead number from the “GrpLd” drop-down menu. Once a “GrpLd” is selected the system automatically populates the “Area” drop-down menu and only the machine number from the “Machine” drop-down is entered. Next, the operator employee number is entered in the “Operator” text box. A job number is selected from the “Job #” drop-down menu. For a job number selected, all the activity codes scheduled for the job number would be automatically populated in the “Act Code” drop-down menu. In some instances, operations might run different activities due to changes in machine configuration and machine availability, and they work with the scheduling department to add the activity information. Furthermore, the production counts and spoilage (bad products) are entered in the respective “Amount” and “Spoilage” text box. If there is not production spoilage, this text box entry is skipped. A pop-up window confirms that there was no spoilage entered. Next, the operator hours used to perform the activity are entered in increments of ten minutes in the “Hours” drop-down menu. Then, job characteristics (for instance, the package number, drop number, and the number of operators used) are selected from the “Pkg #,” “Drop #,” and “#Opers” drop-down menus. Finally, for precise calculation of hours, the operator's role “L” for lead and “A” for assist is selected from the “L/A” drop-down menu. Upon successful entry, the activity production SRPH will be calculated based on the ratio of amount/hours and the data will be displayed for editing.

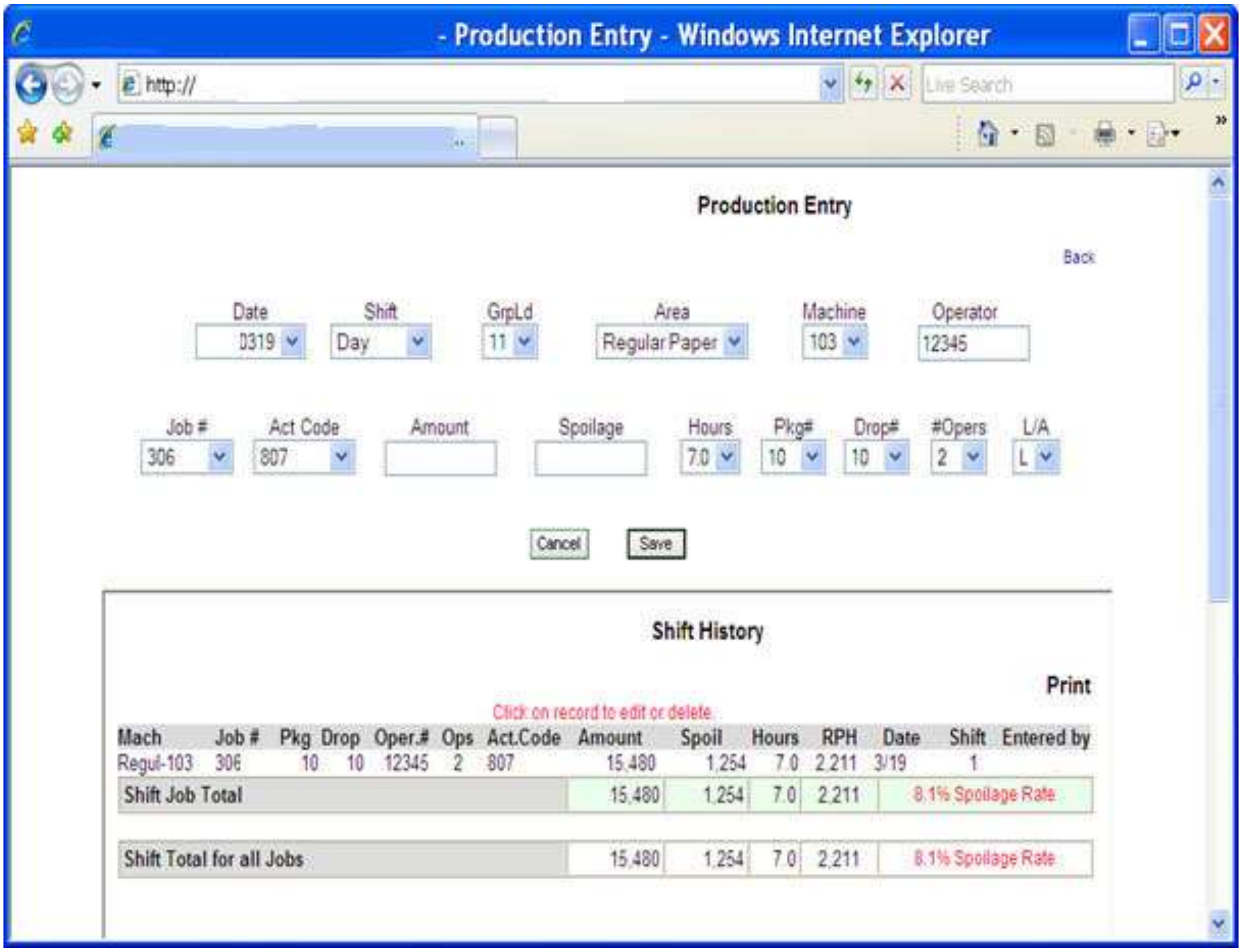
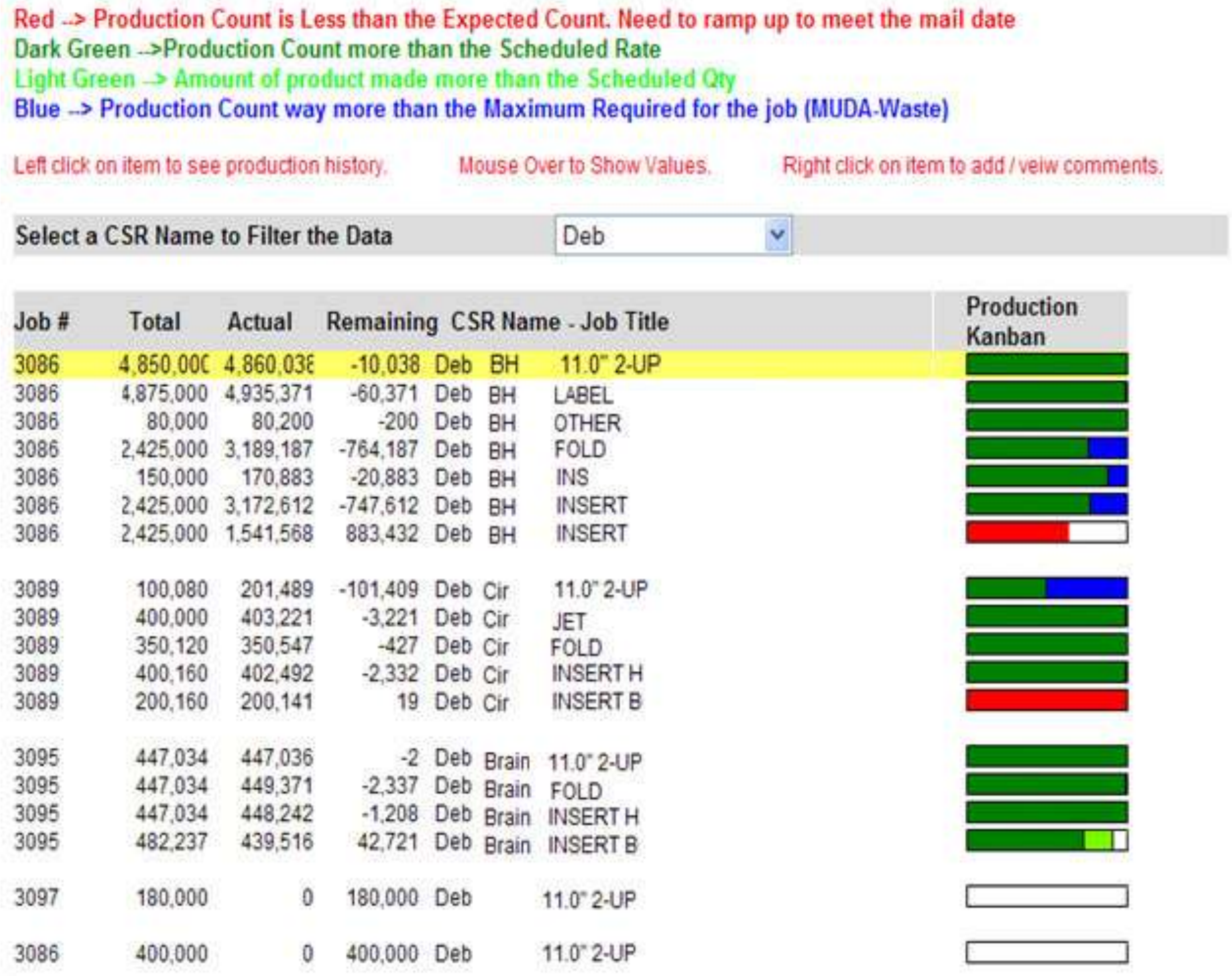


Figure 15 WKDSS - Production Entry Completed Screen

4.1.3.2 Web-based Kanban

The Kanban had default enterprise makespan dates set to 30 Days Back and 45 Days Forward. It indicates the production can start as early as 30 days of the first mailing day and a forecast of 45 days ahead. Figure 16 shows a view of the Kanban screen. The different colors of the Kanban represents the following: “Red” → production count is less than the expected count and needs to ramp up to meet the mail date, “Dark Green” → total production count is more than the expected completion quantity indicating that overall process is ahead than scheduled, Light “Green” → production rate is more than the planned rate indicating higher process efficiency, and "Blue" → total production count is more than the job quantity indicating Muda, "Over Production."

In Figure 16, job 3086 and job 3089 have a task "Insert" flagged with red because the jobs are running behind by the expected end counts. In contrast, the task "Insert B" for job 3095 is making significant progress exceeding the standard run rate, and hence, has dark green and light green fill. Job 3089 has one task (11.0" 2-UP) that has a lot of Muda (about 101,409 pieces overproduced than requirement) while other tasks are lagging the anticipated due date. During the daily production meeting, the CSR, production, quality, and warehouse management team review this information to make necessary management decisions. The FLS can review Kanban on an hourly basis. The drill-down capability helps to make critical alternative production options, such as to forecast project completion based on the current run and to calculate a number of machines, shifts, operators needed for on-time completion. Figure 17 shows another view of the Kanban based on FMD. Typically, the due date is broken down into a series of mini fulfillments referred to FMD. It helps the operations to prioritize the job that needs attention to avoid being late on the job order.



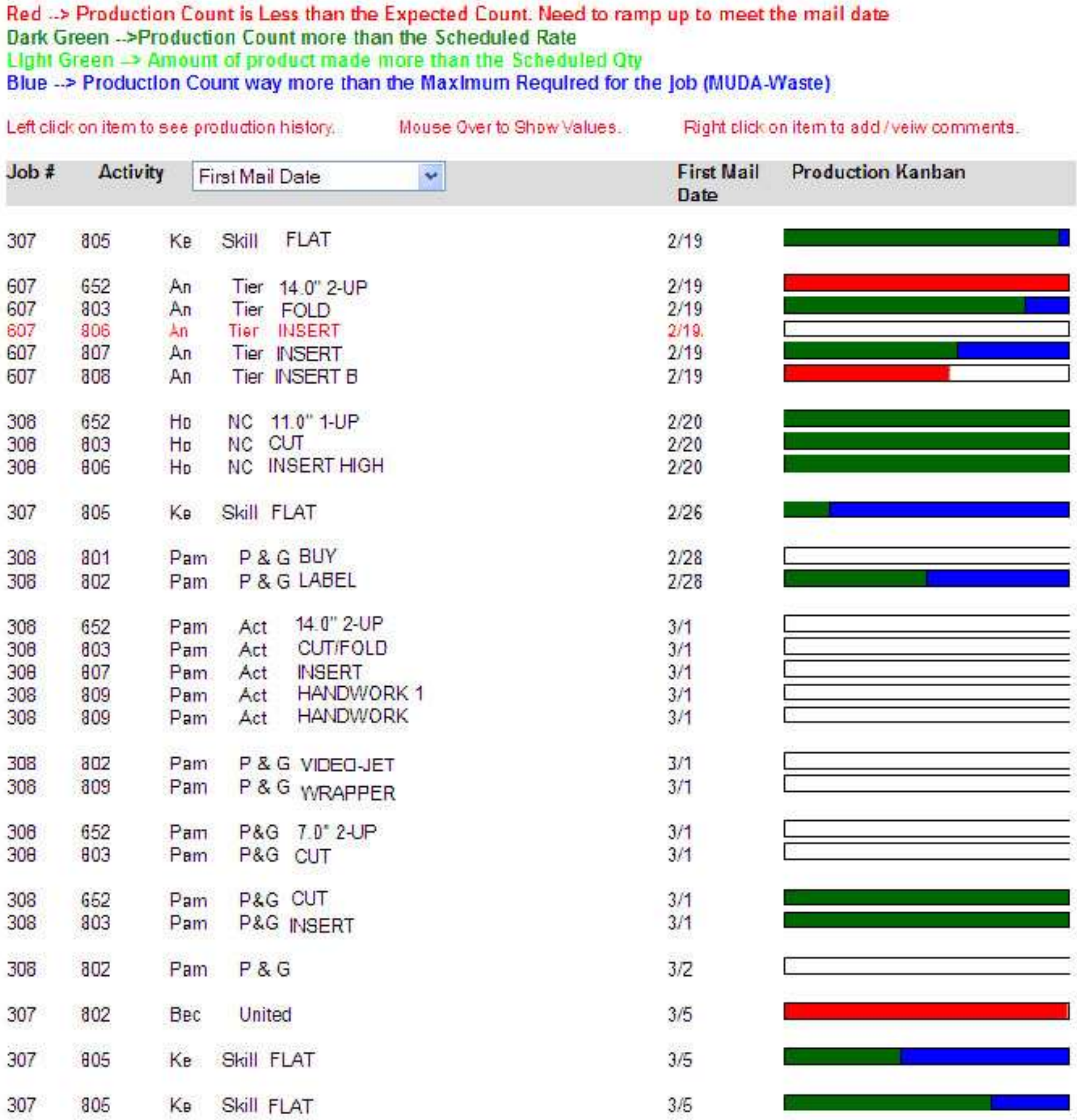
Red --> Production Count is Less than the Expected Count. Need to ramp up to meet the mail date
Dark Green -->Production Count more than the Scheduled Rate
Light Green --> Amount of product made more than the Scheduled Qty
Blue --> Production Count way more than the Maximum Required for the job (MUDA-Waste)

Left click on item to see production history. Mouse Over to Show Values. Right click on item to add / veiw comments.

Select a CSR Name to Filter the Data: Deb

Job #	Total	Actual	Remaining	CSR Name		Job Title	Production Kanban
3086	4,850,00C	4,860,03E	-10,038	Deb	BH	11.0" 2-UP	
3086	4,875,000	4,935,371	-60,371	Deb	BH	LABEL	
3086	80,000	80,200	-200	Deb	BH	OTHER	
3086	2,425,000	3,189,187	-764,187	Deb	BH	FOLD	
3086	150,000	170,883	-20,883	Deb	BH	INS	
3086	2,425,000	3,172,612	-747,612	Deb	BH	INSERT	
3086	2,425,000	1,541,568	883,432	Deb	BH	INSERT	
3089	100,080	201,489	-101,409	Deb	Cir	11.0" 2-UP	
3089	400,000	403,221	-3,221	Deb	Cir	JET	
3089	350,120	350,547	-427	Deb	Cir	FOLD	
3089	400,160	402,492	-2,332	Deb	Cir	INSERT H	
3089	200,160	200,141	19	Deb	Cir	INSERT B	
3095	447,034	447,036	-2	Deb	Brain	11.0" 2-UP	
3095	447,034	449,371	-2,337	Deb	Brain	FOLD	
3095	447,034	448,242	-1,208	Deb	Brain	INSERT H	
3095	482,237	439,516	42,721	Deb	Brain	INSERT B	
3097	180,000	0	180,000	Deb		11.0" 2-UP	
3086	400,000	0	400,000	Deb		11.0" 2-UP	

Figure 16 WKDSS - Kanban by CSR



Job #	Activity	First Mail Date			First Mail Date	Production Kanban
307	805	Ke	Skill	FLAT	2/19	
607	652	An	Tier	14.0" 2-UP	2/19	
607	803	An	Tier	FOLD	2/19	
607	806	An	Tier	INSERT	2/19	
607	807	An	Tier	INSERT	2/19	
607	808	An	Tier	INSERT B	2/19	
308	652	Hb	NC	11.0" 1-UP	2/20	
308	803	Hb	NC	CUT	2/20	
308	806	Hb	NC	INSERT HIGH	2/20	
307	805	Ke	Skill	FLAT	2/26	
308	801	Pam	P & G	BUY	2/28	
308	802	Pam	P & G	LABEL	2/28	
308	652	Pam	Act	14.0" 2-UP	3/1	
308	803	Pam	Act	CUT/FOLD	3/1	
308	807	Pam	Act	INSERT	3/1	
308	809	Pam	Act	HANDWORK 1	3/1	
308	809	Pam	Act	HANDWORK	3/1	
308	802	Pam	P & G	VIDEO-JET	3/1	
308	809	Pam	P & G	WRAPPER	3/1	
308	652	Pam	P&G	7.0" 2-UP	3/1	
308	803	Pam	P&G	CUT	3/1	
308	652	Pam	P&G	CUT	3/1	
308	803	Pam	P&G	INSERT	3/1	
308	802	Pam	P & G		3/2	
307	802	Bec	United		3/5	
307	805	Ke	Skill	FLAT	3/5	
307	805	Ke	Skill	FLAT	3/5	

Figure 17 WKDSS - Kanban by FMD

4.1.3.3 Features of WKDSS

Figure 18 shows the easy-to-read Kanban quantities. When the user moves the mouse over any text before the Kanban bar, they would see the following values: required → refers to the scheduled total quantity needed at the end of the previous shift, actual → refers to quantity that was produced at the end of the previous shift, maximum → relates to the total quantity of the activity as required by the customer, and, if the actual production counts is less than the required then the difference is shown as "Behind."

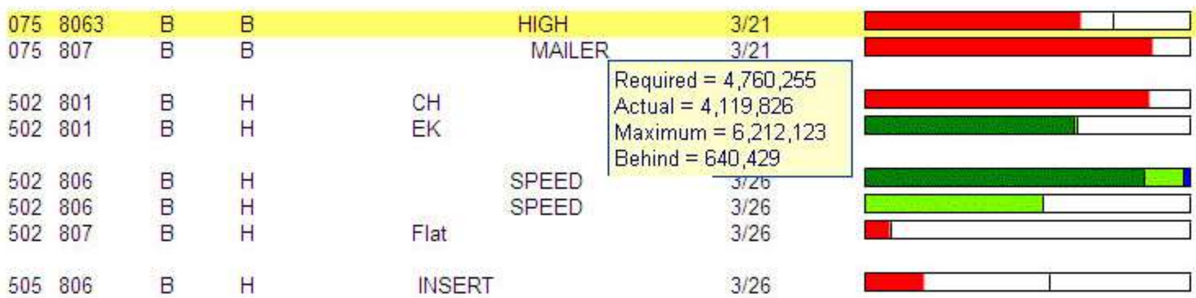


Figure 18 WKDSS - Kanban Display Quantities

Figure 19 shows the decision support behind the Kanban. When the users left click on the Kanban bar, a production history page opens. This screen has four different sections: (1) the first section has information, such as "job title," "activity name," "client," "CSR," "job total quantity," "activity total quantity," "price per thousand," "SRPH," "job description," "FMD" and "LMD", (2) the second section has the production information for that Kanban, i.e., the combination of job and activity code. It gives information on SRPH which is expressed as the "% EFF" the ratio "Amount" divided by "Hours." The color of the efficiency number depends on the following: >100% → "Green," >80 but < =100 → "Blue," >60 but <=80 → "Orange," < 60 →"Red." (3) the third section is the decision support that provides scheduling outlook.

Back Print

Section 1

Job Title	307
Activity	807 Flat
Client	High
CSR	B

Job Total Quantity	Activity Total Quantity	Price/M	Std. Rate Per Hour	Job Description	First Mail Date	Last Mail Date
1,342,094	750,000	$48	1,750	pre-sortinkjet	3/26	3/28

Section2

Prod Date	Shift	Opr.#	Amount	Hours	RPH	Pkg#	Drop#	Ops	Mach#	% EFF	Enter Time
3/19	3	28	9,884	7.80	1,267	5	1	2	311	72%	6:58:59 AM
3/19	3	61	12,700	7.80	1,628	5	1	2	314	93%	6:59:30 AM
3/19	3	68	15,000	7.80	1,923	5	1	2	315	110%	7:00:00 AM
3/16	2	61	7,300	8.00	913	5	1	2	315	52%	10:55:30 PM
3/16	2	50	12,701	8.00	1,588	5	1	2	311	91%	10:55:04 PM
Total			**57,585**	**39.40**	**1,462**						

Rate Per Hour (RPH) based on most recent 3 values out of total 5 values is -- 1,606

Section 3

Actual	Amount Needed	Remaining to Make	Est. Completion Date and Shift	Est. Hours Needed	Shifts Needed	Shifts Scheduled	Machines Scheduled	Machines Needed	New Rate
57,585	60,000	692,415	4/6 6:00:00	431.14	57.5	20	3	2.9	1,539

Click Here to View Job Schedule

Figure 19 WKDSS - Production History Page

Figure 20 shows a view of the DSS recommendation for managing the FMD. Based on the production and scheduling information, the DSS calculates the following: (a) estimated completion date and shift, (b) shifts needed, (c) number of shifts and number of machines on which the activity is scheduled, (d) machines needed, and (e) new rate. When an activity does not have any scheduled shift remaining, the Kanban gives a warning and estimates the hours and shifts needed at standard rate to complete the job before the last mail date. If the number of machines scheduled is less than the number of machines available, then this value is highlighted in “orange” color as an indication of the production need to double up on the machines or achieve new rate per hour to meet the mail date. This section also provides a quick view of scheduled activities via a link: “Click Here to View Job Schedules Link.” Figure 21 shows the relationship between how many days and for what quantities the job is scheduled.

Rate Per Hour (RPH) based on most recent 21 values out of total 42 values is -- 4,859

Actual	Amount Needed	Remaining to Make	Est. Completion Date and Shift	Est. Hours Needed	Shifts Needed	Shifts Scheduled	Machines Scheduled	Machines Needed	New Rate
1,296,195	1,300,000	3,805	3/21 3:00:00 PM	0.78	0.1	0	0	**0.0**	0

All Machine Scheduleds for this Job Number and Activity Code is Past Current Date

Est. Hours Needed at 4,859 RPH With 1 Machine Per Shift	1
Shifts Needed	1

Click Here to View Job Schedule

Figure 20 WKDSS - Schedule Warning

ACT	Job Number	Job Title	SRPH	Shift	Sch.Date	Mach	Opr Hrs.	Amt. Per Shift	Job Total Qty.	First Mail Date	Last Mail Date
INSERT	502	HF	1750	2	3/16	2	0	24,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	1	3/19	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	2	3/19	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	3	3/19	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	1	3/20	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	2	3/20	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	3	3/20	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	1	3/21	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	2	3/21	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	3	3/21	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	1	3/22	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	2	3/22	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	3	3/22	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	1	3/23	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	2	3/23	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	3	3/23	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	1	3/26	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	2	3/26	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	3	3/26	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	1	3/27	3	0	36,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	2	3/27	0.5	0	6,000	1,342,094	3/26	3/28
INSERT	502	HF	1750	3	3/27	3	0	36,000	1,342,094	3/26	3/28
Total							62.50	0.00	750,000		
Average Scheduled Rate Per Hour			1,600								

Figure 21 WKDSS - View Job Schedule

4.1.3.4 DSS Features – Enhanced Communication

Figure 22 shows another feature of the DSS that enables communication across shifts and departments. When the users click on the Kanban bar, a new comments-history page opens. The new page provides a quick overview with the various elements, including the “total job quantity,” “Price Per Task -PPT,” “SRPH,” “FMD,” and “LMD” along with other job information. Any comments that need to be passed down from CSR to FLS are entered in this screen that streamlines the communication channel and helps to make effective operations decisions in off-hours shifts when there is less management and CSR team oversite.

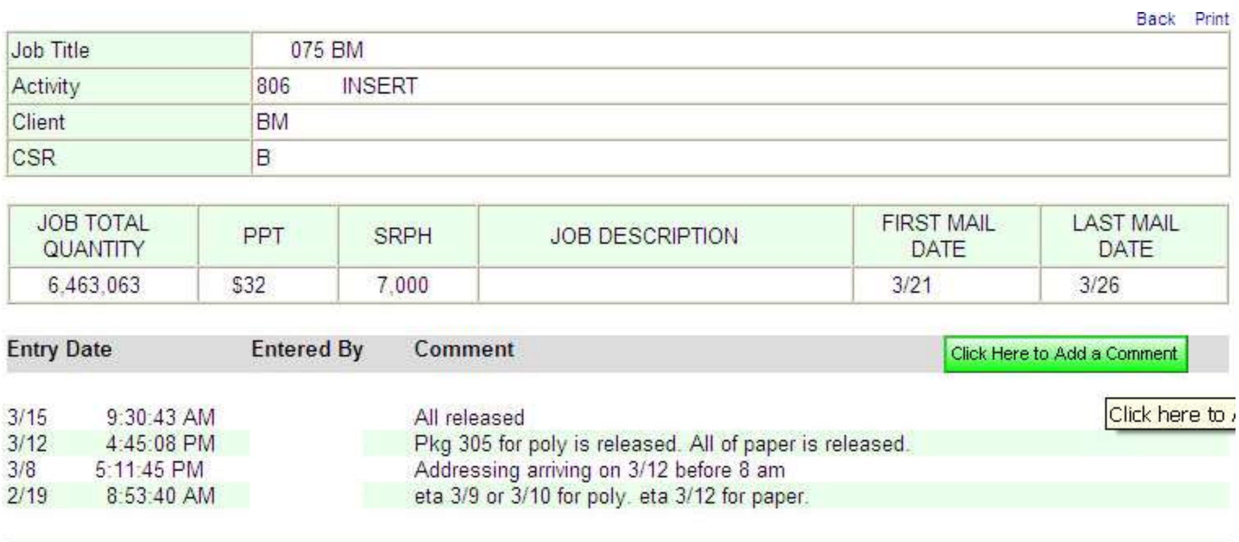


Figure 22 WKDSS - Comments History Entry

4.1.3.5 DSS Features – Reports

One of the key advantages of the DSS is the versatility of the reports available to aid various departments. The DSS pulls information from different sources, such as the ERP, the production, and the quality databases. It acts as a one-stop shop for all information to manage operations. This section provides an overview of various reports used.

4.1.3.6 View Production Schedule

This report shows the entire production schedule based on the “date,” “shift,” “job #,” and “activity” selection. It helps the FLS to understand the overall macro scheduling from the ERP. It also summarizes the entire machine, operator hours scheduled. If no “Shift” or “Job #” or “Activity Name” is selected, the report assumes all values within the selected date range. Each activity name on the report (as shown in Figure 23) displays the “total machines,” “operator hours,” the amount per shift needed for each shift and date. A sum of the shift and entire range of date selected is also displayed.

EKTA-JET	307	HF	6000	3	3/19	2	16	47,996	1,342,094	3/26	3/28
EKTA-JET	307	Re	8000	3	3/19	1	8	61,200	444,296	3/28	3/28
EKTA-JET	307	Cc	8000	3	3/19	1	8	56,058	259,971	3/26	3/26
Activity Sub Total						**4.00**	**32.00**	**165,254**			
INSERT BOW	307	Re	3500	3	3/19	1	7.6	19,000	62,774	3/20	3/20
INSERT BOW	307	Re	2800	3	3/19	1	8	19,208	270,840	3/27	3/27
Activity Sub Total						**2.00**	**15.60**	**38,208**			
INSERT HIG	307	HF	9000	3	3/19	1	24	39,983	1,342,094	3/26	3/28
INSERT HIG	307	HF	9000	3	3/19	1	32	47,997	1,376,793	3/26	3/28
INSERT HIG	308	BM	7000	3	3/19	5	120	280,015	6,463,063	3/21	3/26
Activity Sub Total						**7.00**	**176.00**	**367,995**			
INSERT MM	307	Co	1900	3	3/19	2.1	16.1	27,377	259,971	3/26	3/26
Activity Sub Total						**2.10**	**16.10**	**27,377**			
INSERT POL	307	HF	1750	3	3/19	3	0	36,000	1,342,094	3/26	3/28
Activity Sub Total						**3.00**	**0.00**	**36,000**			
INSERT VIP	307	Fa	2800	3	3/19	1	8	24,050	64,933	3/20	3/20
INSERT VIP	307	Pri	3000	3	3/19	3	23.6	69,892	1,427,261	3/16	3/20
INSERT VIP	308	AD	2800	3	3/19	2.1	16.2	44,514	858,218	3/20	3/20
Activity Sub Total						**6.10**	**47.80**	**138,456**			
MUSTANG	308	P	1800	3	3/19	2	48	19,202	454,000	3/28	3/28
Activity Sub Total						**2.00**	**48.00**	**19,202**			
SEMINARS	308	Sk	6000	3	3/19	1	8	47,990	2,000,000	3/19	4/2
SEMINARS	308	Sk	10000	3	3/19	1	8	47,990	2,000,000	3/19	4/2
SEMINARS	308	Sk	10000	3	3/19	3	24	240,000	4,000,000	3/19	3/19
Activity Sub Total						**5.00**	**40.00**	**335,980**			
VIDEO-JET	307	Me	9000	3	3/19	1	8	46,958	550,000	4/2	4/6
VIDEO-JET	307	Un	8000	3	3/19	1	8	40,000	601,759	3/26	3/30
Activity Sub Total						**2.00**	**16.00**	**86,958**			
Shift Sub Total						**37.30**	**442.60**	**1,387,430**			

Figure 23 WKDSS - View Production Schedule

4.1.3.7 View Activity Schedule

Figure 24 provides a view based on the different activities to be completed. This report shows all the activities scheduled based on the “date,” “shift,” and “activity name” selection. It also summarizes the number of machines to be used, and the operator hours scheduled. The report displays the selected activity name the “number of machines scheduled,” “operator hours,” “amount per shift” needed for each shift and date scheduled.

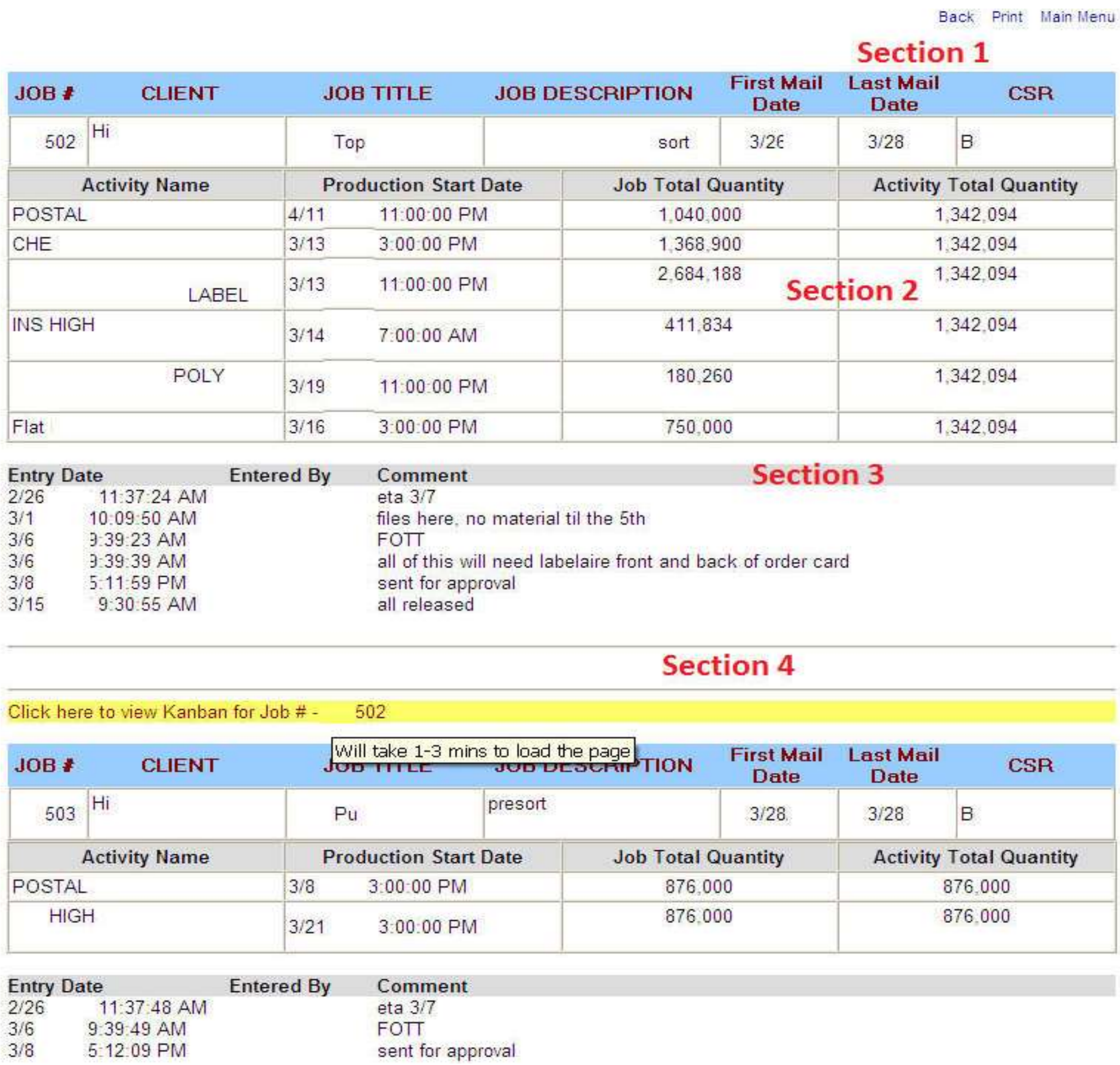
ACT	Job Number	Job Title	SRPH	Shift	Sch.Date	Mach	Opr Hrs.	Amt. Per Shift	Job Total Qty.	First Mail Date	Last Mail Date
INSERT	307	Co	1900	1	3/19	2	16	27,204	259,971	3/26	3/26
Shift Sub Total						2.00	16.00	27,204			
INSERT	307	Re	1800	2	3/19	3	24	28,804	444,296	3/28	3/28
INSERT	307	Co	1900	2	3/19	1.1	8.8	14,962	259,971	3/26	3/26
INSERT	308	Ja	1200	2	3/19	2	10.6	10,579	10,861	3/20	3/20
Shift Sub Total						6.10	43.40	54,345			
INSERT	307	Co	1900	3	3/19	2.1	16.1	27,377	259,971	3/26	3/26
Activity Sub Total						10.20	75.50	108,926			
Shift Sub Total						2.10	16.10	27,377			
Total					10.20	75.50		108,926			

Figure 24 WKDSS - View Activity Schedule

4.1.3.7.1 View Comments Summary

This report shows all the comments entered, start date and shift for all scheduled activities of a job within the selected “Date Range,” “Job #,” and “CSR Name” selection. If no specific “Job #” or “CSR Name” is selected, by default, the report summarizes for all “Job #” and “CSR Name.” The report sorts the comment history in the ascending order of “CSR Name,” and job number. Figure 25 has four sections: (1) Job information section has “Job #,” “Client Name,” “Job Title,” “Job Description,” “FMD,” “LMD,” and “CSR Name.” (2) Production information section table has the production “Start Date and Shift,” “Job,” and “Activity Total

Quantity" for all the activities scheduled for the job. (3) Comments history section has all comments for the job is listed along with the user id of the person who entered the observations in an oldest to the latest entry date order. The printed report has a couple of user-friendly lines. These blank lines allow the user to make their notes during the meeting. (4) View Kanban section has a link to demonstrate the Kanban for the specific job.



Back Print Main Menu

Section 1

JOB #	CLIENT	JOB TITLE	JOB DESCRIPTION	First Mail Date	Last Mail Date	CSR
502	Hi	Top	sort	3/26	3/28	B

Activity Name	Production Start Date		Job Total Quantity	Activity Total Quantity
POSTAL	4/11	11:00:00 PM	1,040,000	1,342,094
CHE	3/13	3:00:00 PM	1,368,900	1,342,094
LABEL	3/13	11:00:00 PM	2,684,188	1,342,094
INS HIGH	3/14	7:00:00 AM	411,834	1,342,094
POLY	3/19	11:00:00 PM	180,260	1,342,094
Flat	3/16	3:00:00 PM	750,000	1,342,094

Section 2

Section 3

Entry Date		Entered By	Comment
2/26	11:37:24 AM		eta 3/7
3/1	10:09:50 AM		files here, no material til the 5th
3/6	9:39:23 AM		FOTT
3/6	9:39:39 AM		all of this will need labelaire front and back of order card
3/8	5:11:59 PM		sent for approval
3/15	9:30:55 AM		all released

Section 4

Click here to view Kanban for Job # - 502

Will take 1-3 mins to load the page

JOB #	CLIENT	JOB TITLE	JOB DESCRIPTION	First Mail Date	Last Mail Date	CSR
503	Hi	Pu	presort	3/28	3/28	B

Activity Name	Production Start Date		Job Total Quantity	Activity Total Quantity
POSTAL	3/8	3:00:00 PM	876,000	876,000
HIGH	3/21	3:00:00 PM	876,000	876,000

Entry Date		Entered By	Comment
2/26	11:37:48 AM		eta 3/7
3/6	9:39:49 AM		FOTT
3/8	5:12:09 PM		sent for approval

Figure 25 WKDSS - Comments History Summary

4.1.3.7.2 View Job Production History

For the selected job number, Figure 26 shows all the production counts and spoilage % summarized by activity code and package number. Specific “Activity Code” or “Package #” is selected, by default the report summarizes all activity codes and package numbers. It is used as a job completion report and is attached to the work order. This report enables verification and validation of the production quantities and quality issues.

For Job Number 305

Prod Date	Shift	Opr.#	Amount	Hours	Spoil	Pkg#	Drop#	Ops	Mach#	Enter Time
1/6	2	30	14.440	1.00	0	13	1	1	236	2/1 3:52:35 PM
1/6	2	640	18.051	2.00	0	13	1	1	231	2/1 3:52:35 PM
Act. Pkg. Total-8030			**32,491**	**3.00**	**0**	Package Spoilage 0.00%				
1/6	2	30	20.290	6.00	0	14	1	1	236	2/1 3:52:35 PM
1/6	2	500	4.900	1.00	0	14	1	1	232	2/1 3:52:35 PM
1/7	2	500	26.315	4.50	0	14	1	1	232	2/1 3:52:35 PM
Act. Pkg. Total-8030			**51,505**	**11.50**	**0**	Package Spoilage 0.00%				
1/6	2	500	44.000	7.00	0	17	1	1	232	2/1 3:52:35 PM
1/6	2	640	28.500	4.00	0	17	1	1	231	2/1 3:52:35 PM
Act. Pkg. Total-8030			**72,500**	**11.00**	**0**	Package Spoilage 0.00%				
1/7	2	640	32.100	4.50	0	19	1	1	231	2/1 3:52:35 PM
Act. Pkg. Total-8030			**32,100**	**4.50**	**0**	Package Spoilage 0.00%				
1/4	2	500	43.500	7.00	0	20	1	1	232	2/1 3:52:35 PM
1/5	2	500	51.000	8.00	0	20	1	1	232	2/1 3:52:35 PM
Act. Pkg. Total-8030			**94,500**	**15.00**	**0**	Package Spoilage 0.00%				
1/8	2	500	34.880	6.00	0	27	1	1	232	2/1 3:52:35 PM
1/9	3	500	21.938	3.50	0	27	1	1	232	2/1 3:52:35 PM
Act. Pkg. Total-8030			**56,818**	**9.50**	**0**	Package Spoilage 0.00%				
1/8	2	640	48.755	7.00	0	28	1	1	231	2/1 3:52:35 PM
1/9	3	500	6.715	2.50	0	28	1	1	232	2/1 3:52:35 PM
Act. Pkg. Total-8030			**55,470**	**9.50**	**0**	Package Spoilage 0.00%				
1/3	1	678	13.923	2.00	0	6	1	1	231	2/1 3:52:34 PM
Act. Pkg. Total-8030			**13,923**	**2.00**	**0**	Package Spoilage 0.00%				
1/3	2	500	24.120	4.00	0	8	1	1	232	2/1 3:52:34 PM
Act. Pkg. Total-8030			**24,120**	**4.00**	**0**	Package Spoilage 0.00%				
1/3	2	500	21.000	3.00	0	9	1	1	232	2/1 3:52:34 PM
Act. Pkg. Total-8030			**21,000**	**3.00**	**0**	Package Spoilage 0.00%				
Act. Total-8030			**454,427**	**73.00**	**0**	**Activity Spoilage 0.00%**				

Figure 26 WKDSS - Work Order Summary

4.1.3.7.3 View Job Summary

Figure 27 shows the final job summary used by CSR and management. For the selected job number, the report summarizes, by activity code and name, the quantity, hours, and RPH for the job. The RPH data enables the scheduling team and the management to understand the process performance and fine tune the bidding process during the job quotation.

Job Number 201

ACT CODE	ACTIVITY NAME	TOTAL AMOUNT	TOTAL HOURS	RPH
101	CUSTO	0.00	1.50	0.00
101	PRODU	0.00	4.50	0.00
101	QUALIT	0.00	0.50	0.00
101	JOB CC	0.00	1.25	0.00
101	CUST. :	0.00	0.50	0.00
101	DATA N	0.00	0.50	0.00
802	PRODU	0.00	3.00	0.00
806	JACKE	834,615.00	171.80	4,858.06
806	JACKE	24.00	37.30	0.64
806	JACKE	2.00	4.00	0.50
806	JACKE	2.00	11.00	0.18
806	JACKE	19.00	68.50	0.28
806	JACKE	0.00	14.00	0.00
806	INS HS	3.00	6.00	0.50
807	INSERT	789,368.00	345.40	2,285.37
807	INS VIF	0.00	15.50	0.00
807	INS VIF	2.00	7.00	0.29
807	INS VIF	0.00	0.40	0.00
807	INS VIF	18.00	42.50	0.42
809	TRAINI	13.00	89.20	0.15
961	MATER	0.00	2.00	0.00
961	STOCK	16.00	118.70	0.13

Figure 27 WKDSS - Job Summary

4.1.3.7.4 View Activity Performance

Figure 28 shows, by shift and month, the total quantity and hours for a selected activity name. It is used to understand the variability of the RPH. This example shows that job 157 has the highest volume and job 474 has the lowest volume. Furthermore, based on the values of the "Total Amount" and "Total Hours" the FLS efficiently computes the average RPH.

JOB	ACT	ACTIVITY NAME	TOTAL AMOUNT	TOTAL HOURS	SHIFT	MONTH
157	8078	INSERT	2,128,379.00	697.30	1	1
074	8078	INSERT	41,124.00	12.80	1	1
205	8078	INSERT	180,762.00	52.10	1	1
474	8078	INSERT	904.00	0.30	1	1
475	8078	INSERT	22,880.00	5.40	1	1
476	8078	INSERT	29,803.00	8.00	1	1
477	8078	INSERT	11,259.00	4.40	1	1
480	8078	INSERT	1,508.00	0.70	1	1
490	8078	INSERT	1,128,595.00	315.90	1	1
492	8078	INSERT	221,794.00	54.20	1	1
323	8078	INSERT	17,300.00	6.00	1	1
419	8078	INSERT	2,492.00	1.00	1	1
447	8078	INSERT	5,913.00	3.50	1	1
624	8078	INSERT	483,070.00	132.20	1	1
672	8078	INSERT	205,557.00	88.60	1	1
673	8078	INSERT	34,334.00	17.00	1	1
870	8078	INSERT	39,104.00	15.50	1	1
110	8078	INSERT	49,150.00	22.90	1	1
551	8078	INSERT	254,901.00	114.90	1	1
279	8078	INSERT	1,717,844.00	650.70	1	1
219	8078	INSERT	25,400.00	7.50	1	1

Figure 28 WKDSS - View Activity Summary

4.1.3.7.5 View Shift Production Performance

Figure 29 shows details of how the shift performed. It helps the FLS understand the variability by date, shift, and machine number. It displays the total quantity produced, hours used, and computes the RPH. By default, the "From Date" is one day back from current date. If not specific "Shift" or "Job#" or "Activity Code" is selected, the report displays all values between the chosen "from" and "to" dates. The report also has subtotal of amount, hours and RPH for each activity and job number for all shift and days between the selected "from" and "to" dates.

Mach#	Job#	Pkg#	Drp#	Emp#	Act Name	Amount	Hours	RPH
042	307	105	2	28	CHES	12,845	4.00	3,211
045	307	105	2	500	CHES	5,095	1.00	5,095
045	307	105	2	615	CHES	3,649	3.40	1,073
046	307	105	2	610	CHES	34,000	4.00	8,500
046	307	105	2	28[illegible]	CHES	17,316	3.80	4,557
Sub Total		3/18			Shift-3	72,905	16.20	4,500
102	307	3	1	666	CHES	13,956	2.30	6,068
102	307	101	2	666	CHES	34,230	5.70	6,005
Sub Total		3/18			Shift-3	48,186	8.00	6,023
107	307	4	2	500	CHES	40,031	7.80	5,132
107	307	4	2	500	CHES	8,945	2.00	4,473
Sub Total		3/18			Shift-3	48,976	9.80	4,998
108	307	1	1	30	EKT	79,936	8.00	9,992
Sub Total		3/18			Shift-3	79,936	8.00	9,992
111	307	5	1	500	EKT	53,825	8.00	6,728
Sub Total		3/18			Shift-3	53,825	8.00	6,728
112	307	105	2	500	CHES	20,137	4.60	4,378
Sub Total		3/18			Shift-1	20,137	4.60	4,378
113	307	4	1	500	EKT	3,347	1.00	3,347
113	307	5	1	610	EKT	34,568	8.00	4,321
Sub Total		3/18			Shift-3	37,915	9.00	4,213
114	308	300	2	266	VIDEO	4	0.10	40
114	308	500	2	266	VIDEO	24	0.10	240
114	308	4	1	266	VIDEO	309	0.20	1,545
114	308	2	1	266	VIDEO	399	1.00	399
114	308	200	2	266	VIDEO	572	0.50	1,144
114	308	5	1	266	VIDEO	913	0.20	4,565
114	308	1	1	266	VIDEO	3,943	1.50	2,629
114	308	3	1	266	VIDEO	4,512	1.00	4,512
Sub Total		3/19			Shift-3	10,676	4.60	2,321
118	308	8	1	500	INSERT	725	2.00	363
Sub Total		3/19			Shift-3	725	2.00	363
122	307	1	2	616	INSERT	18,843	8.00	2,355
Sub Total		3/19			Shift-3	18,843	8.00	2,355

Figure 29 WKDSS - View Shift Production Performance

4.1.3.7.6 View Machine Performance

Figure 30 shows the performance of a selected machine. Date and shift, total quantity produced, hours used, total spoilage, machine RPH, and spoilage percentage are displayed. It helps to understand the RPH, shift and the % spoilage variation. By default, the "From Date" is one month back from current date. If no specific shift is selected, the report assumes "All" shifts.

Shift 1,2,3 Regular Paper - EMC Inserters-102

Prod Date	Shift	Amount	Hours	Spoil	% Spoil	RPH
2/26	2	18,036	6.00	18	0%	3,006
2/27	1	22,400	8.00	25	0%	2,800
2/27	2	19,805	7.00	30	0%	2,829
2/27	3	5,180	2.00	20	0%	2,590
2/28	1	23,643	8.00	20	0%	2,955
2/28	2	18,200	7.80	30	0%	2,333
2/28	3	10,472	8.00	0	0%	1,309
3/1	1	124	0.30	20	16%	413
3/1	3	6,400	8.00	50	1%	800
3/8	1	30,056	7.00	1	0%	4,294
3/8	2	11,768	2.50	10	0%	4,707
3/9	1	16,716	7.00	0	0%	2,388
3/9	2	10,464	3.90	0	0%	2,683
3/12	1	15,588	4.50	3	0%	3,464
3/12	2	21,163	8.00	26	0%	2,645
3/12	3	19,734	7.80	0	0%	2,530
3/13	2	11,800	3.50	3	0%	3,371
3/13	3	2,540	1.50	4	0%	1,693
3/14	1	30,900	8.00	10	0%	3,863
3/14	2	17,586	7.50	0	0%	2,345
3/15	1	4,644	2.40	0	0%	1,935

Figure 30 WKDSS - View Machine Performance

4.1.3.8 DSS Features - Enterprise Capacity Forecast

One of the critical abilities of the DSS is the capability to understand current resource capacity. Figure 31 shows the scheduled vs. available hours of people and machine. The ratio of the scheduled vs. open people is referred to "% capacity." This ratio is monitored closely by the management to determine the number of shifts needed and to identify opportunities to bid for more jobs.

Scheduled Hours	Avl. Hours	Scheduled People	Avl. People	% Capacity
2,503.90	11,280	63	282	22.34%
3,449.10	11,280	86	282	30.50%
2,820.50	11,280	71	282	25.18%
4,129.30	11,280	103	282	36.52%
2,113.30	11,280	53	282	18.79%
5,722.00	11,280	143	282	50.71%
4,146.90	11,280	104	282	36.88%
3,028.60	11,280	76	282	26.95%
3,639.60	11,280	91	282	32.27%
4,277.10	11,280	107	282	37.94%
2,013.60	11,280	50	282	17.73%
2,374.40	11,280	59	282	20.92%
1,606.50	11,280	40	282	14.18%
524.00	11,280	13	282	4.61%
47.40	11,280	1	282	0.35%
185.30	11,280	5	282	1.77%
487.30	11,280	12	282	4.26%
1,555.00	11,280	39	282	13.83%

Figure 31 WKDSS - Enterprise Capacity Forecast

4.1.3.9 DSS Features - Employee Performance Management

Table 3 shows another key feature of the DSS. It provided the building blocks to calculate employee overall performance and grade level. Report data is based on operator's demonstrated multi-skills and efficiency. For example, in "Area 1," "Grade I" is achieved if an operator can successfully operate three types of equipment at 85% efficiency. An operator can achieve "Grade II," by demonstrating 95% efficiency and the PACE-setter grade. "Grade III" is obtained when the effectiveness of the operator is at 105%. The DSS helped the human resources and operations team to monitor these efficiencies on a day to day basis as well as on a pre-set quarterly/yearly frequency. This information, along with the quality performance metrics, were used to identify key talent within the organization. Furthermore, this information was also used as a benchmark for other employees to emulate.

Figure 32 shows the efficiency % in a visual color-coded manner (> 100% →"Green," 80% < X < 100% →"Blue," 60% < X <80% →"Amber," < 60% →"Red.") It helps management to assign the grade levels to employees, which ultimately determines their hourly rate of pay and bonus. For example, if an operator operates in "Area 1" and can perform at more than 105% efficiency at three types of equipment, then he/she is rated as "Grade III," the highest pay scale. An employee with experience in multiple areas and who gains multiple "Grade III" level skills, will be considered a potential candidate for FLS role.

Table 3 Performance Aligned to Customer Satisfaction (PACE)

	Area 1	Area 2	Area 3	Area 4
Grade III	PACE Setter - Can operate three types of equipment in a highly proficient manner - 105% efficiency	PACE Setter - Can operate two types of equipment in a highly proficient manner - 105% efficiency	PACE Setter - Can operate three types of equipment in a highly proficient manner - 105% efficiency	PACE Setter - Can operate three types of equipment in a highly proficient manner - 105% efficiency
Grade II	Skilled - Can operate three types of most complex equipment - 95% efficiency	Skilled - Can operate two types of most complex equipment in the area - 95% efficiency	Skilled - Can operate three types of most complex equipment types in the area - 95% efficiency	Skilled - Can operate 1 type of most complex equipment in the area - 95% efficiency
Grade I	Basic - Can operate 3 types of less complex equipment - 85% efficiency	Basic - Can operate 2 types of less complex equipment - 85% efficiency	Basic - Can operate 3 types of less complex equipment - 85% efficiency	Basic - Can operate 3 types of less complex equipment - 85% efficiency

Back Print Main Menu

On changing the 'Year' or 'Month' or 'Shift' or 'Area' Drop Down the page would be refreshed

From May To June **Shift** All **Area** All

an Employee from Menu All

:MP. NAME	EMP.#	AREA	SHIFT	HOURS	ACTUAL	STD	EFF %
Vira	242	Jumbo	Ev	42.00	82,361	84,000	98%
Vira	242	Regular	Ev	48.00	161,806	215,640	75%
usan	247	Regular	Ev	3.20	3,364	8,960	38%
usan	247	Regular	Da	25.70	54,801	71,960	76%
Hung	251	Jumbo	Da	4.00	7,280	8,000	91%
Hung	251	Regular	Da	7.00	28,387	35,000	81%
Maria	252	Hanc	Da	1.00	267	999	27%
Maria	252	Jumbo	Da	95.70	169,452	185,120	92%
Maria	252	Regular	Da	24.00	77,100	102,400	75%
Huong	253	Jumbo	Da	31.50	65,469	57,800	113%
Huong	253	Regular	Da	298.00	1,379,253	1,381,200	100%
Herm	253	Flowl	Ev	29.00	68,046	129,000	53%
Herm	253	Jumbo	Ev	44.00	64,443	74,400	87%
Herm	253	Personal	Da	16.00	165,214	192,000	86%
Herm	253	Regular	Ev	71.00	294,310	313,750	94%
Gen	253	Bowie I	Da	94.00	263,844	293,560	90%
Gen	253	Jumbo	Ev	8.00	19,400	14,400	135%
Gen	253	Personal	Da	36.50	99,290	109,500	91%
Gen	253	Regular	Da	12.50	23,227	43,320	54%
Vicen	253	Jumbo	Ev	24.00	50,069	44,800	112%
Vicen	253		Ev	103.30	1,386,524	1,782,001	78%
Vicen	253	Personal	Da	44.00	436,193	441,000	99%
Vicen	253	Personal	Ev	3.00	19,249	21,000	92%

Figure 32 WKDSS - Employee Performance Rating

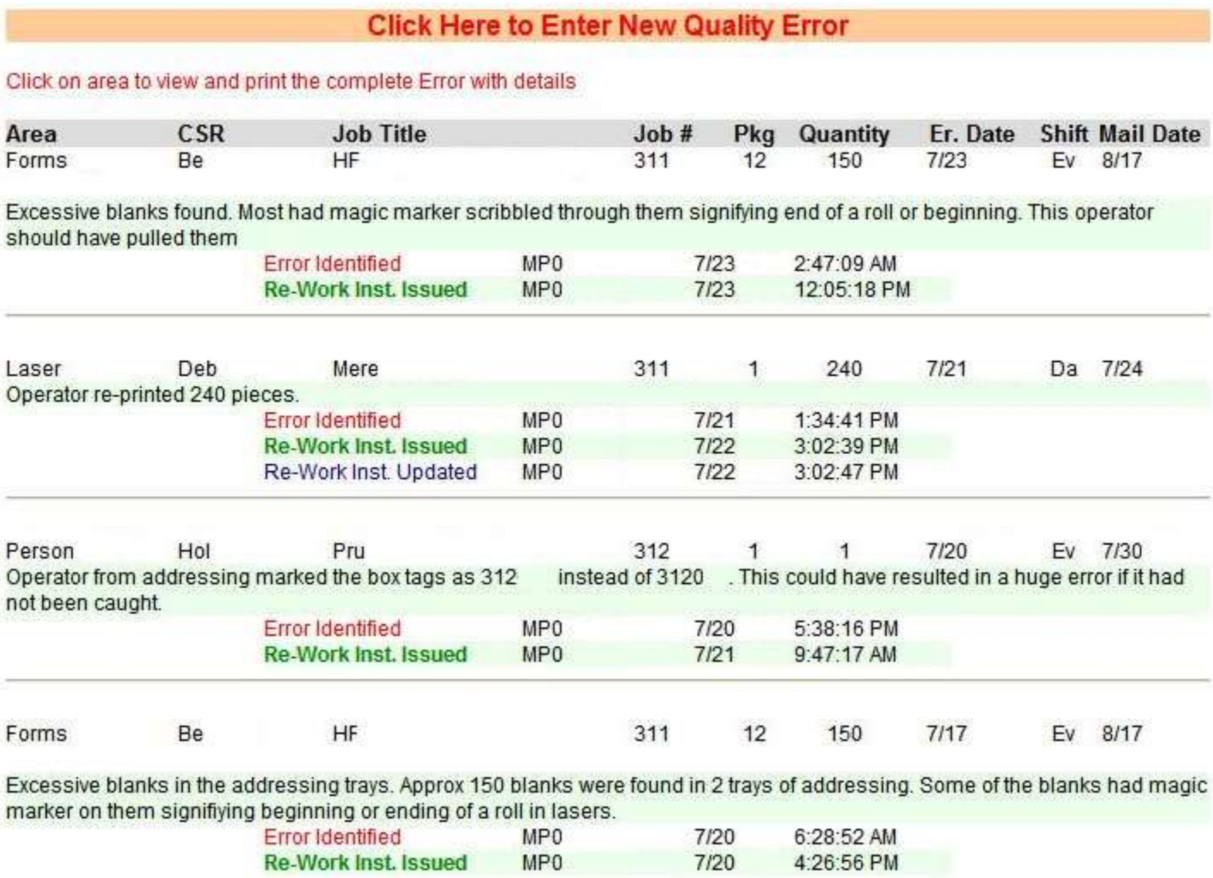
4.1.4 Case 1: Action Research Cycle 2

Based on the success of the implementation of AR Cycle 1, new areas to implement were identified, and the system was updated. Figure 33 provides an updated WKDSS covering various functions across the enterprise. Each department was given customized access to the applicable Kanban view and the DSS reports. There are: (1) Production Performance → various reports that gauge the efficiency of the process, and the machines listed under production, (2) Scheduling → Kanban with choice of decisions (either increasing the number of machines that can be run in parallel or increasing number of people on a machine for that activity), floor plans (i.e machine layout), and open capacity, (3) Customer Service → provides a job-drop calendar, and comments about jobs for communication, (4) Distribution → displays jobs released to mail, and the flow of job from production to distrubution area, (5) Warehouse → shows receiving material entries, and daily efficiency, (6) Quality → presents the quality error reports, and the overall quality performance, (7) Presort & Programming → shows the postal equipment entries, (8) Human Resources → allows employee absent tracking and employee overall performance including efficiency and quality rate and (9) Metrics/Reports → displays financial performance of job for various clients, revenue, and invoice status.

One of the new features of AR cycle 2 is the quality module. Figure 34 shows the quality error reports. Periodic audits are conducted, and the non-conforming finished products are isolated. The error that caused the non-conformance is identified and entered into the system; the quality team routinely checks this report and acts on it. They perform the RCA and issue re-work instructions as needed. Upon rectifying the errors, the FLS coordinates the sign off with quality and the status of the re-work is updated. For example, job 311162 has an excessive blank material. Upon investigation, it was found that the operator ran through the "test material marked with magic marker” that got mixed up with the finished product. The complete details of the error including the operator information (employee number, shift, date and time), machine information (machine number, area, and task), job information (customer service rep, quantity, and mail date), and quality issues are captured in the decision support system.

Figure 33 Enhanced WKDSS

This serves two purposes: (1) A quick decision-making process to evaluate the urgency of the situation, as the key to this identification is to understand the impact to mail date (2) historical job quality performance tracking that helps the scheduler’s and the pricing agents to consider this when the company bids for the prospective jobs. The old process of reporting a quality error was to fill in a spreadsheet and send it to a group comprising of quality, customer service, and production people. This data is entered into a database for tracking. Often, the communication about the problem was not clear. Furthermore, there was no visibility of challenges across the upstream and downstream process. The new system eliminated the duplicate entry of data. It had checks and balances for data inconsistency. The user-friendliness became a significant success as a number of errors reported jumped to all record levels. It helped the organization to catch the errors before they shipped the product.



Click Here to Enter New Quality Error

Click on area to view and print the complete Error with details

Area	CSR	Job Title	Job #	Pkg	Quantity	Er. Date	Shift	Mail Date
Forms	Be	HF	311	12	150	7/23	Ev	8/17
Excessive blanks found. Most had magic marker scribbled through them signifying end of a roll or beginning. This operator should have pulled them								
		Error Identified	MP0	7/23	2:47:09 AM			
		Re-Work Inst. Issued	MP0	7/23	12:05:18 PM			
Laser	Deb	Mere	311	1	240	7/21	Da	7/24
Operator re-printed 240 pieces.								
		Error Identified	MP0	7/21	1:34:41 PM			
		Re-Work Inst. Issued	MP0	7/22	3:02:39 PM			
		Re-Work Inst. Updated	MP0	7/22	3:02:47 PM			
Person	Hol	Pru	312	1	1	7/20	Ev	7/30
Operator from addressing marked the box tags as 312 instead of 3120 . This could have resulted in a huge error if it had not been caught.								
		Error Identified	MP0	7/20	5:38:16 PM			
		Re-Work Inst. Issued	MP0	7/21	9:47:17 AM			
Forms	Be	HF	311	12	150	7/17	Ev	8/17
Excessive blanks in the addressing trays. Approx 150 blanks were found in 2 trays of addressing. Some of the blanks had magic marker on them signifiying beginning or ending of a roll in lasers.								
		Error Identified	MP0	7/20	6:28:52 AM			
		Re-Work Inst. Issued	MP0	7/20	4:26:56 PM			

Figure 34 WKDSS - Quality Error Reports

4.1.5 Case 1: Summary

The initial focus of WKDSS was one plant or one geographic location of the organization in the first two AR cycles. With the lessons learned from the two AR cycles, the management decided that the third cycle would extend the concept to three other plants in the US. Utilizing the methodology described in section 03, Figure 11, the system was updated and implemented. The pilot system implementation showed promising results in an Intranet web-server environment. The primary constraint was the legacy computer/computation architecture. In the age of digital first, migrating legacy systems to a cloud architecture could significantly enhance operations management and could significantly reduce capital and non-capital expenses in the form of time (in years), cost, and resources. With the use of AR, EAT Kanban, and DSS, we could continuously improve the system and provide significant value to the organization by helping it to make efficient and efficacious decisions. Our approach leverages the existing data from the transactional core, including ERP systems, and only transfers the data that will be needed to support an efficient CKDSS. The detailed steps involved to migrate to a cloud-based environment are covered in chapter 5.

4.2 Case 2: Overview - Education Services

Providing educational services (publishing, assessment, and solutions) is a complex process that is bound by various government regulations. Figure 35 shows the high-level process that starts with customer requests for proposals. This case process starts with state/national education boards request for proposal to conduct assessments. Upon review of multiple proposals against pre-defined selection criterion, the contract is awarded. The award kick-starts the plan-admin activities, including gathering baseline customer requirements, setup program management, and shared services. Internal specification and configure systems are prepared. The development team then performs five activities. They are (1) configure the system for item authoring, (2) create test forms, (3) create test maps, (4) create ancillary and accommodated forms/materials, and (5) perform the key review. The customer reviews and approves during the various stages of these activities to ensure that their standards are met. The distribution team creates a material requirement forecast using the ERP system and coordinates the printing and receiving of the materials at the warehouse. The operations team configures various systems, such as ERP, pack and distribution, setup and customer processing rules. A dry run is then performed using a mock customer order. This task should be synced with the client's enrollment start date to enable a proper order forecast. Operations personalize the test materials and media in a four-stage process. Stage 1 is to apply an adhesive seal to various sections of the test booklets so that they can be accessed only at the appropriate time during the test. This process is called "tabbing." Stage 2, the booklets are sealed into different pack sized based on the number of students in each class taking the test. Stage 3, various ancillary materials are pre-packed. Finally, in stage 4, these pre-packed test materials and other test instructions are assembled and shipped out. The customer closes the enrollment window, and the tests are administered. Typically, there is little excess test material to accommodate last-minute enrollments. Depending on the client standards, if unused test materials are classified as "secured test materials (i.e., total test materials received by the school for giving the test must be matched to materials returned for scoring)," then they are sent back for matching.

The scorable test materials are prepared for scanning in data prep. The booklets are run through slitting machines that convert them to individual pages for scanning. The pages are scanned, and the resulting images are edited and sent for scoring. Various systems are setup, and the scoring is performed in a joint session with the customers to perform range finding and "equating." Upon final score aggregation, a data file is generated. A standard setting task with the client is conducted to develop score reporting standards per customer requirements. These reports are printed, packed and shipped by an activity called output processing. Finally, project close-out activities such as billing, archiving and reflection on lessons learned are performed. A test administration cycle can span multiple semesters and years. Except for the bidding process, this cycle is repeated for every test administration cycle. The focus areas of this research are highlighted in "red" color that covers the operations activities.

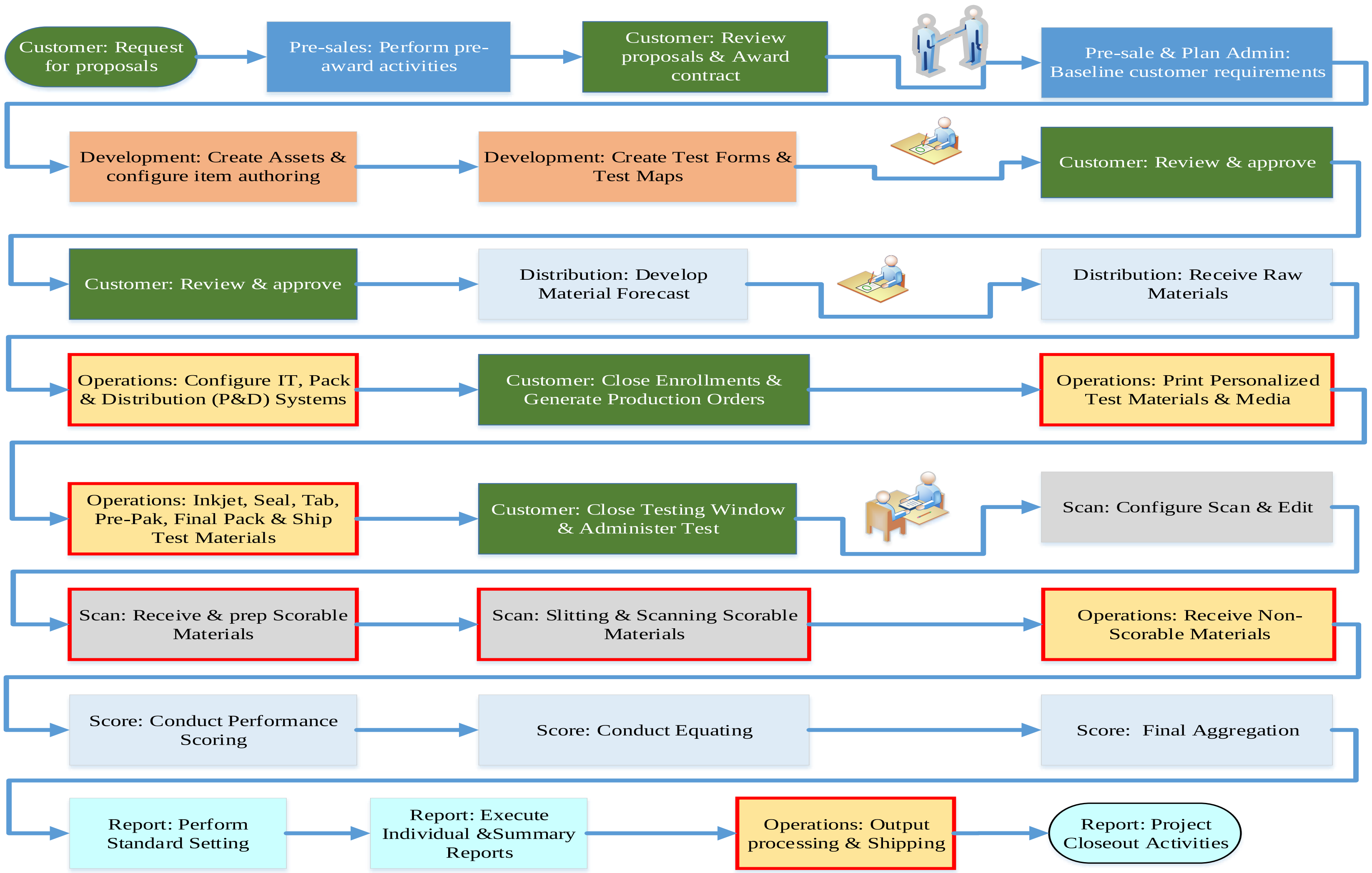


Figure 35 High-level Overview of Educational Service Process

4.2.1 Case 2: Action Research for Educational Services

Figure 36 shows the deployment approach that utilizes the principles of the AR and the 3DS methodology described in section 3.1 Figure 6. In the first cycle, and as part of the diagnose, a time study was performed to understand the process, material, and information flow. It was presented to management to gain approval for further analysis. In the second cycle, a focused area to implement Kaizen was identified using the design stage of the methodology. In the structured Kaizen workshop, the area's machine layout was modified to achieve a better flow of products to the machines. In the third cycle, as part of the deliver and sustain stage, opportunities to streamline the data flow in the operations were addressed. Microsoft Excel files were used by different departments to manage transactions, which resulted in the lack of a single source of truth. To mitigate, a pilot system (ODSS) to eliminate the Excel files was deployed. As the last cycle, upon successful implementation of ODSS, the system was enhanced to accommodate all departments on the site, and finally, the system was duplicated across multiple sites.

Figure 37 shows the five-step gap analysis that was used to understand the customer requirements. The first step was to identify the client and the potential stakeholders. In the next step, their needs are translated into a problem that they are trying to solve. The steps allow identification of current state and options to meet requirements. Finally, a solution is selected from the options. For example, an operations representative might have a need to track defects along with production entries. During the current state analysis, it was found the team used separate Microsoft Excel files. The use of multiple files to track data errors for one department resulted in duplicate data. This tracking was not user-friendly for management to reports across the department. The solution was to build and implement a quality module in ODSS.

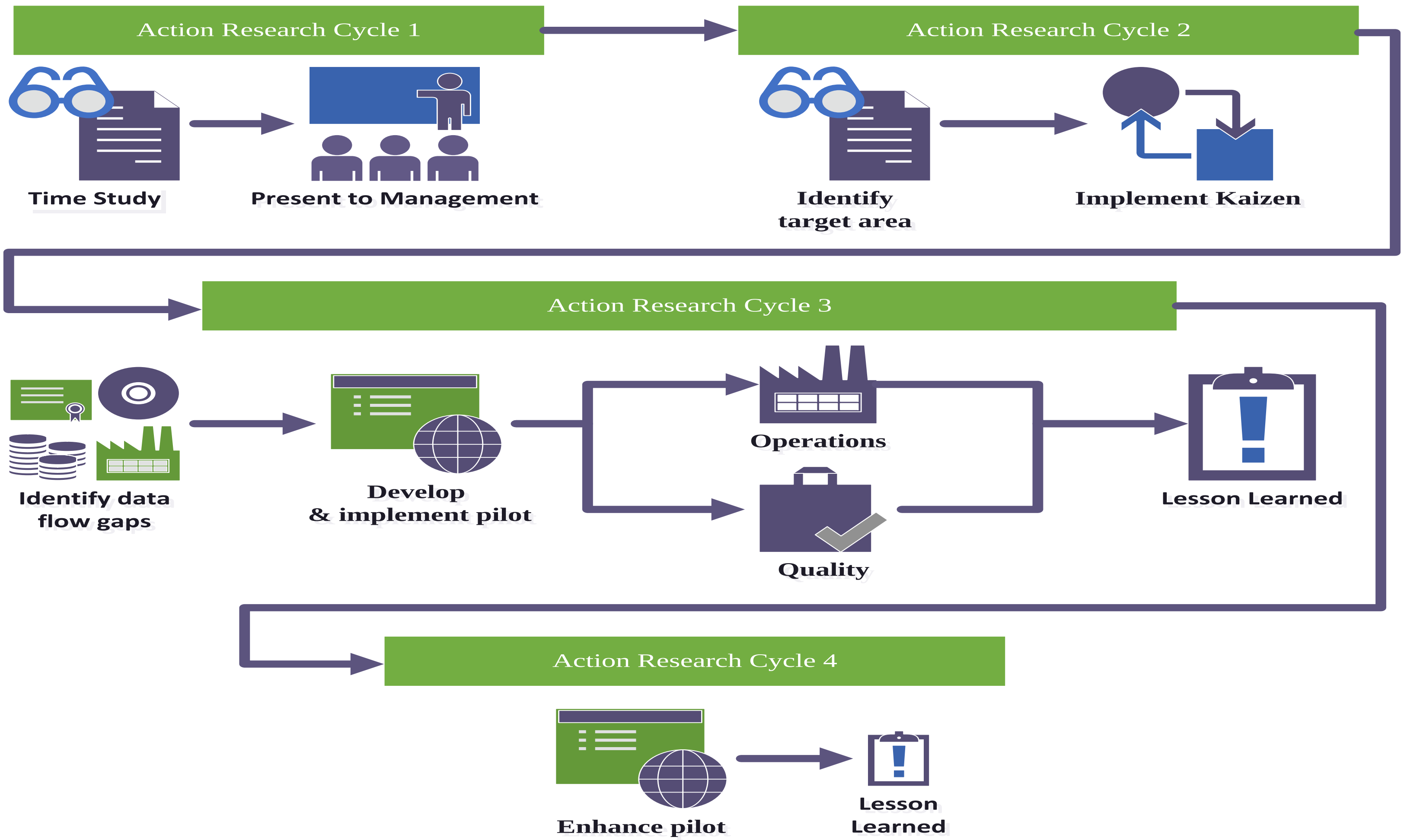


Figure 36 Action Research Approach for Education Services Implementation

Step 1 Who Customer?	Step 2 Garner Customer Requirements	Step 3 Fact-Finding Current Situation	Step 4 Evaluate Options	Step 5 Implement Solution
Lead	For packaging we'd like to add an entry for number of pieces to enter, and rates for each?	Excel file had lookups and was not linked up right.	Developed sub task and new reports	ODSS Reports
Lead	Why can we not enter both internal and external damage for the same item? Also I do not see a report for damage of any kind to see if it took both entries or if it overwrote the first entry and wasted time.	Current excel file has multiple entry options	Developed multiple entry for errors and down time	ODSS Quality Reports
Lead	Can we plot the data by every hour of entry for us "Manual Sealing" as shift performance?	Currently the access database was providing a tabular data. No charts	Provided a auto one click chart report by each hour of production entry	ODSS Chart
Senior	Need a simple user-friendly system to enter, track and report production data	Various excel files are present. Information is keyed in twice from paper to paper or from one excel to another	1. Direct Data Entry by Operators against a micro-schedule	Developed a system and was not able to implement owing to technology challenges
		Develop a simple system with existing resources	2. Operations Decision Support System (ODSS)	Rolled out initial version
Ops. Rep	when we have defects, and we want to do away with the Database, how will this be worked into this system?	Existing excel file not user friendly	Developed quality entry module	ODSS Quality Reports
Manager	We'd like to be able to get rates rolled up and by number of pieces for packaging and assembly type	Currently the excel file was not able to provide it	Developed sub task and new reports	ODSS Reports
Scheduler	We have to be able to pull up data by week and by accounting month. Are all the days of the year in the data base so we can use them for reports?	Current excel file has macros and has issues as date is stored as text	Developed automatic accounting calendar lookup using SQL functions.	ODSS Reports
Director	Can we enter comments so that we can track it as communication tool for shift pass down?	Verbal shift pass down and do not know who wrote the production data on the log	Add comment field to data entry	ODSS Data Entry Comment
Director	Can we use this for helping me with planning?	Excel file and multiple sources of data.	1.0 Fetch data directly from Oracle via existing report. 2.0 Export data manually from Oracle and re-import into ODSS.	Waiting for RFS On hold due to Oracle 12.0

Figure 37 ODSS - Gap Analysis

4.2.2 Case 2: Operations Decision Support System (ODSS)

ODSS is a central repository to capture production and performance data. It is an integrated system for managing project, operator, machine, quality, and sub-tasks. It is used to evaluate: (a) performance of a project, (b) efficiency of resources used, and (c) quality of materials produced. The ODSS menu is customized based on the security level granted to a user. Appendix C: Case 2 ODSS Features provides the details of the various user roles and their access level. Figure 38 shows a high-level overview of the ODSS. It has the three core modules. They are: (1) Enter production and quality data → It is used to create the linkage of various inventory numbers to a project, enter forecast for a new project, enter/update production, quality, and operations comment about how well the machine/product/people performed, (2) ERP & system setup → The macro scheduling data from the ERP system is loaded at the start of a project. It is used to add/update various project/machine/people information such as area, machine number, subtask, employee number, product inventory number, PGM - a unique number to track project, (3) Performance Kanban → This has various performance reports to manage operations, for instance, operator, machine, quality for a given area, and custom reports for planning and budgets.

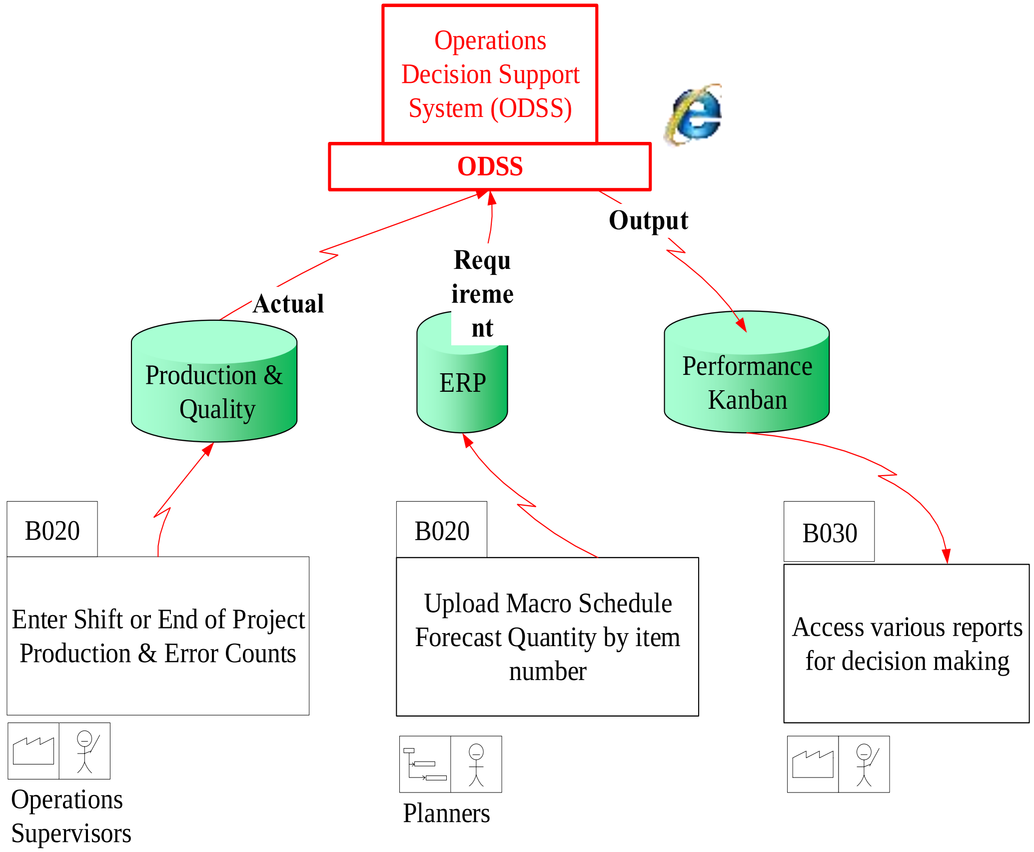


Figure 38 ODSS Framework

4.2.3 Case 2: ODSS Implementation

The ODSS has various features that addressed the existing pain points for the organization. They are discussed in the following sub-sections. Figure 39 shows the main menu of the ODSS. The system has nine different sub menus. They are (1) Production → used to enter data, (2) Area → used to monitor the performance of the departments at shift, monthly and yearly intervals, (3) Quality → used to enter product quality errors, (4) Operator → used to report performance of operators, (5) Project → used to report the project performance and identify gaps in progress referred as "% complete," (6) Machine → used to enter the downtime and monitor performance, (7) System Setup → used to enter master data such as area name, machine name, sub-task rate, (8) Custom Report → used to show customized performance report, and (9) Performance chart → used to show the performance in a graphical format. Based on the user security level, a customized ODSS menu is displayed to the user.

4.2.3.1 Enter Production Details

Figure 40 shows the production entry screen. When the area is selected from the "Area" drop-down, the "Machine #" associated with the area is displayed along with the "Sub-Task" associated with the area. Once these are selected, the program "PG." is selected. It populates the listed "Inventory Number" that is planned for the area. If no inventory number was entered in the ERP, a generic number such as "9999" is selected. Then the "Operator #," "Hours," "Amount," and "Team Size" is selected. Finally, any comments that can be used for the next shift is entered. Once the production data is entered, the production history menu will list all the entries and provide an option to enter downtime, and defects data.

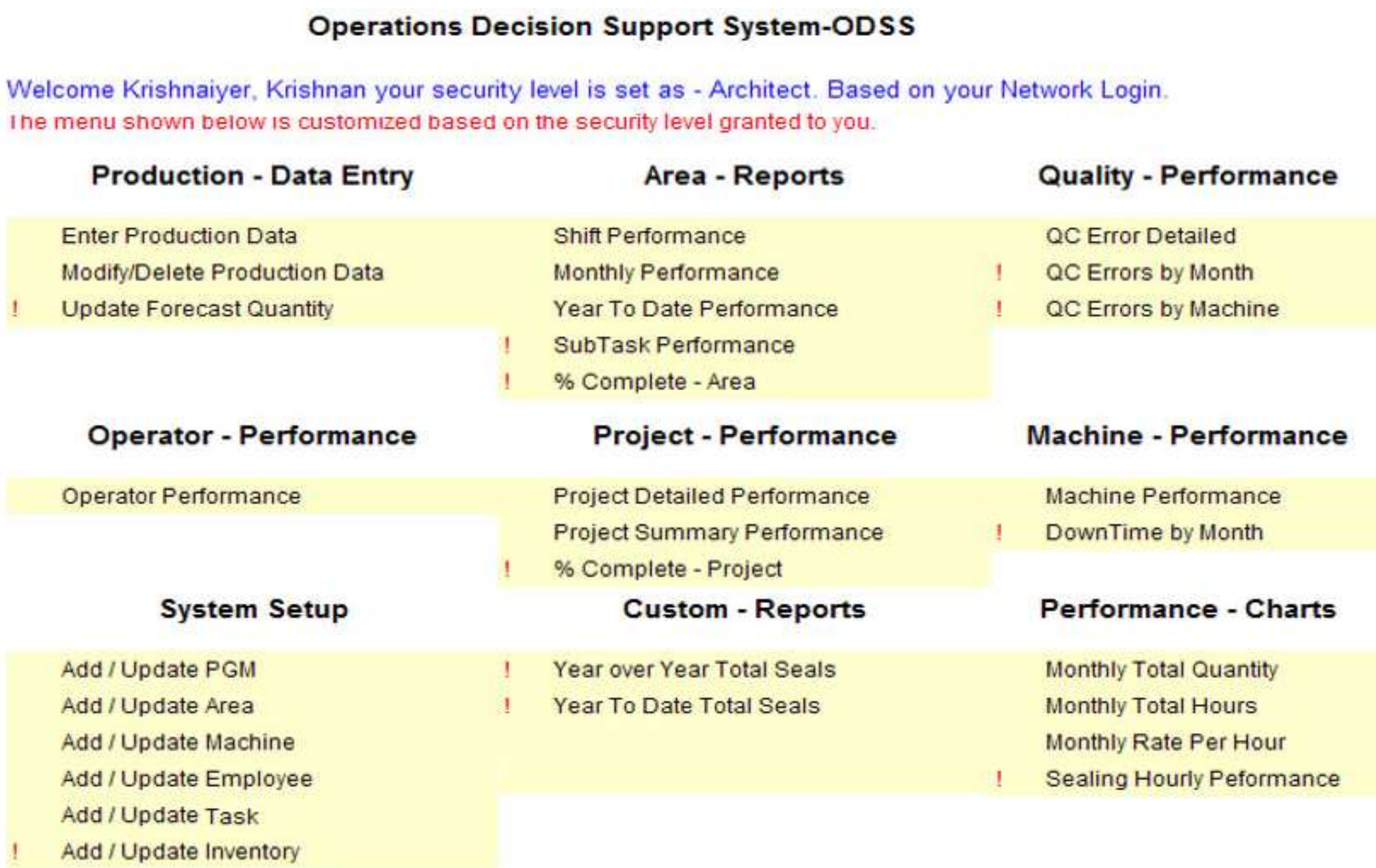


Figure 39 ODSS - Main Menu

Figure 40 shows option "Q" to enter error and "D" to enter downtime. The options are color coded for ease of data entry. For example, "green" indicates that the production entry has no quality or downtime data and "red" indicates entry.

Figure 40 ODSS - Production Entry

Figure 41 shows the screen used to add the number of items that have quality issues (referred as “Error Quantity”), the description of the details about the error, the reason for the error, the action is taken and any additional comments for future reference. Once the entry is saved, it shows the ratio of bad to good products as %Q. This data can be further used to trend the quality issues by the program and by machine at various time periods, including daily, monthly, and yearly.

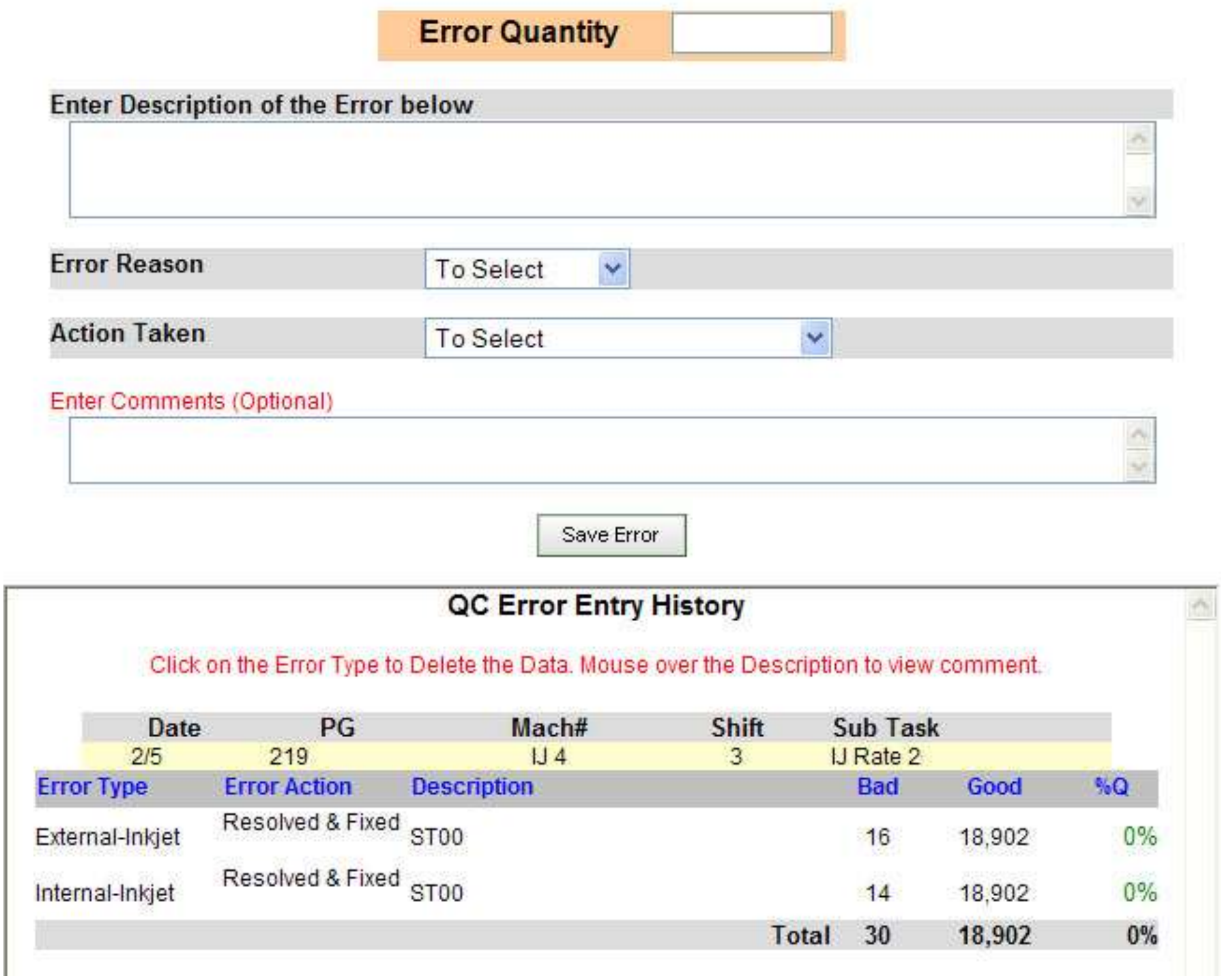


Figure 41 ODSS - Quality Defects Entry

Similarly, Figure 42 shows the downtime entry. Once the reason and hours of downtime are entered, the system calculates the % uptime, based on the total time entered in the production entry. The comments sections provide a simple way to document details behind the reason for the downtime. Information regarding equipment breakdown and quality data is a vital part of the ODSS. This information, coupled with the production rate, is used for various performance report that helps with the planning.

Figure 42 ODSS - Down Time Entry

4.2.3.2 Performance Kanban

In this implementation, the Kanban is used to calculate and estimate the hours needed to complete the forecast quantity. One of the key features of performance Kanban is the "% complete." For a selected area, this report provides the status of the production and the forecast. Figure 43 shows that the delta between the actual and the forecast quantities is expressed as "% complete." The system estimates the hours and shifts needed to complete the tasks for the job using the line standard rate. This valuable analysis allows the operation team to plan and understand their efficiency. For example, Figure 43 lists all the "PGM" for the "Area" "Spi." "PGM" 068 shows that the first activity is lagging the "Forecast Qty" by two, but the third activity is 126% more than the "Forecast Qty." The "% complete" Kanban provides the lagging and leading indicators to monitor performance and suggests new "Line Rate" and "Shifts Needed" to complete the activities on time.

Operations Decision Support System-ODSS - % Complete Act + To-do Summary

Back Print Main Menu

Change 'Area' to refresh the page

Area Spi

PGM	Forecast Qty (1)	Actual Qty (2)	% Complete (3)=(2)/(1)	Remaining Qty (4)=(1)-(2)	Line Rate/STD (5)	Line Hours Needed (6) =(4)/(5)	Shifts Needed (7)=(6)/7.5
068	2	0	0.0%	2	5,650	0.00	0.00
068	22,663	24,624	108.7%	0	5,130	0	0
068	16,156	20,482	126.8%	0	1,751	0	0
822	748,762	0	0.0%	748,762	5,650	132.52	17.67
822	3,363,826	3,514,526	104.5%	0	5,887	0	0
822	2,760,568	295,719	10.7%	2,464,849	5,430	453.89	60.52
826	782,687	762,896	97.5%	19,791	5,393	3.67	0.49
Totals	**7,694,664**	**4,618,247**	**60.02%**	**3,233,404**		**590.08**	**78.68**

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Figure 43 ODSS - Performance Kanban

4.2.3.3 Shift Performance

Figure 44 shows the shift performance. This report compares the overall performance of shifts for an area. The calculation made to arrive at the “labor,” “machine rate,” and “% to STD” are displayed under the column heading, for ease of interpretation of the data. Users can sort the data by “program,” and “sub-task” the system provided “labor rate,” “machine rate” and “% to STD.”

Change 'Area' or 'Date Range' Drop Down to refresh the page

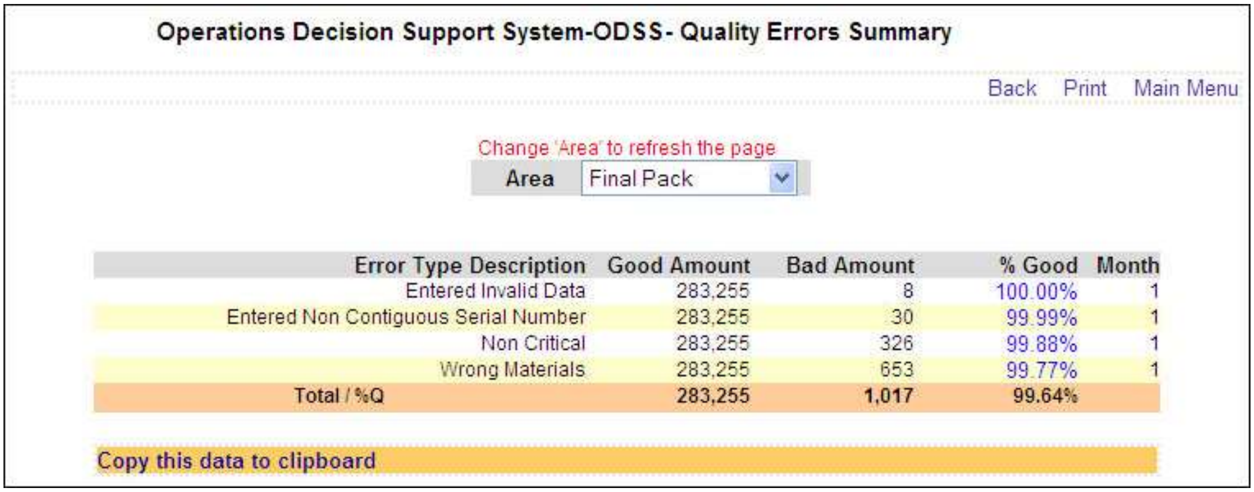
Area: Tab | Date Range: 5 | Sort by PGM | Sort by Sub Task

Date	Shift	PGM	Sub Task	Amount	Labor Hours	Machine Hours	Labor Rate	Machine Rate	% to STD
				(1)	(2)	(3)	(4)=(1)/(2)	(5)=(1)/(3)	(6)
1/28	1	826	1 Tab 3	30,930	15.0	5.0	2,062.0	6,186.0	119%
1/26	1	826	1 Tab 3	15,466	6.0	2.0	2,577.7	7,733.0	149%
1/25	1	826	1 Tab 3	37,024	18.9	6.3	1,958.9	5,876.8	113%
1/24	1	826	1 Tab 3	12,403	4.8	1.6	2,584.0	7,751.9	149%
1/24	2	826	1 Tab 3	24,758	14.7	4.9	1,684.2	5,052.7	97%
		Total / Rate		120,581	59.4	19.8	2,030.0	6,089.9	117%

Figure 44 ODSS - Shift Performance

4.2.3.4 % Good

This report provides errors by area. Figure 45 shows all the errors and provides a % Q for the entire year. It is given by the ratio of bad to good products over a selected period. The final pack is operated at a % Q level of 99.64 %


Operations Decision Support System-ODSS- Quality Errors Summary

Back Print Main Menu

Change 'Area' to refresh the page

Area: Final Pack

Error Type Description	Good Amount	Bad Amount	% Good	Month
Entered Invalid Data	283,255	8	100.00%	1
Entered Non Contiguous Serial Number	283,255	30	99.99%	1
Non Critical	283,255	326	99.88%	1
Wrong Materials	283,255	653	99.77%	1
Total / %Q	283,255	1,017	99.64%	

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Figure 45 ODSS - % Good Performance

4.2.3.5 % Up Time Performance

This report provided the uptime percentage of the machines within an area. Utilizing the production and the downtime entries, Figure 46 shows "% uptime." It is based on a pre-set production hour from the calendar days. The "% uptime" is calculated as the ratio of downtime to production expressed in hours.

Inkjet

Description	Down Hours	Production Hours	% UP Time	Month
Base Issues	0.4	2,285.0	99.98%	1
Replenish Ink Fluids	0.4	2,285.0	99.98%	1
Waiting for BLUE	0.9	2,285.0	99.96%	1
Replenish Plastic Wrap	1.0	2,285.0	99.96%	1
Feeder (Person)	1.0	2,285.0	99.96%	1
Palletizer	1.1	2,285.0	99.95%	1
Printer (Scitex)	1.1	2,285.0	99.95%	1
Heat Tunnel Issues	1.5	2,285.0	99.93%	1
In Line Scale	5.3	2,285.0	99.77%	1
MISC (See Comments)	6.4	2,285.0	99.72%	1
Clean Up	6.5	2,285.0	99.72%	1
Line Setup	16.5	2,285.0	99.28%	1
Meetings	17.0	2,285.0	99.26%	1
Autowrapper Issues	19.4	2,285.0	99.15%	1
Feeder (Mechanical)	28.3	2,285.0	98.76%	1
Exercise & Breaks	51.3	2,285.0	97.75%	1
Total / % Up	**158.1**	**2,285.0**	**93.08%**	

Figure 46 ODSS - % UP Time

4.2.3.6 Operator Performance

Figure 47 shows an operator performance report that compares the production rate to the standard rate. This example shows that the operator is performing at almost twice the SRPH. Typically, this data is used to update production standards for the "Sub Task." This report runs on demand by the FLS and schedulers to understand the calibration needs of the SRPH. Furthermore, this report provides a valuable tool for annual performance evaluation conversation.

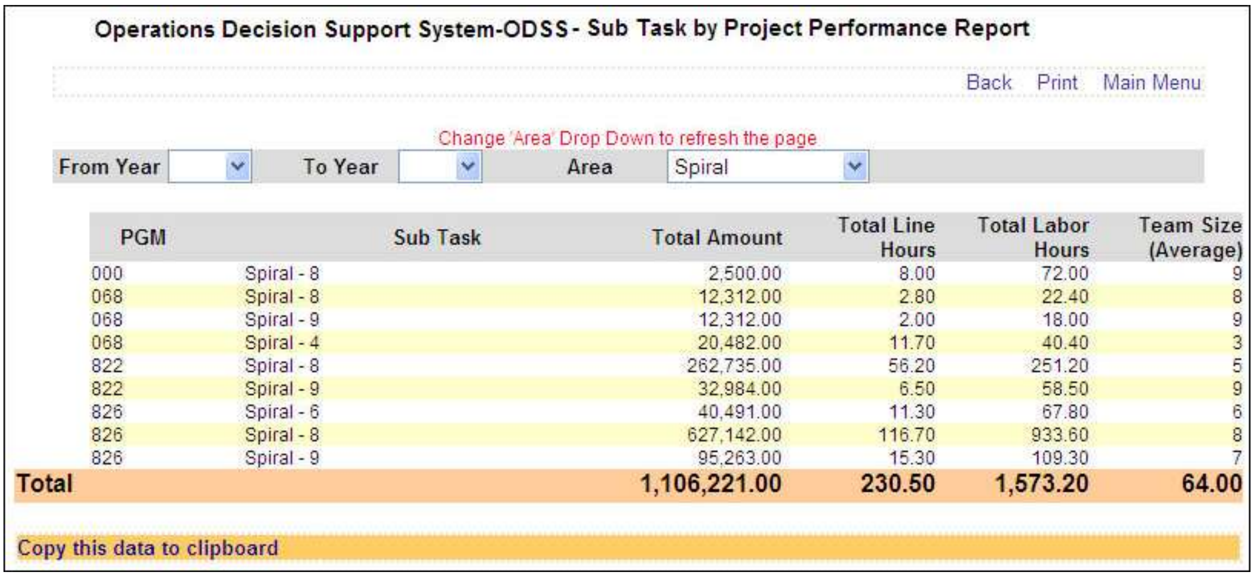
From 12/29 To 1/28 Employee # Smith

PGM	Sub Task	Prod Date	Shift	GIO	Amount	Hours	Rate	STD	STD Amt	% Eff
826	2 Seal	1/10	1	1	60	0.10	600.00	300	30	200%
826	2 Seal	1/14	1	1	60	0.10	600.00	300	30	200%
826	2 Seal	1/14	1	1	60	0.10	600.00	300	30	200%
826	2 Seal	1/14	1	1	60	0.10	600.00	300	30	200%
826	2 Seal	1/14	1	1	60	0.10	600.00	300	30	200%
826	2 Seal	1/14	1	1	60	0.10	600.00	300	30	200%
826	2 Seal	1/14	1	1	60	0.10	600.00	300	30	200%
826	2 Seal	1/14	1	1	60	0.10	600.00	300	30	200%
826	2 Seal	1/14	1	1	33	0.10	330.00	300	30	110%
Total					513	0.90	570.00	270		190%

Figure 47 ODSS - Operator Performance

4.2.3.7 Sub-Task Performance

Figure 48 shows the performance of various activities within an area. It provides key information on how the “Sub Task” was performed along with an average size of the team used. It can be noted that even for a same “Sub Task” (i.e., “Spiral”) with eight people, the actual average can be more than the SRPH.


Operations Decision Support System-ODSS - Sub Task by Project Performance Report

Back Print Main Menu

Change 'Area' Drop Down to refresh the page

From Year | To Year | Area Spiral

PGM	Sub Task	Total Amount	Total Line Hours	Total Labor Hours	Team Size (Average)
000	Spiral - 8	2,500.00	8.00	72.00	9
068	Spiral - 8	12,312.00	2.80	22.40	8
068	Spiral - 9	12,312.00	2.00	18.00	9
068	Spiral - 4	20,482.00	11.70	40.40	3
822	Spiral - 8	262,735.00	56.20	251.20	5
822	Spiral - 9	32,984.00	6.50	58.50	9
826	Spiral - 6	40,491.00	11.30	67.80	6
826	Spiral - 8	627,142.00	116.70	933.60	8
826	Spiral - 9	95,263.00	15.30	109.30	7
Total		**1,106,221.00**	**230.50**	**1,573.20**	**64.00**

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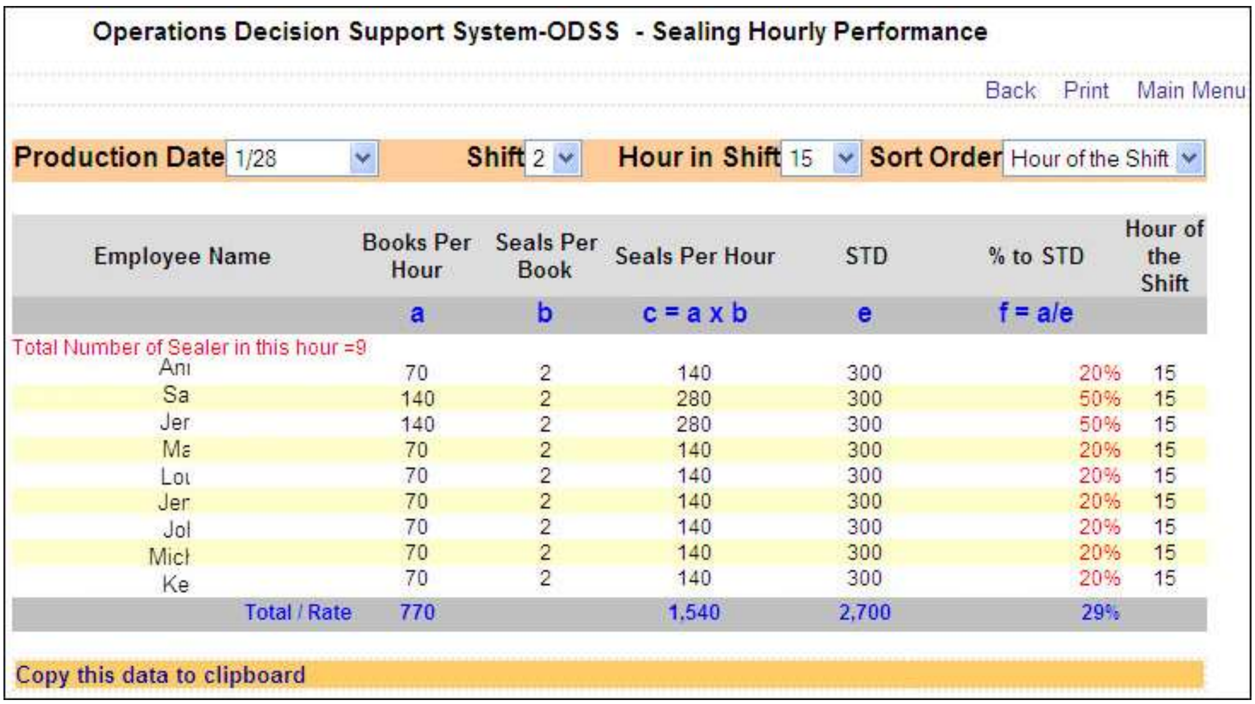
Figure 48 ODSS - Sub-Task Performance

4.2.3.8 Hourly Productivity

Figure 49 shows the hourly performance of the sealing department. “Sealing” is the first step of packaging. This hourly monitoring was achieved by gathering the data at the end of the conveyor line where the sealed booklets are counted, scanned and entered in the ODSS. This report shows how at each hour the team is performing relative to the SRPH. It is used as the Kanban for subsequent operations, for example injecting, pre-pack, and final packing activities.


Operations Decision Support System-ODSS - Sealing Hourly Performance

Back Print Main Menu

Production Date 1/28 Shift 2 Hour in Shift 15 Sort Order Hour of the Shift

Employee Name	Books Per Hour	Seals Per Book	Seals Per Hour	STD	% to STD	Hour of the Shift
	a	b	c = a x b	e	f = a/e	
Total Number of Sealer in this hour =9						
Ani	70	2	140	300	20%	15
Sa	140	2	280	300	50%	15
Jer	140	2	280	300	50%	15
Ma	70	2	140	300	20%	15
Lo	70	2	140	300	20%	15
Jer	70	2	140	300	20%	15
Jol	70	2	140	300	20%	15
Mic	70	2	140	300	20%	15
Ke	70	2	140	300	20%	15
Total / Rate	770		1,540	2,700	29%	

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Figure 49 ODSS - Hourly Productivity

4.2.3.9 Usage Tracking

Figure 50 shows the usage trend of the system on a weekly and monthly frequency. All unique single clicks of the users are tracked to see what reports are being used by the users.

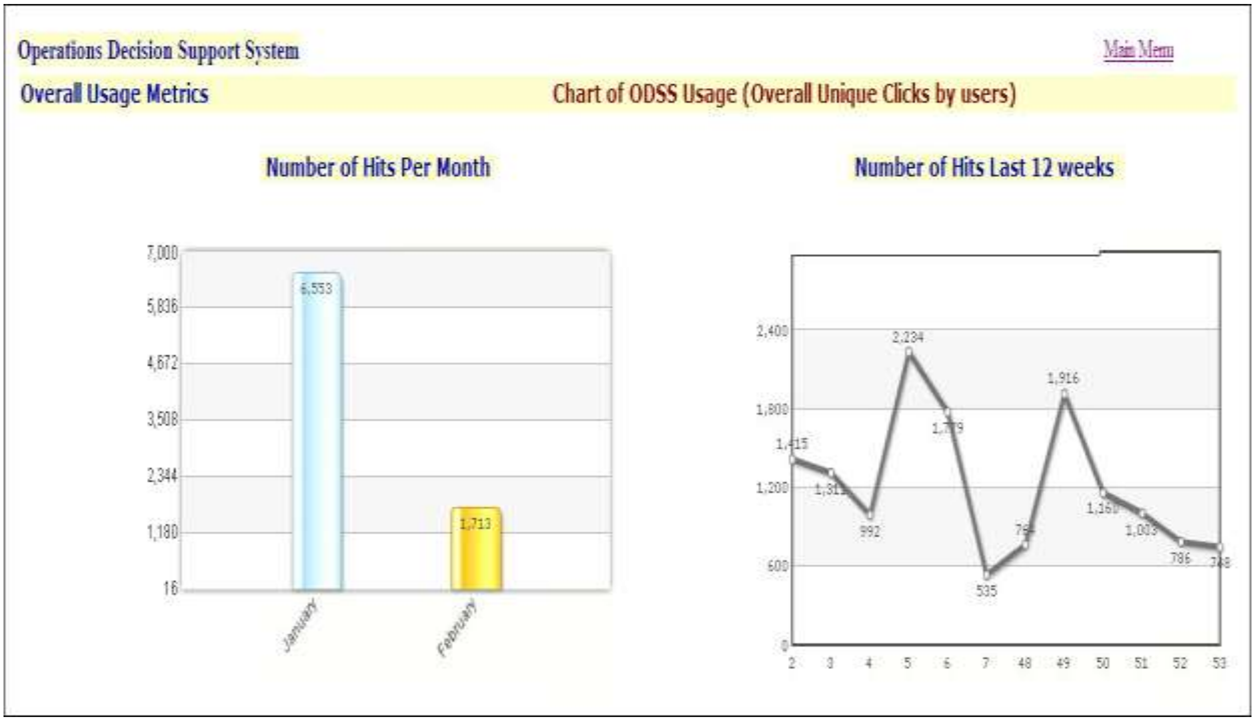


Figure 50 ODSS - Usage metrics

4.2.3.10 Yearly Planning Horizon

Utilizing the run rates in the ODSS and the forecasted volume from the ERP, the ODSS creates a weekly plan. Figure 51 shows the report that provides a summary of expected hours, people or shifts by default. The peak demand of individuals occurs in the week 13, and it tapers down after week 13. This trend is same in “line hours,” “shift,” “labor hours” and “people needed.” This report is quite useful to sort through planned hours, individuals or shifts and provides a high-level resource planning information to the FLS. It is easy to visualize the peak periods in a stacked bar chart format that aids the FLS to plan over time and flex-labor resources

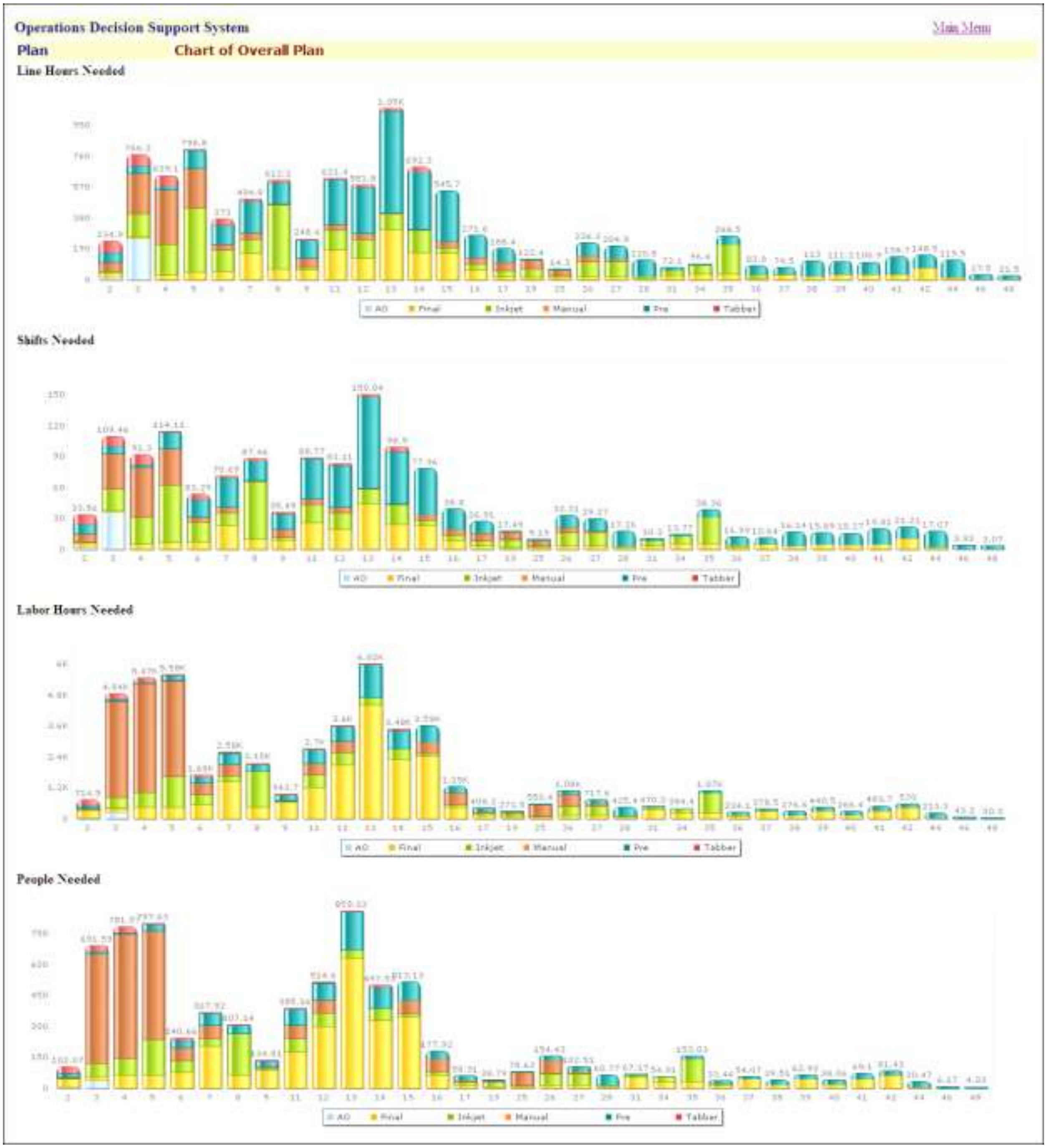


Figure 51 ODSS - Operations Resource Plan by Week

4.2.4 Case 2: Summary

Using the AR and CI approach ODSS was designed, implemented and sustained as a DSS for FLS and management. ODSS was first implemented successfully at one site. The initial value creation allowed the management to make the decision to utilize ODSS in one more site. Team. ODSS became the “Single Source of Truth” for making efficient and effective resource management decisions. The benefits obtained by implementing ODSS are detailed in section 6.2. Both the implementations were constrained by the legacy systems and dependency on existing infrastructures. Framework to migrate ODSS to a cloud-based DSS is covered in chapter 5. By leveraging CKDSS, TCO and deployment time can be further reduced.

CHAPTER FIVE: CLOUD-BASED KANBAN IMPLEMENTATION

This chapter describes the cloud-based Kanban design, development and implementation referred as “Cloud Kanban (CK).” The first part of the chapter describes CKDSS framework. The second section of the chapter highlights’ ACO for TCT minimization. The third section describes the Microsoft cloud platform architecture –Azure™, followed by the implementation steps Lastly, this chapter covers the various features of CKDSS including the cloud-based EAT Kanban and the ACO based job TCT minimization DSS.

5.1 Cloud-based Kanban Decision Support System (CKDSS)

CKDSS is one of the key features of CK. Figure 52 shows the six foundational elements of CK. They are (1) Service Plan → houses the license key for the system that determines the size and scale of the system, (2) Database → holds the production and planning data needed. The database server can be configured based on the application need, (3) Application Server → a container that facilitates publishing of web pages, (4) Active Directory (AD) → which forms the base of user authentication. This layer eliminates the need or a separate username and password for the application access. End users can log in using the organization’s email credentials, (5) User Interface → front-end screen for end user interactions and contain the drop-down menu, and buttons, and (6) Business Logic → encompasses the business rules needed to accomplish data entry and reporting. These six elements of the cloud model can be switched on and off, scaled up and from any modern web browsers. In our example, our active directory was user@cloudkanban.onmicrosoft.com; the database was a Microsoft SQL server, App service was

Microsoft Azure Web Service, Service Plan was Microsoft Imagine, the User Interface was built in Model-View-Controller .Net Framework and the business logic was written in c#.

Figure 52 CK - Framework

5.2 Ant Colony Optimization for Cloud Kanban Implementation

Figure 53 shows the five steps of the Ant Colony Systems (ACS) algorithm. The five stages are (1) Input Parameters → captures the parameters for the algorithm, (2) Initialization → computes the job completion time and due date matrix, calculates the tour length, and initiates the pheromone matrix, (3) Ant Generation → generates the ants randomly and place them on each job and initiates the tour array matrix, (4) Ant Walk → moves ants from one node to another based on the local pheromone update. When the tour is completed the TCT is calculated, and the global pheromone is updated. The top three best paths for the iteration is stored, and (5) Output → repeats the steps one to four until the maximum iteration is reached, computes the best path is computed and displays the best job sequence and its TCT.

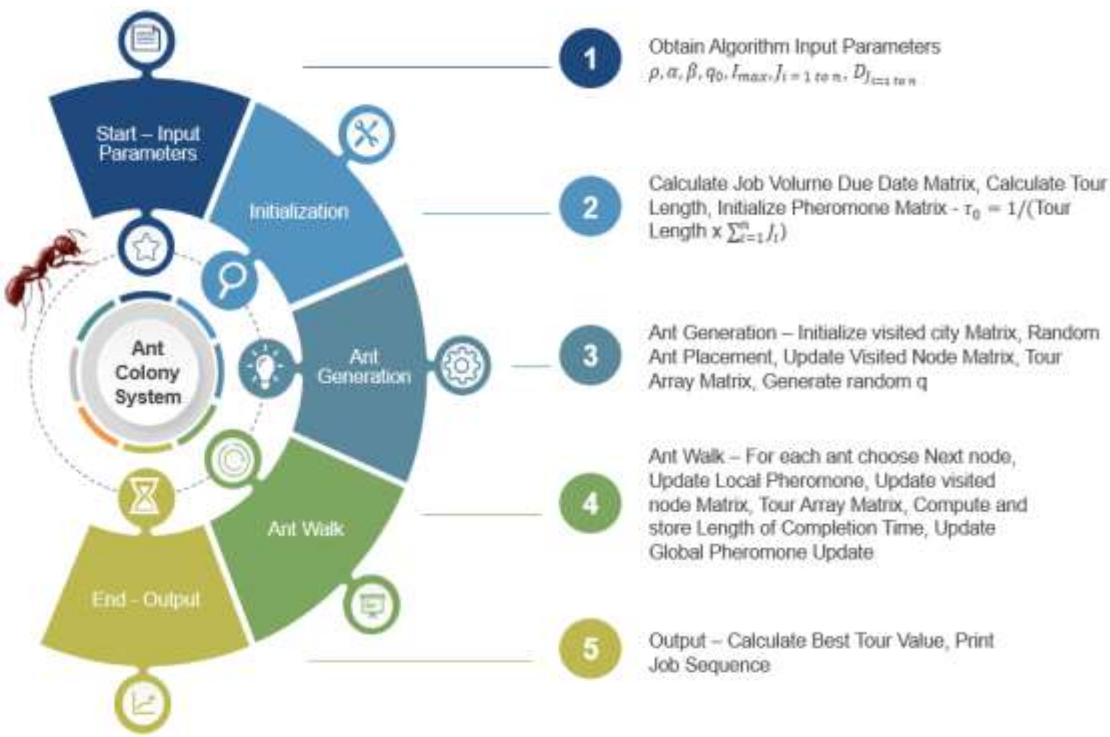


Figure 53 CK - Ant Colony System [5]

5.3 CK Architecture

The four-tier Microsoft Azure architecture of CK (Refer Figure 54) are (1) App Tier → end-user facing tier that has the Model-View-Controller based Microsoft .Net application,(2) Data Tier → Microsoft Azure SQL database that host the relationship tables, (3) Identity Tier → AD domain controller that redirects traffic for authentication (prompt credentials) and authorization (secure token for access), and (4) Azure Virtual Network → enables communication for all resources and the Internet.

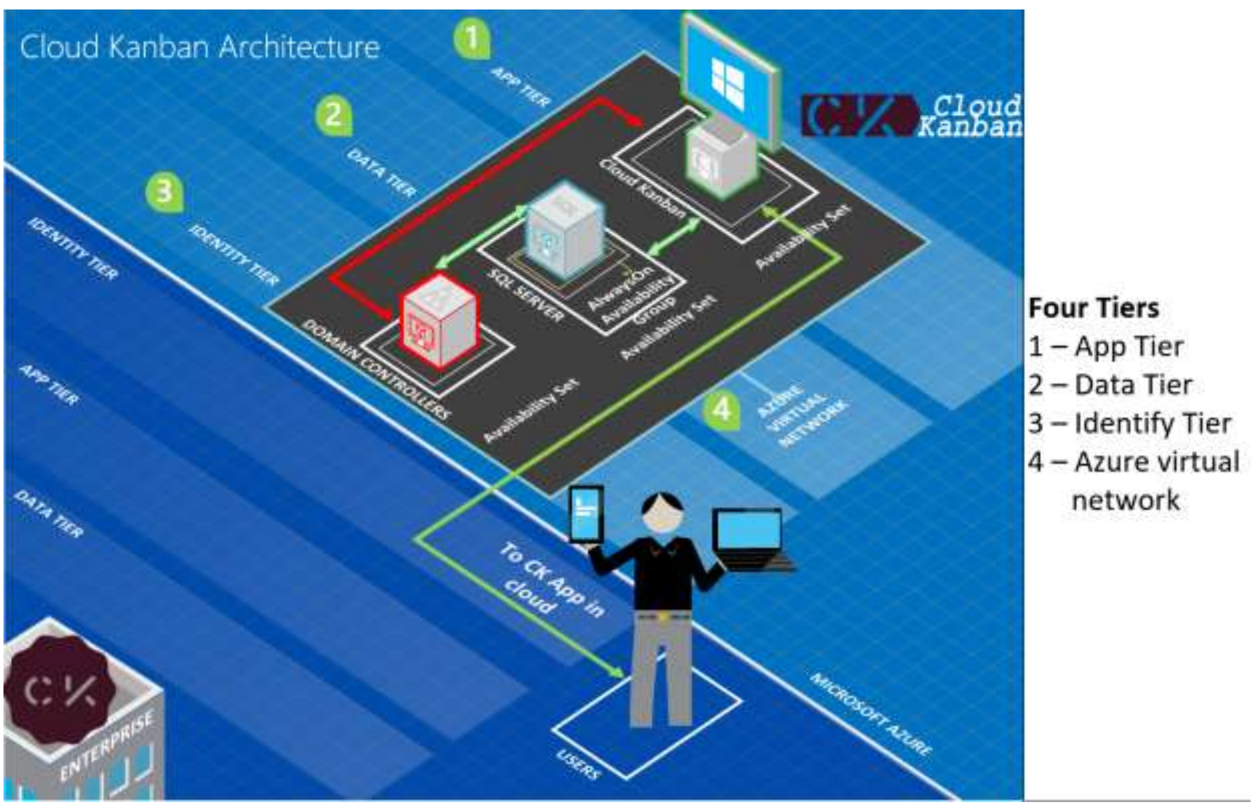


Figure 54 CK - Azure Architecture

5.4 CKDSS Implementation

Figure 55 shows a five-step implementation framework for operations engineering. In a typical operation, there is a job order that constitutes multiple activities. The first step is to schedule the total amount of the job and create individual activities for it. For all the activities (n=1,2,3 to N) for the job, an estimated amount per shift (s =1 to 3) is built. The amount per shift is computed based on the SRPH for the activity. The second is to establish a rough-cut schedule. Typically, a "Capacity Vs. Requirement" analysis is performed based on existing resources. Various factors such as the number of machines available, number of employees and raw material availability are displayed. The third step is a decision support system simulation. For priority jobs, an Ant Algorithm based simulation is run to understand the optimization feasibility of the rough-cut schedules. Based on the results, fine-tuning of rough cut schedules is performed if needed. The fourth step is to gather the actual production quantities. The labor hours used, amount of bad quality product and production hours lost due to downtime is also entered. Over time production data gathered helps to refine and set SRPH. The final step is the display the job and activity progress based on the EAT Kanban.

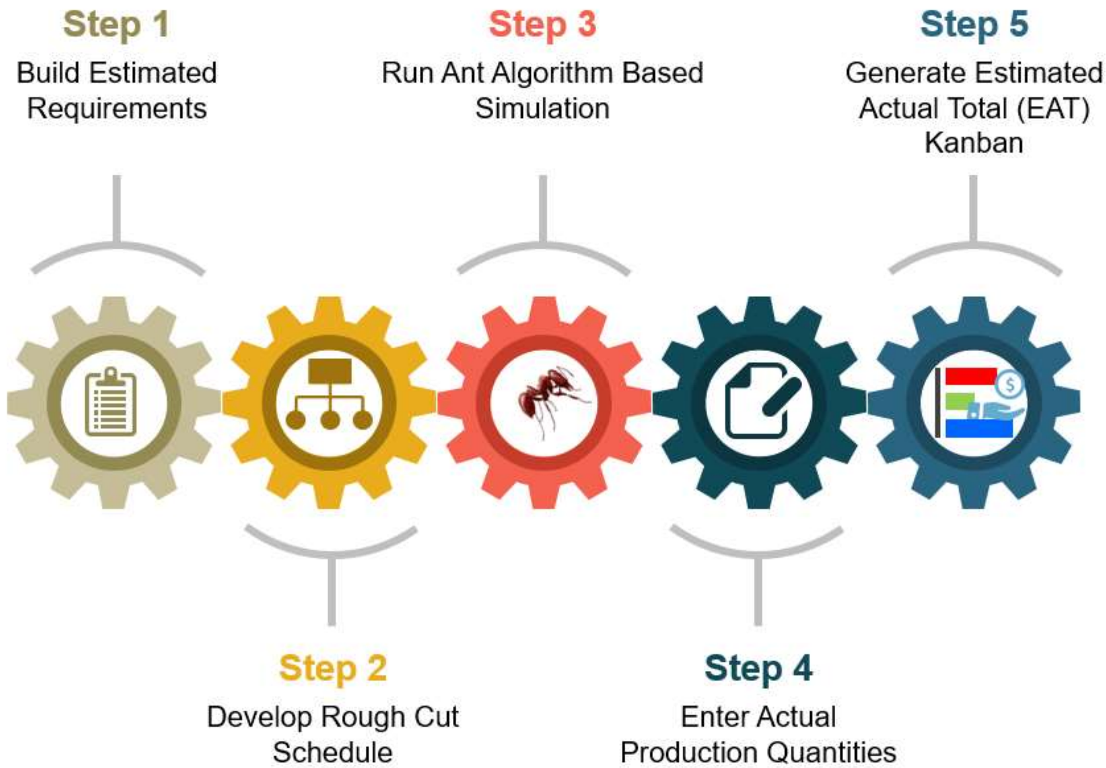


Figure 55 CKDSS Implementation Framework

5.5 CK Features

Figure 56 shows the CK system main menu. There are seven modules in CK. They are: (1) Production → enter production data, (2) Scheduling → select activities for a job, to create job schedule and to view EAT Kanban, (3) Performance Indicators → view operator, machine and job performance for a selected timeframe, (4) Decision Support → run ACS based TCT for selected jobs, (5) Quality → perform corrective and preventative actions, (6) Customer Support → enter job status comments for communication, and (7) Financial Engineering → shows the job profit EAT Kanban. The CK can be completely customized based on the user roles.

Figure 56 CK – EAT Kanban DSS Main Menu

5.5.1 CK Administration

Figure 57 shows the administration menu. This menu is used for managing various existing and new master data, such as customer name, job details for a customer (including job description, quality, start and end due dates,) activity details (activity description, SRPH, MCPH, and LCPH), department name, machine name and linking machines to department, quality error, and, downtime descriptions. Appendix D: CK Features has screenshots of the various administration screens.

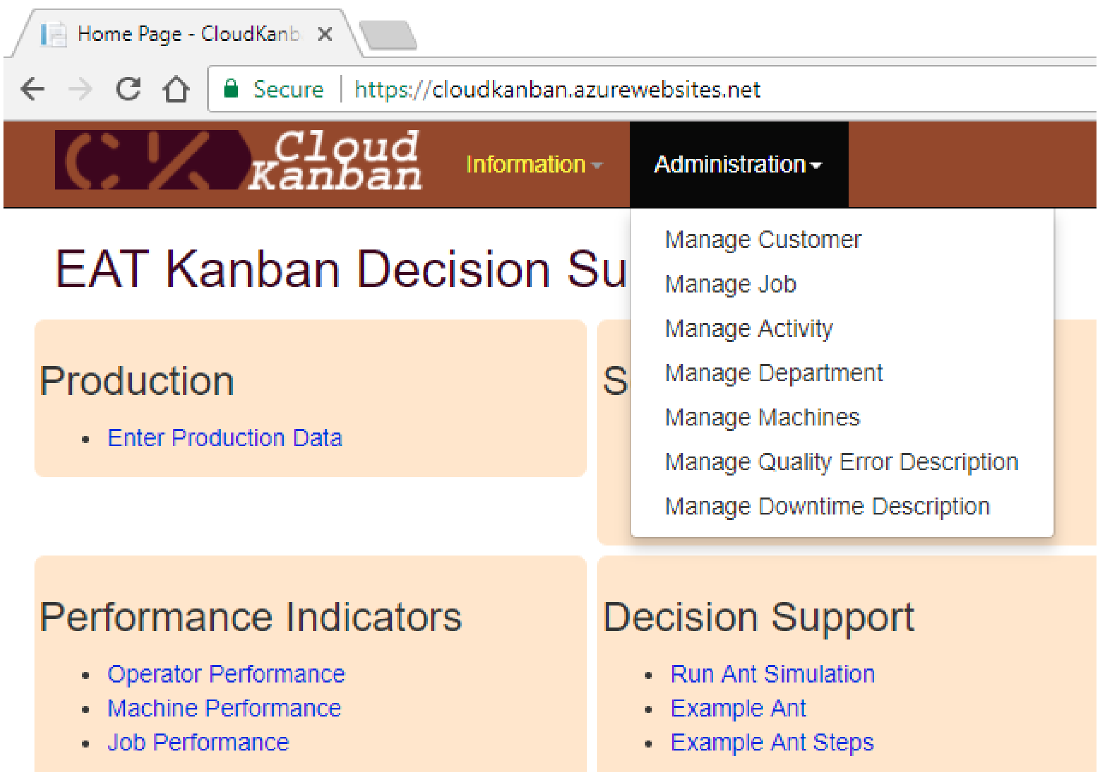


Figure 57 CK - Administration Menu

5.5.2 CK Scheduling

After setting up the master data in the administration, CK scheduling, as shown in Figure 58, allows the schedulers to link various activities that must be completed for a selected job. The activities are selected by checking/unchecking the boxes next to it. After checking the required activities, pressing the “Save” button creates the job-activity link. The link helps with increased data accuracy during production data entry as only the activities that are scheduled will appear in the drop-down menu.

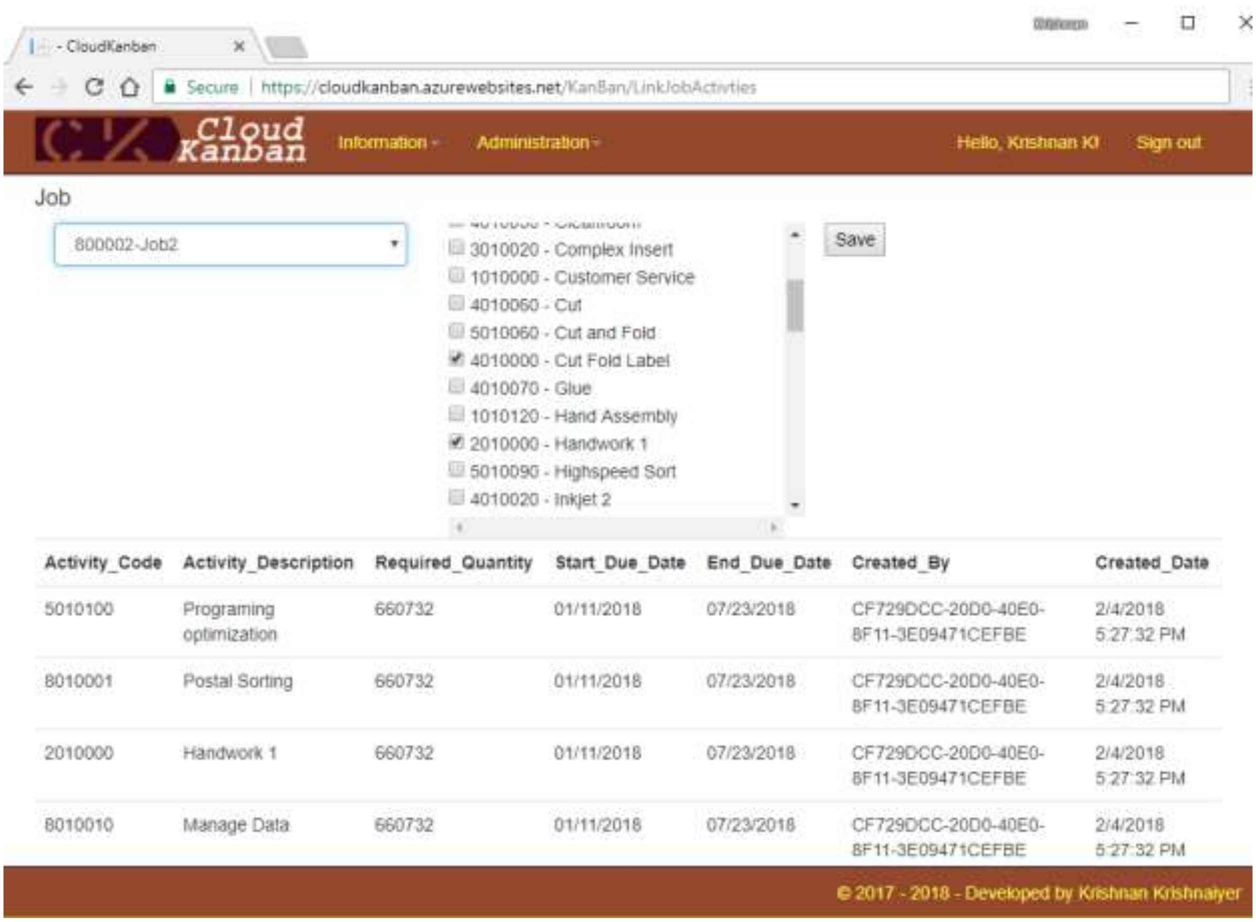


Figure 58 CK - Create Job Activities

5.5.3 CK Rough-cut Scheduling

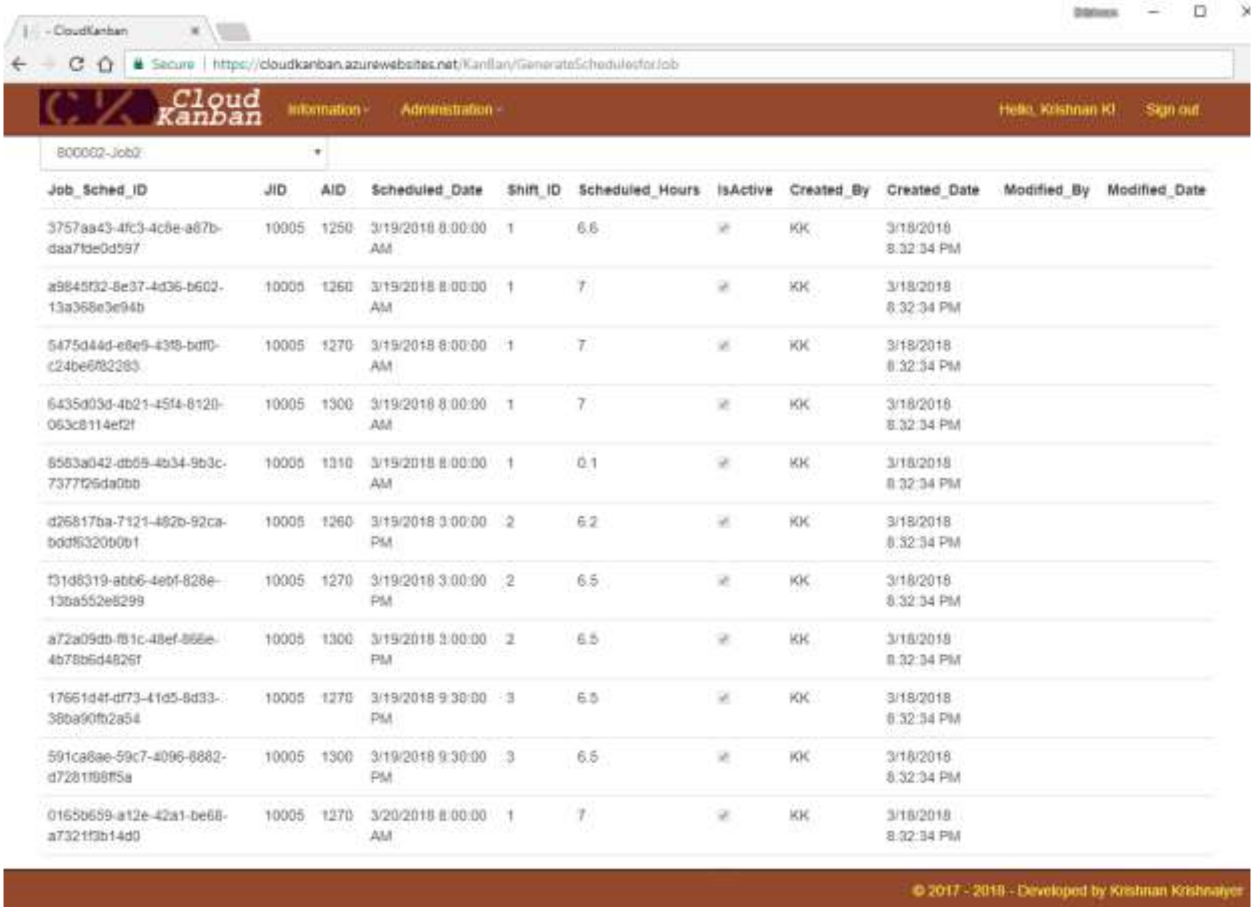
CK has a user-friendly feature to develop a rough-cut schedule. The Number of Schedule Days (NSD) is calculated based on the following values (1) TPH → ratio of activity total quantity and SRPH, and (2) Hours Per Shift (HPS). When the user selects the job, then CK displays the schedule if it is already scheduled or will show "Create Schedule" button (Refer Figure 59.) When the users click the "Create Schedule" button, the CK will create the schedule based on Equation 15 and Equation 16

$$TPH = \frac{Activity\ Total\ Quantity}{SRPH} \qquad \textit{Equation 15}$$

$$Schedule\ for\ Activity_{i=1\ to\ TPH} = (TPH - HPS_s)\ where\ s = 1\ to\ 3 \qquad \text{Equation 16}$$

Figure 59 CK - Create Schedule

For example, for activity 1260 in job 10005 the values are PHPD = 20, SRPH = 50,000, activity total quantity is 660,732. CK calculates TPH as 13.2, and it schedules 7 hours for shift 1 and remaining 6.2 hours for shift 2. Figure 60 shows the rough-cut schedule generated by CK for job 2.



Job_Sched_ID	JID	AID	Scheduled_Date	Shift_ID	Scheduled_Hours	IsActive	Created_By	Created_Date	Modified_By	Modified_Date
3757aa43-4fc3-4c8e-a87b-daa71de0d597	10005	1250	3/19/2018 8:00:00 AM	1	6.6	✓	KK	3/18/2018 8:32:34 PM		
a9845f32-8e37-4d36-b602-13a368e3e94b	10005	1260	3/19/2018 8:00:00 AM	1	7	✓	KK	3/18/2018 8:32:34 PM		
5475d44d-e8e9-43f8-bdf0-c24be6f82283	10005	1270	3/19/2018 8:00:00 AM	1	7	✓	KK	3/18/2018 8:32:34 PM		
6435d03d-4b21-45f4-8120-063c8114ef2f	10005	1300	3/19/2018 8:00:00 AM	1	7	✓	KK	3/18/2018 8:32:34 PM		
8583a042-db69-4b34-9b3c-7377f26da0bb	10005	1310	3/19/2018 8:00:00 AM	1	0.1	✓	KK	3/18/2018 8:32:34 PM		
d26817ba-7121-482b-92ca-bddf6320b0b1	10005	1260	3/19/2018 3:00:00 PM	2	6.2	✓	KK	3/18/2018 8:32:34 PM		
f31d8319-abb6-4ebf-828e-13ba552e8299	10005	1270	3/19/2018 3:00:00 PM	2	6.5	✓	KK	3/18/2018 8:32:34 PM		
a72a09db-f81c-48ef-866e-4b78b6d4826f	10005	1300	3/19/2018 3:00:00 PM	2	6.5	✓	KK	3/18/2018 8:32:34 PM		
17661d4f-df73-41d5-8d33-38ba90fb2a54	10005	1270	3/19/2018 9:30:00 PM	3	6.5	✓	KK	3/18/2018 8:32:34 PM		
591ca8ae-59c7-4096-8882-d7281f88ff5a	10005	1300	3/19/2018 9:30:00 PM	3	6.5	✓	KK	3/18/2018 8:32:34 PM		
0165b659-a12e-42a1-be68-a7321f3b14d0	10005	1270	3/20/2018 8:00:00 AM	1	7	✓	KK	3/18/2018 8:32:34 PM		

Figure 60 CK - Rough-cut Job Scheduling

5.5.4 CK EAT Kanban

Figure 61 shows an EAT Kanban, based on the section 300 description. CK displays the Kanban depending on the “From date” and “To date” selected.

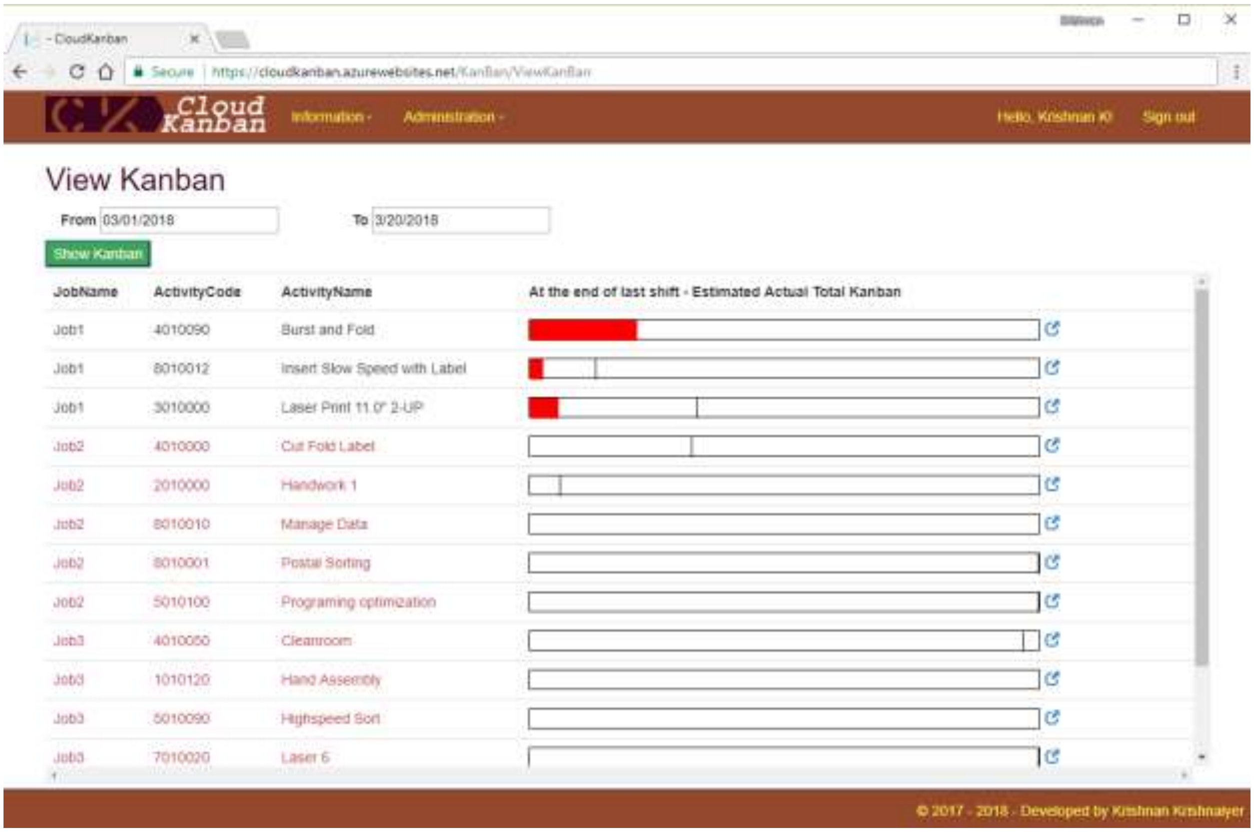


Figure 61 CK - EAT Kanban

5.5.5 CK Decision Support Predictive Kanban

When end-users click the icon near the Kanban bar, CK shows Figure 62 which is a predictive Kanban. For example, job 1's due date is 03/22/18. CK predicts the estimated completion date and shift of the job and shows in "red" if the completing date is beyond end due date. Furthermore, predictive Kanban calculated the average current production rate and estimated two options (1) New run rate based on the existing machine schedule. For job 1, the run rate should improve from 8,690 to 25,642, and (2) Number of machines needed to complete the job with the new run rate. In this example, job 1 needs a total of 3 machines. The predictive Kanban is a DSS that helps end-users to monitor resource needs without going through laborious calculations, thereby saving valuable time and effort.

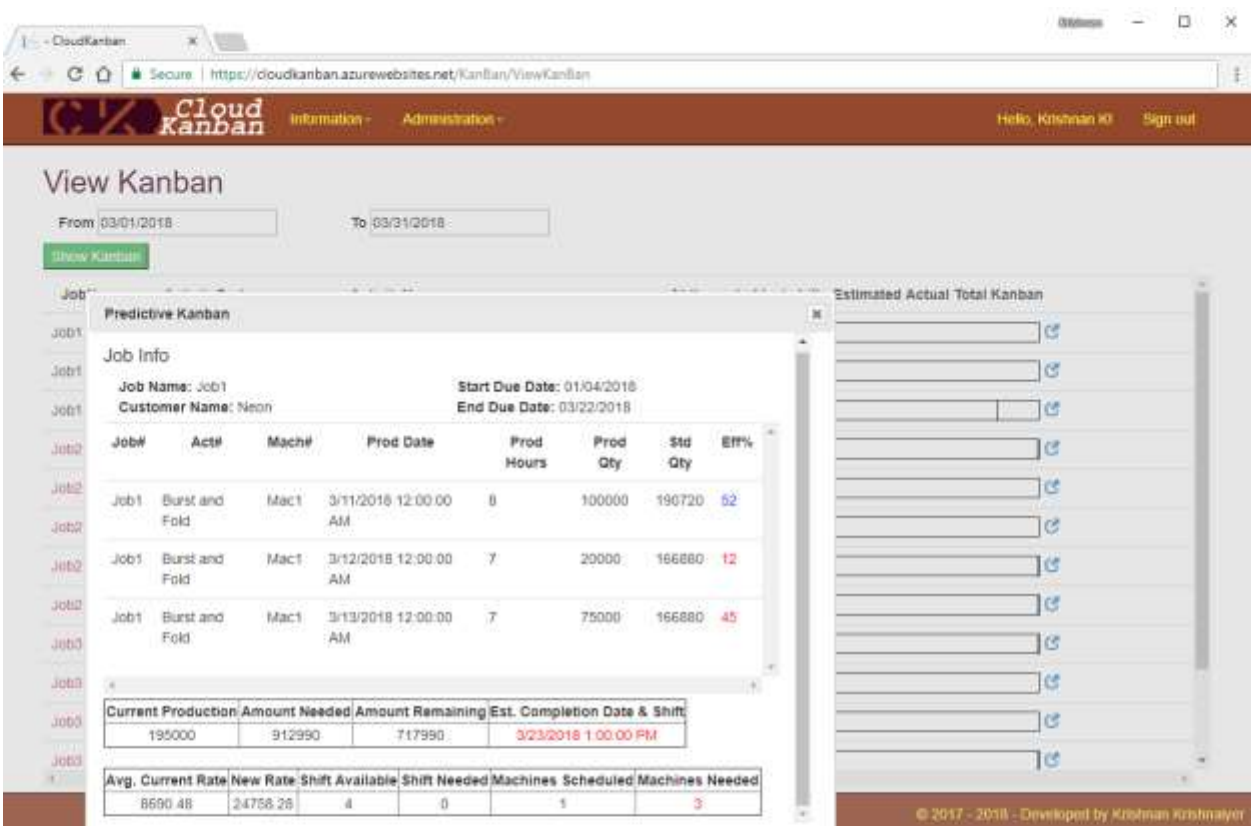


Figure 62 CK - Predictive Kanban

5.5.6 CK Production

Figure 63 shows the screen for production data entry. CK allows entry of production details including the “Quality Error” and “Machine Downtime” data. This data entry feature helps to understand machine, operator and job performance. Furthermore, it provides awareness to mature the CI journey of an organization by computing OEE which is based on the % up-time, % quality and % to standard.

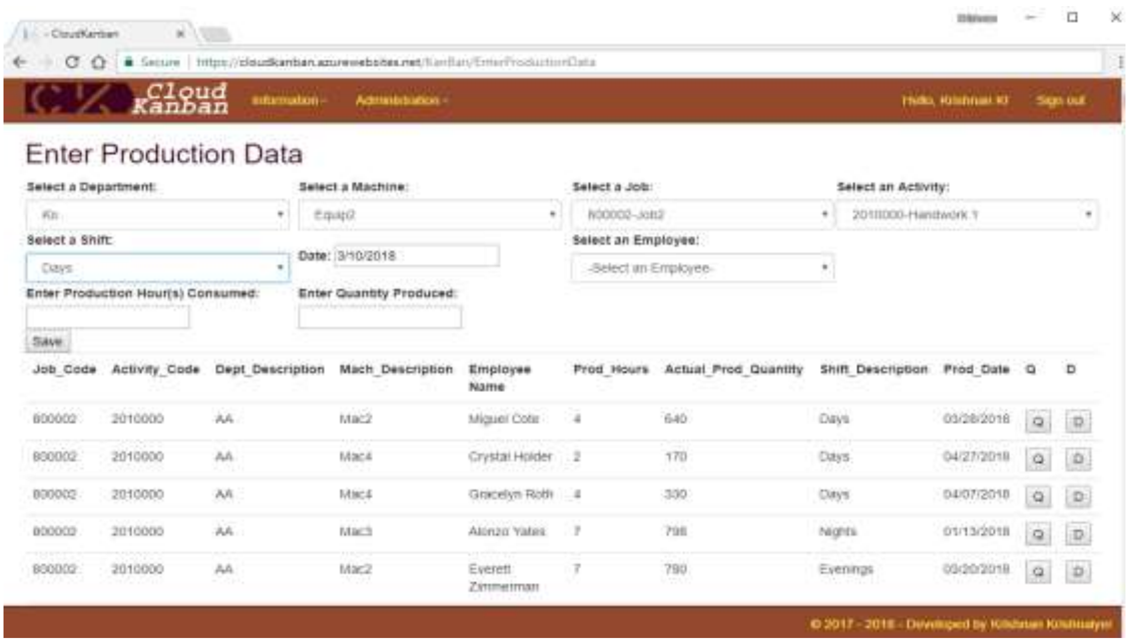


Figure 63 CK - Enter Production Data

5.5.7 CK Financial Engineering

Figure 64 shows a job cost Kanban, using the EAT Kanban for the scheduling. The finance Kanban depicts the cost of jobs. For example, job 1 activity 8010012 has a total machine and labor cost of \$20 vs. an expected cost of \$310. The conversion of volume to cost is performed by the CK using the following formula (Refer Equation 17):

$$Cost = Hours * (Labor\ Cost + Machine\ Cost) \qquad \textit{Equation 17}$$

CK financial engineering view is the reverse view of the EAT Kanban used in the scheduling module. The visual representation helps to understand in real time the cost of operations and the impact of various decisions.

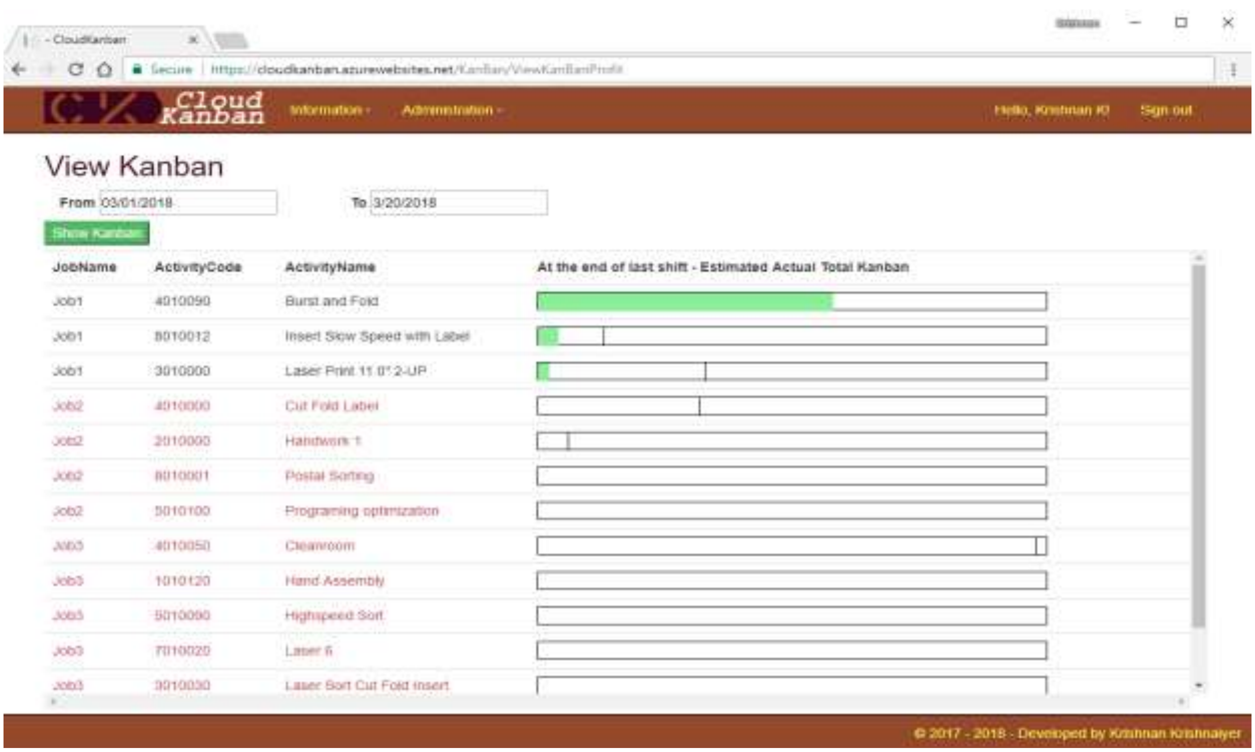


Figure 64 CK - Financial Kanban

5.5.8 CK Performance Indicators

CK has three performance indicator views. They are (1) Operator, (2) Machine, and (3) Job. Figure 65 shows for a selected "Job Name," and "Date From/To," the "Total Hours," "Total Quantity," "Standard Quantity if the activity ran at the SRPH," and "% Efficiency." The efficiency value is color-coded to distinguish the range of performance over SRPH. The other two performance indicators are shown in Appendix D: CK Features

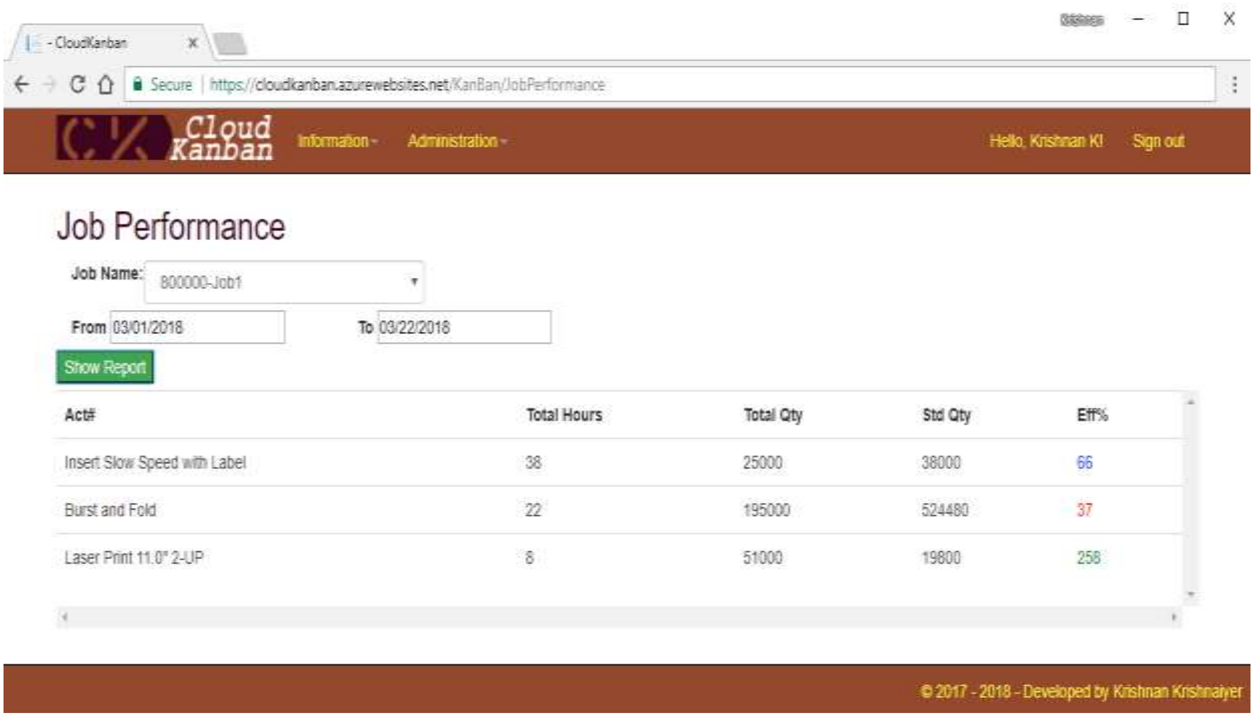


Figure 65 CK - Job Performance

5.5.9 CK Quality

Figure 66 shows the Corrective and Preventative Action (CPA) data entry screen. For every production entry, the CK allows Quality department to enter any quality issues. With the quality entry, the defects can be tracked at an operator and machine level and improve the traceability of product to the date of production.

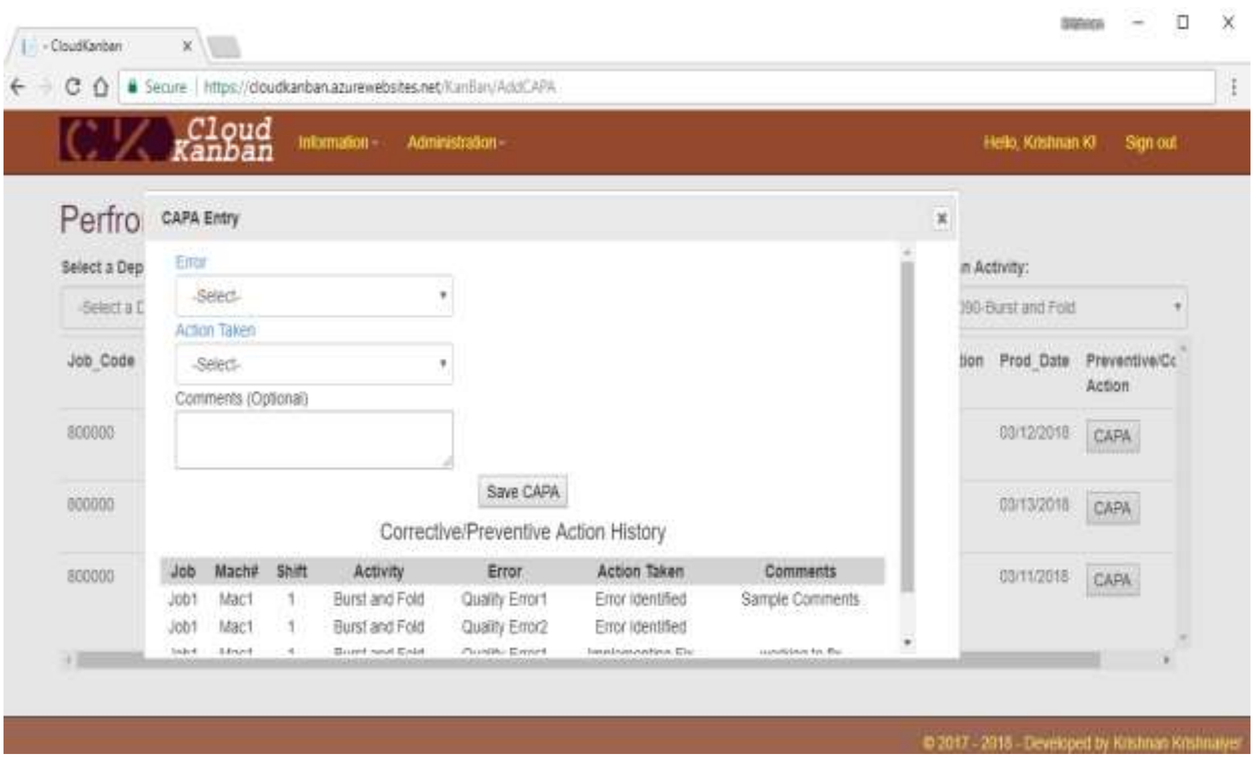


Figure 66 CK - CAPA Entry

5.5.10 CK Customer Support

Figure 67 shows the job comments entry. This screen is useful in maintaining a history of communication relevant to the job progress across various stages.

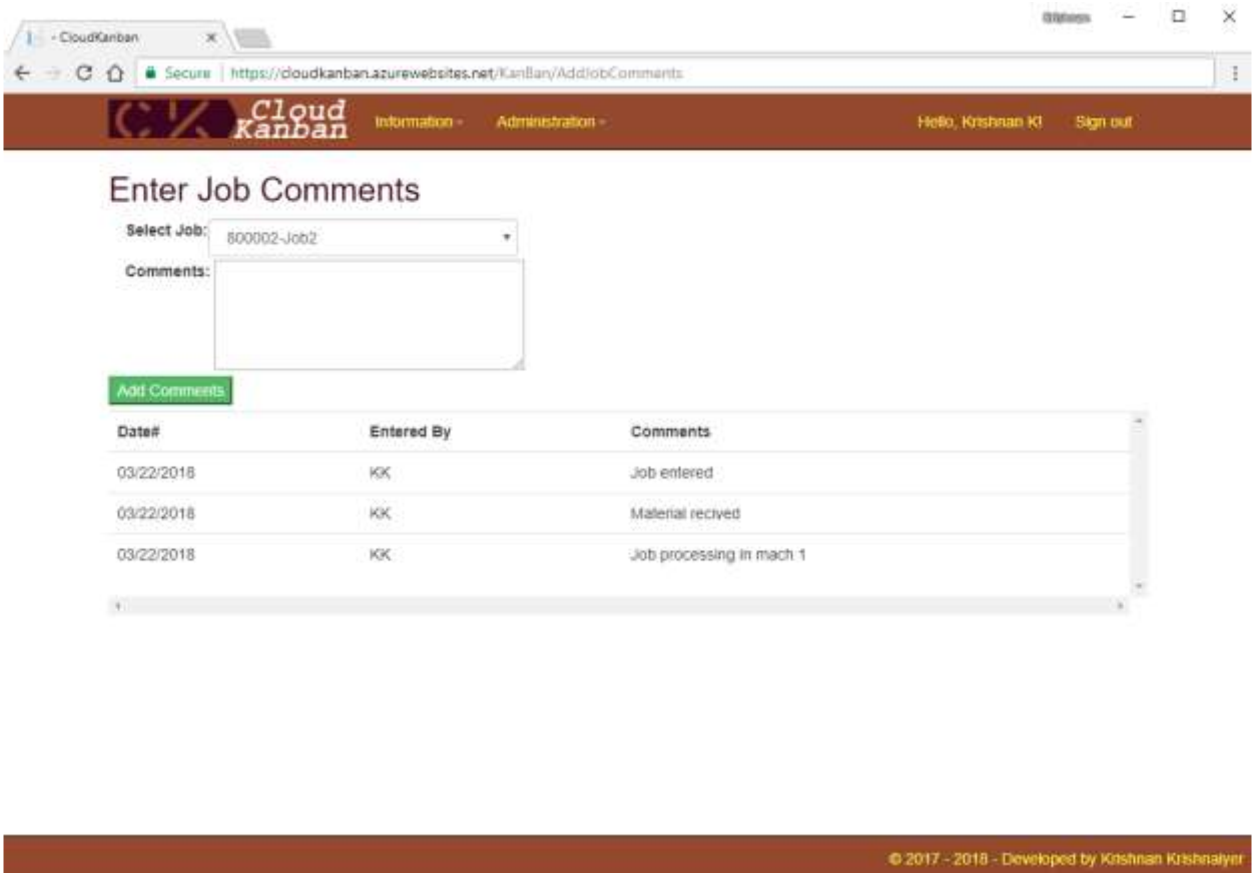


Figure 67 CK - Customer Support

5.5.11 CK Decision Support

Figure 68 shows the ACS for TCT minimization. A list of jobs that are scheduled to run is displayed when the user selects the desired start and end date. By clicking the checkbox near the job in the list, the users select jobs that instruct CK to pass the values to ACS to compute the TCT. The screen allows to enter various parameters value for the ACO and then click the "Show Ant simulation." CK runs the ACS algorithm and displays the best sequence and the TCT.

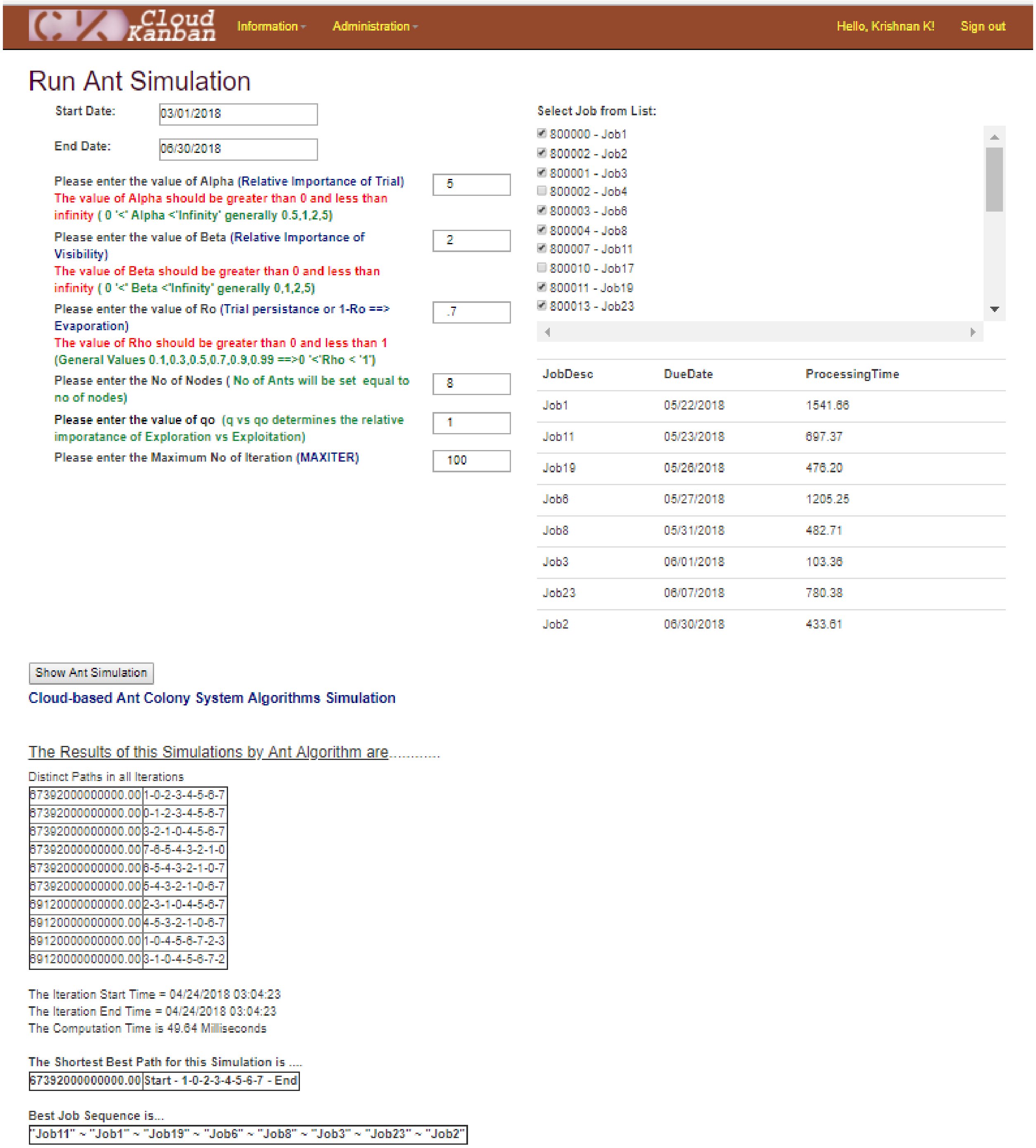


Figure 68 CK – ACS job TCT Minimization

CHAPTER SIX: RESULTS & DISCUSSION

This chapter describes results from two cases: (1) direct mail letter shop and (2) educational service provider. Furthermore, it discusses some advantages of the of CKDSS. Finally, it proposes a possible extension of this research work.

6.1 Case 1: Results & Discussion

WKDSS provided an operations decision system for managers and first line supervisors. It helped to inform the FLS to how they are progressing towards their scheduled production goals. Figure 69 shows the before and after implementation value stream map. It reduced the scheduling time from 180 minutes to 3 minutes. Production operations management teams on a daily basis need to know how much to make and how much is done to meet the scheduled delivery date. It improved the communication of what job to run next during off shifts. It eliminated hours of data duplication. It also provided a common communication platform for off-shift operations. The system eliminated duplicate Microsoft Excel spreadsheets and paper copies of production report, from three spreadsheets to zero spreadsheets. It also eliminated the planning team's employee turn-over. It eliminated the reliance on the tribal knowledge of schedulers. The machines needed to complete the job on- time was calculated more scientifically, resulting in improved data accuracy. It surfaced all mistakes in production data entry and provided centralized communication across customer service representatives, production, and planning team. It provided a single source of truth for job information. Along with all the above benefits, it created clear visibility across off-shifts and helped to achieve 100% on-time delivery, meeting the FMD.

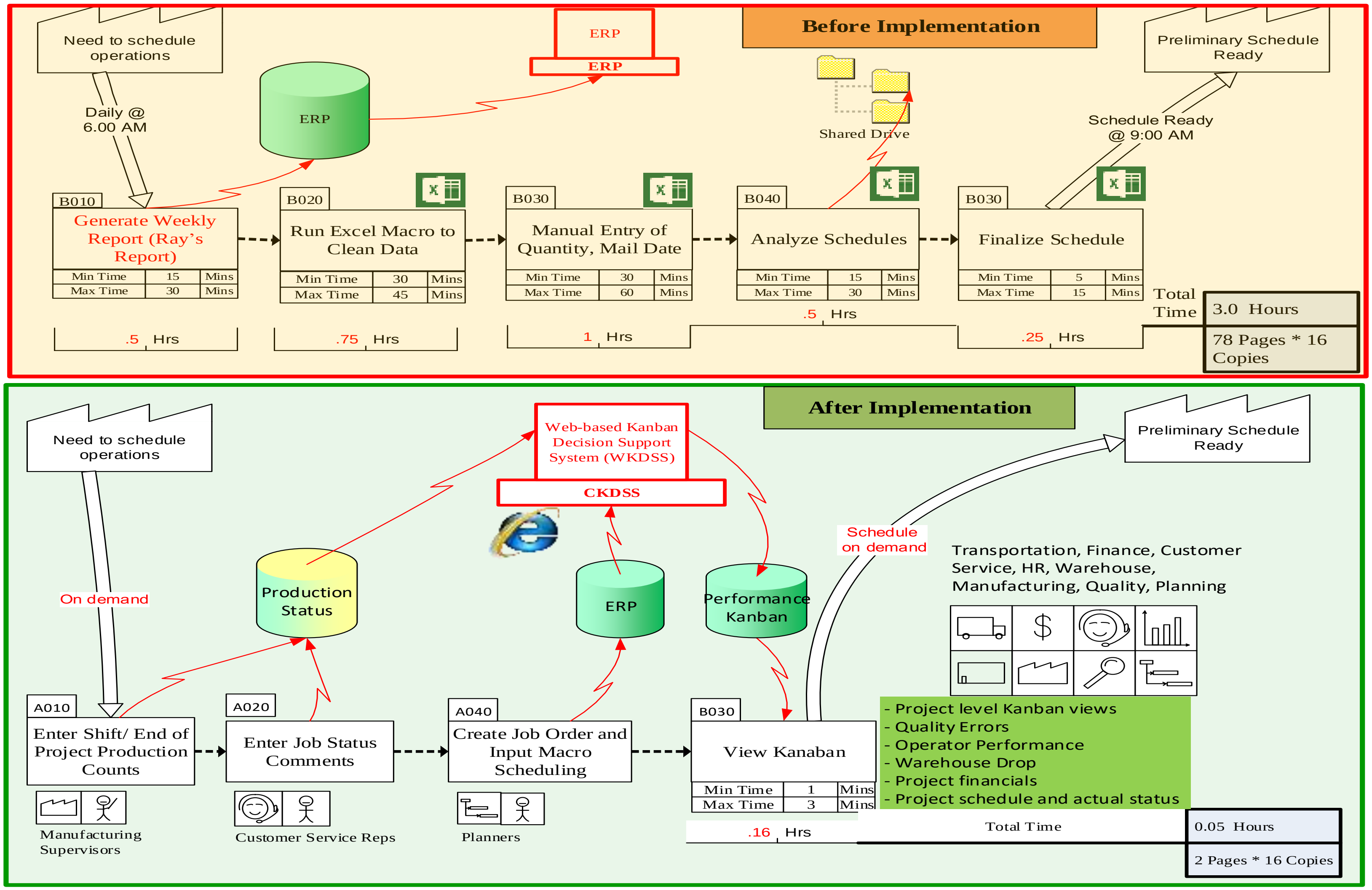


Figure 69 WKDSS Benefits - Scheduling Time Reduction

Figure 70 shows the efficiency trended up, gaining over 6% from the start of the year. When the Kanban is "red," the system aided the supervisor in making appropriate decisions to increase people or machines to meet the scheduled delivery dates. As the system evolved, the users incorporated it into their day-to-day activities. It helped to make many of the team's daily decisions more straightforward. Some of the questions answered were: who the best operators of specific machines are and how did a machine's performance vary over time on a given job. It helped them to plan and identify the best machine for a job by efficiently utilizing people and equipment. Using an enterprise-wide Kanban, underpinned by a robust DSS, helped the organization improve productivity.

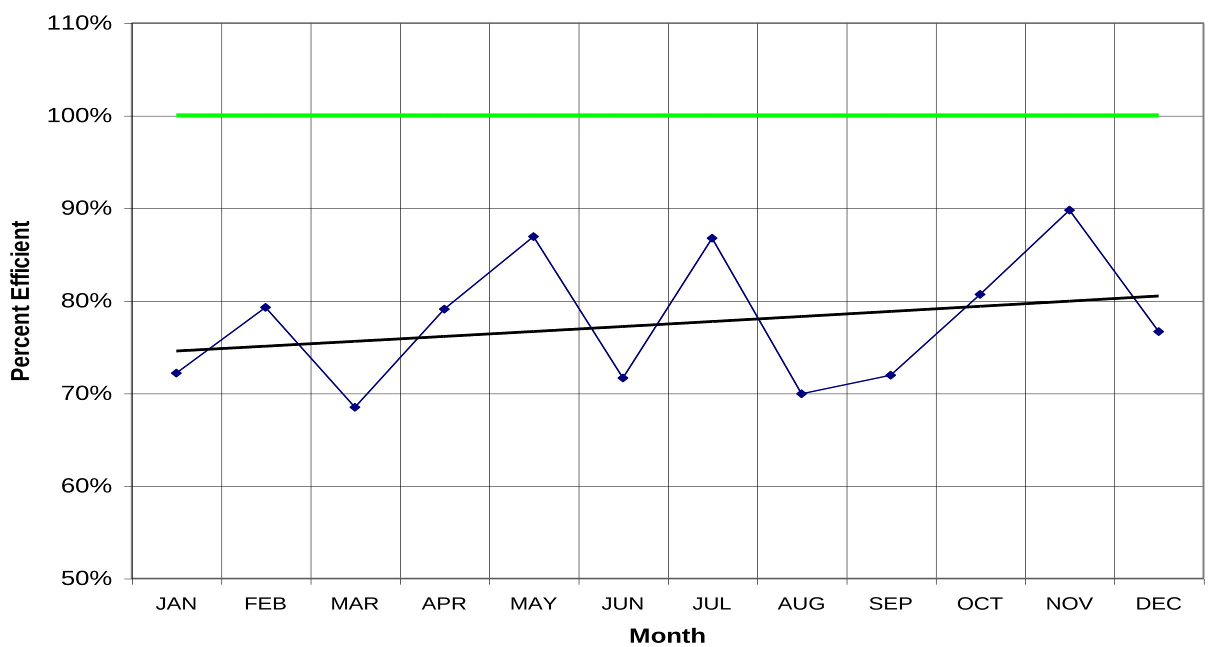


Figure 70 WKDSS Benefits - Productivity Improvement

6.2 Case 2: Results & Discussion

Table 4 and Table 5 show the details of the how the ODSS met the requirements of various departments at two sites. There were different file formats used to track the production and quality details. For example, in site one, the inkjet, pre-pack and final pack teams have Microsoft Excel, and Word-based templates in paper and digital format to track % complete. The ODSS helped to eliminate all these by providing a standardized form for entering the data for all departments. Furthermore, between sites, the same department was utilizing various formats to track productions that result in duplicated data. ODSS helped to consolidate the different types of document formats used to monitor the production data. Three different paper forms for production & quality data entry at inkjet and sealing were consolidated into standard data entry screens for all departments. Before the implementation, the organization had no easy way to compare the performance of departments across sites. ODSS established as a "Single Source of Truth" for operations performance management.

Table 4 ODSS - Benefits Site 1

Needs	Number of Departments	Current Process	Target Solution	Number of Data Sources		% Gain in Data Quality
				Before	After	
1) % End-count by Operator, Project, Machine 2) Machine Downtime 3) Quality Errors count 4) % Complete	4	Individual files in three different formats	ODSS	12	1	92%
1) % End-count by Operator, Project, Machine 2) Machine Downtime 3) Quality Errors count 4) % Complete 5) Hour by hour performance 6) Shift projections	3	Individual files in two different process	ODSS	6	1	83%
1) Project Performance 2) Shift Performance 3) Operator Performance 4) Machine Downtime 5) Quality Error count 6) Forecast Quantity by area	6	None exist	ODSS	6	1	83%
1) Shifts needed by the program by area to complete the project 2) Inventory numbers by the project by area 3) due date and quantities by the program by area	3	Un-quantifiable number of sources	ODSS	100	1	99%

Table 5 ODSS - Benefits Site 2

Needs	Number of Departments	Current Process	Target Solution	Number of Data Sources		% Gain in Data Quality
				Before	After	
1) % End-count by Operator, Project, Machine 2) Machine Downtime 3) Quality Errors count	5	Individual files in four different formats	ODSS	20	1	95%
1) % End-count by Project	2	Un-quantifiable number of sources	ODSS	3	1	67%

Use of the consolidated view resulted in identifying areas to sustain quality, productivity improvements which translated to bottom line cost savings. Furthermore, this laid the foundation for scientific data-based scheduling and operations management. This data consistency helped the team to develop internal benchmarks across sites and identify the actual capacity of processes. It reduced the hours spent by middle management to get ready for performance metrics meetings. Figure 71 shows the user adoption. Since the initial launch in February, the users have continued to see the value of the system as they migrate into it.

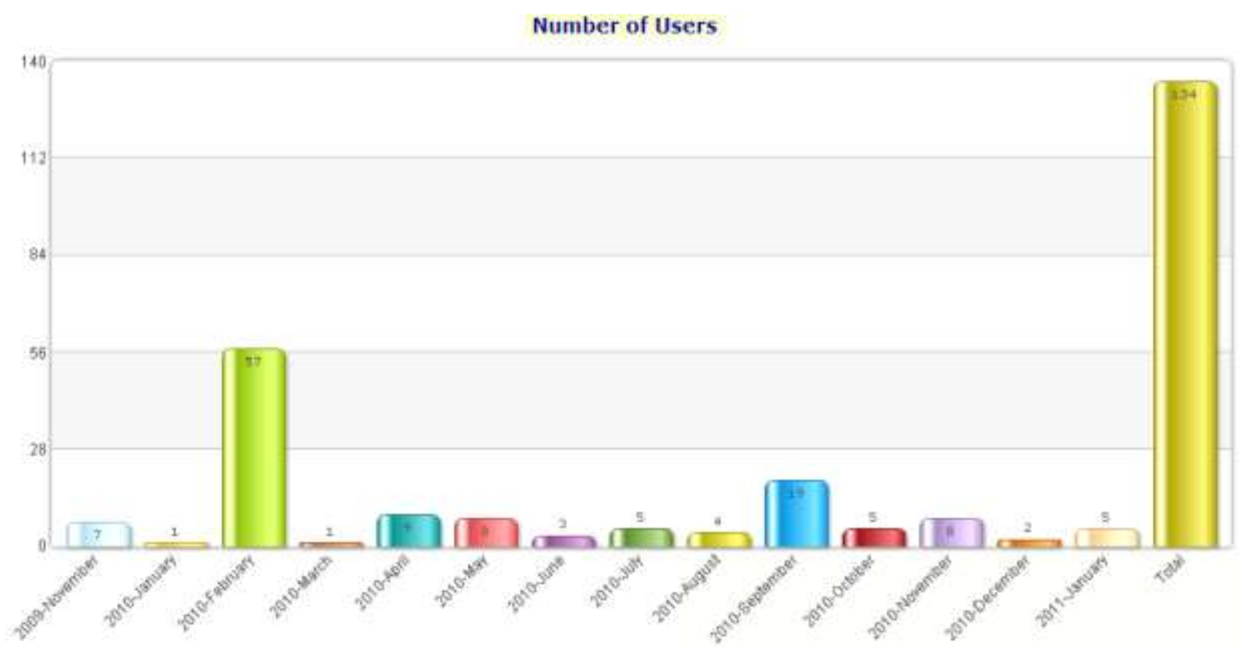


Figure 71 ODSS User Adoption

Another benefit of the system is the elimination of Microsoft Excel files that were scattered across the organization. Figure 72 shows the details of resource scheduling and reporting files used by one site. One hundred and seventy-five files were used to track operations across fours departments. ODSS eliminated data duplication and these files entirely by adding features that were easy to use by the FLS. Furthermore, it helped to move towards pull-based scheduling with the activities synced between various somethings via the "% complete" Kanban reports. It resulted in a flexible operation to accommodate short turn around. Finally, the system was used to develop data-based budget planning rather than budgets based on individual tribal knowledge.

Area	Files	Size (Mb)	Time per File	Lines per File	Total Time Minutes	Time Hrs
	a	b	c	d	e=axcxd	f=e/60
AO	-	-				
FP	56	8.95	3	25	4200	
IJ	24	19.9	3	26	1872	
PP	36	5.38	3	27	2916	
Seal, Spir, Tab	59	5.91	3	28	4956	
	175	**40.14**		**106**	**13944**	**232.4**

Figure 72 ODSS Excel Files Replacement Statistics

6.3 Advantages of CKDSS

CKDSS is a powerful example of a software-as-a-service utility for operations engineering. There are various general advantages of using cloud-computing such as cost savings, information technology services flexibility, manageability, reliability, data security and efficiency [188-201]. The principal advantages of CKDSS are:

1. Flexible User Interface: CK has a user-friendly interface that is built not only for cloud but also for the mobile environment. To deploy the system to any computing device, no extra coding is needed. Refer Appendix D: CK Features
2. Highest Data Quality: CK is built on cloud-based Azure™ database with relational constraints and unique identifiers. These markers help to mask vital personal data, eliminates duplicate data, and provide highest data traceability and quality. For example, the production information data entry screen has cascading

dropdowns allowing only relevant entries based on linked values in the drop-down. A job number selection will show only the relevant activities.

3. Efficient Visual Display: CK's EAT Kanban provides a visual display of the status of job activities that are easy to understand. For example, if a job is running behind the expected quantity or consuming more cost than expected its Kanban is displayed in "Red."
4. Always On DSS: CK has two built-in DSS. They are (1) EAT Kanban that has predictive Kanban to estimate new activity run rates and machines needed to complete the job within the due date, and (2) ACO based job TMT minimization allows users to pick the jobs that are critical. The sample run of ACS in the CK showed promising results. The marked difference is the reduction in computing time for the benchmark Burma 14 traveling salesman problem. The runtime to obtain the best path with 100 iterations was 2 seconds (Refer Appendix D: CK Features.)
5. Reduced TCO: Overall information technology TCO is reduced. For example, cost of routine system upgrades, and overheads to maintain the hardware infrastructures is included in the subscription.
6. Efficiency at Scale: CK is built for scalability. With the subscription pay-as-you-go model, CK can be easily scaled to meet the needs as the demand grows.
7. Competitive Edge: CK's efficient resource planning. Existing data can be easily migrated to CK that will provide high fidelity to manage resources without the dependency of legacy systems.

8. Unleash Process Data-based Innovation: CK's ability to provide intelligent and effective DSS unleashes the power to innovate and rigorously improve the process. For example, the organization can look at the activity SRPH, calibrate against the production rate and fine tune it for future resource planning.

9. Secure: CK's foundation is built on cloud security and Azure ™ active directory foundation. Users access can be quickly provisioned to fit the needs of the organization.

10. Seamless Collaboration: CK's communication module helps the team to understand the status of the work at various activities. Mainly, when the teams are working off-shifts, the communication notes help with efficient and effective shift information pass-downs.

Table 6 shows the environment deployment time and highlights the fact that CK has the fastest deployment time when compared to the case 1 (WKDSS) and case 2 (ODSS) implementation.

Table 6 Environment Deployment Time

DSS Type	WKDSS	ODSS	CK
Hardware Deployment Time	2 - 4 weeks	6-12 weeks	1 – 2 hours
Optimization Method	Algebraic	Algebraic	Meta-heuristics
Scalability	Limited	Limited	High
Adaptability	Medium	Medium	High
Dependencies	ERP	ERP	In-built scheduling system
Mobile Compatibility	None	None	Ready

6.4 Conclusion

The research demonstrates the efficacy of combining AR and Lean methodology (EAT Kanban) for sustaining CI. CK's features provide the next generation capability for operations engineering. It addresses the three-research question as follows:

1. "How can *a robust cloud-based Kanban decision support system work for a service industry, particularly in scheduling and resource management?"* The research employed two case studies WKDSS and ODSS and provided the foundation for the cloud-based system. Case 1 and case 2 highlights that the Kanban DSS helped to efficiently and effectively monitor and manage production and consumption of resources. In case 1, the Kanban utilized EAT model and in case 2, the Kanban used a variant "% complete." Both the cases could benefit with the CK framework as CK proved to be far superior to web-based systems reducing the deployment time from weeks to hours. (Refer Table 7). Thus, CK is adaptable and scalable for various service operations scenarios. Furthermore, using AR with 3DS method embedded in the tactical CI helped to sustain the gains of the implementation.
2. *"How can an evolutionary algorithm, specifically Ant Colony Optimization, augment a cloud-based Kanban decision support system?"* The research embedded ACS algorithm in CK to offer an adaptable and scalable DSS. Case 1 and case 2 DSS was based on existing ERP system and algebraic heuristics. Using evolutionary algorithm, notably ACS rapidly increases the flexibility of capacity planning and resource management. CK provides rapid response to schedule changes.

3. “*Can the pilot model in operations engineering be implemented in financial engineering?* The research developed EAT model based CK that demonstrated the importance and ease of real-time financial tracking of operations performance. While case 1 had limited financial tracking case 2 had no such capability. CK’s built-in feature to use the EAT model for financial tracking would not only meet operations engineering objectives such as the delivery date and volume commitments but also the financial cost of resource utilization.

6.5 Future Work

A few aspects that could be considered logical extensions of the work are as follows:

- Evaluation of cloud-platforms: What are the best cloud-based platforms that fit the operations engineering for IoT applications and Industry 4.0?
- Finetune Meta-heuristics: Can we modify the ACO to fit various scheduling scenarios? Could other meta-heuristics be embedded in the CK to perform better?
- Real-Time VSM: With CK’s production and scheduling data, can we build real-time VSM and OEE?
- Business Model Validation: Can CK be implemented for other business models such as university resource use, a non-profit organization, banking, and healthcare?
- Commercialization: What are the aspects of CK that can be commercialized?

APPENDICES

Appendix A: Continuous Improvement Survey

Objective: This is a voluntary survey to assess the knowledge of continuous improvement process awareness. It would take approximately 5 to 8 minutes to complete. It is not necessary to write your name or clock number. Your involvement to complete the survey is greatly appreciated. Advanced thanks.

Please check the relevant category: ☐ Operator ☐ Supervisor ☐ Mechanic ☐ Salaried Associate ☐ Manager ☐ Others

1) What is '5S'?

☐ a standard work process ☐ a waste elimination process ☐ right work environment ☐ all of the above

2) What is 'OEE'?

☐ Operator Efficiency ☐ Machine Efficiency ☐ Overall Equipment Efficiency ☐ Do not Know

3) Rate your training and knowledge of '5S'.

☐ Poor ☐ Adequate ☐ None ☐ Good ☐ Outstanding

4) Are you trained on 'OEE'?

☐ Poor ☐ Adequate ☐ None ☐ Good ☐ Outstanding

5) Implementing 5S reduces waste in your daily work.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

6) Implementing OEE reduces waste in your day-to-day work.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

7) There is room for improvement in your current work.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

8) We can improve the current OEE / 5S and other improvement activities or process.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

9) There is a need for the 100% employee involvement for successful improvement.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

10) Do you know the major downtime/delay reasons for your equipment/process?

☐ Know Somewhat ☐ Don't know ☐ Know fully

11) How many time(s) have you participated in a continuous improvement process in the last 12 months?

☐ 0 ☐ 1-5 ☐ 5-10 ☐ 10+ ☐ Don't know

12) Do you know the quality of work expected out of your equipment/process?

☐ Know Somewhat ☐ Don't know ☐ Know fully

13) In this year, how many times you have got feedback on your performance?

☐ 0 ☐ 1-5 ☐ 5-10 ☐ 10+ ☐ Don't know

14) Do you know the production rate or efficiency expectation of your job/machine?

☐ Know Somewhat ☐ Don't know ☐ Know fully

15) Are you aware of lean manufacturing tools and concepts such as 5S, Setup Reduction, Standard Work, Value Stream Mapping, Just-in-Time?

☐ Somewhat aware, ☐ Not Aware ☐ Fully aware

16) Do you know the impact of quality on Material Flow, Process and Product quality?

☐ Know Somewhat ☐ Don't know ☐ Know fully

17) Do you know the revenue per hour generated by the employees?

☐ Know Somewhat ☐ Don't know ☐ Know fully

18) You have excellent communication with other shifts.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

19) You have a basic understanding of the equipment /process that you are doing.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

20) You can effectively troubleshoot basic equipment/process by your knowledge.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

21) Implementing 5S enables a safe work environment.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

22) Implementing 5S enables an efficient work environment.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

23) We continue to become a high-performance organization.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

24) Rate your score on the statement: Standard work ensures efficient work across different operators/persons.

Bad←--→Good

☐ -3 ☐ -2 ☐ -1 ☐ 0 ☐ 1 ☐ 2 ☐ 3

25) Continuous improvement of the process is needed to ensure highest customer satisfaction and meet our mail dates.

☐ Strongly Disagree ☐ Disagree Somewhat ☐ Not sure/don't know ☐ Agree Somewhat ☐ Strongly agree

Appendix B: Case 1: Web-based Kanban features

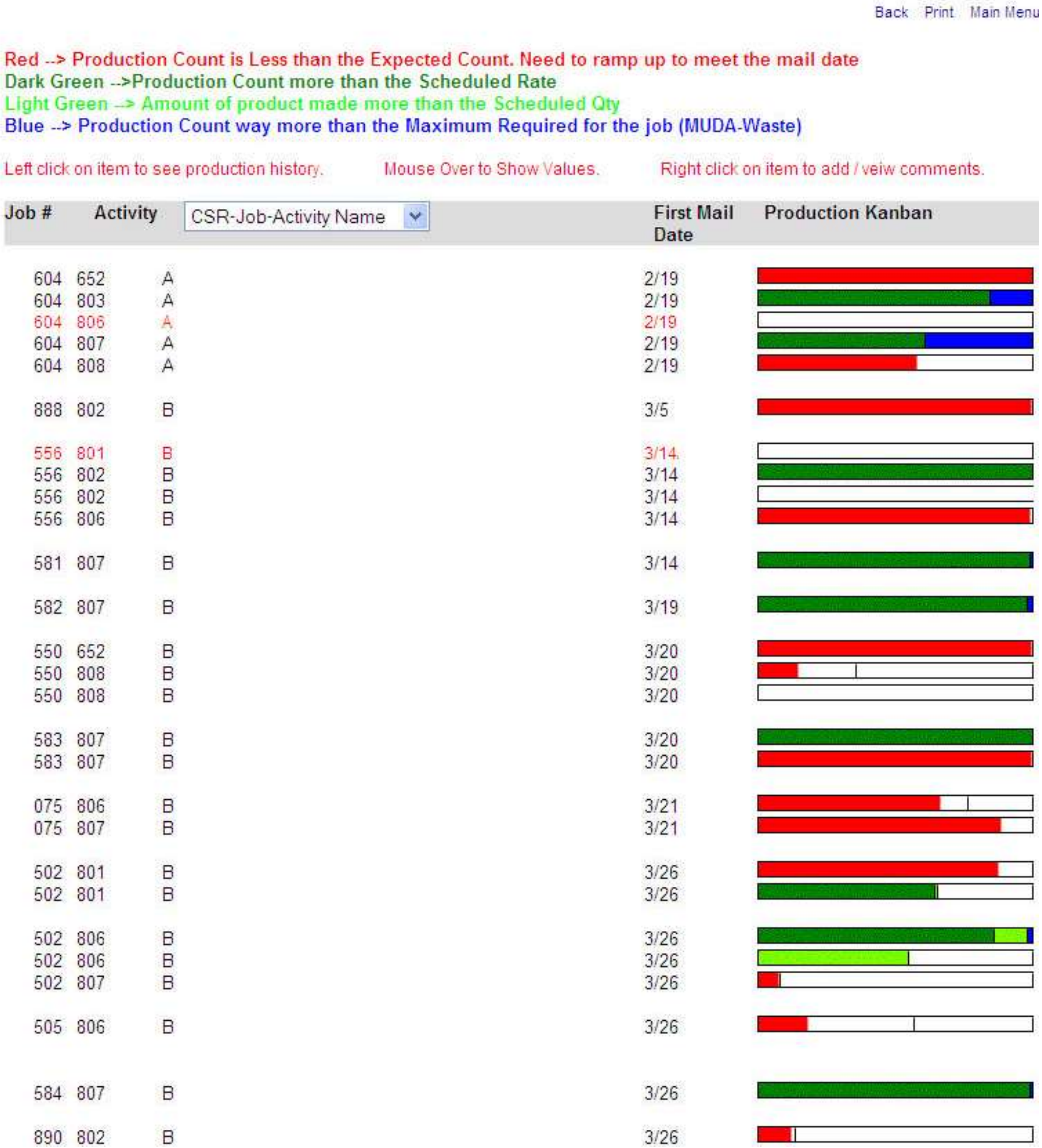


Figure 73 Kanban display sorted by CSR-Job-Activity Name

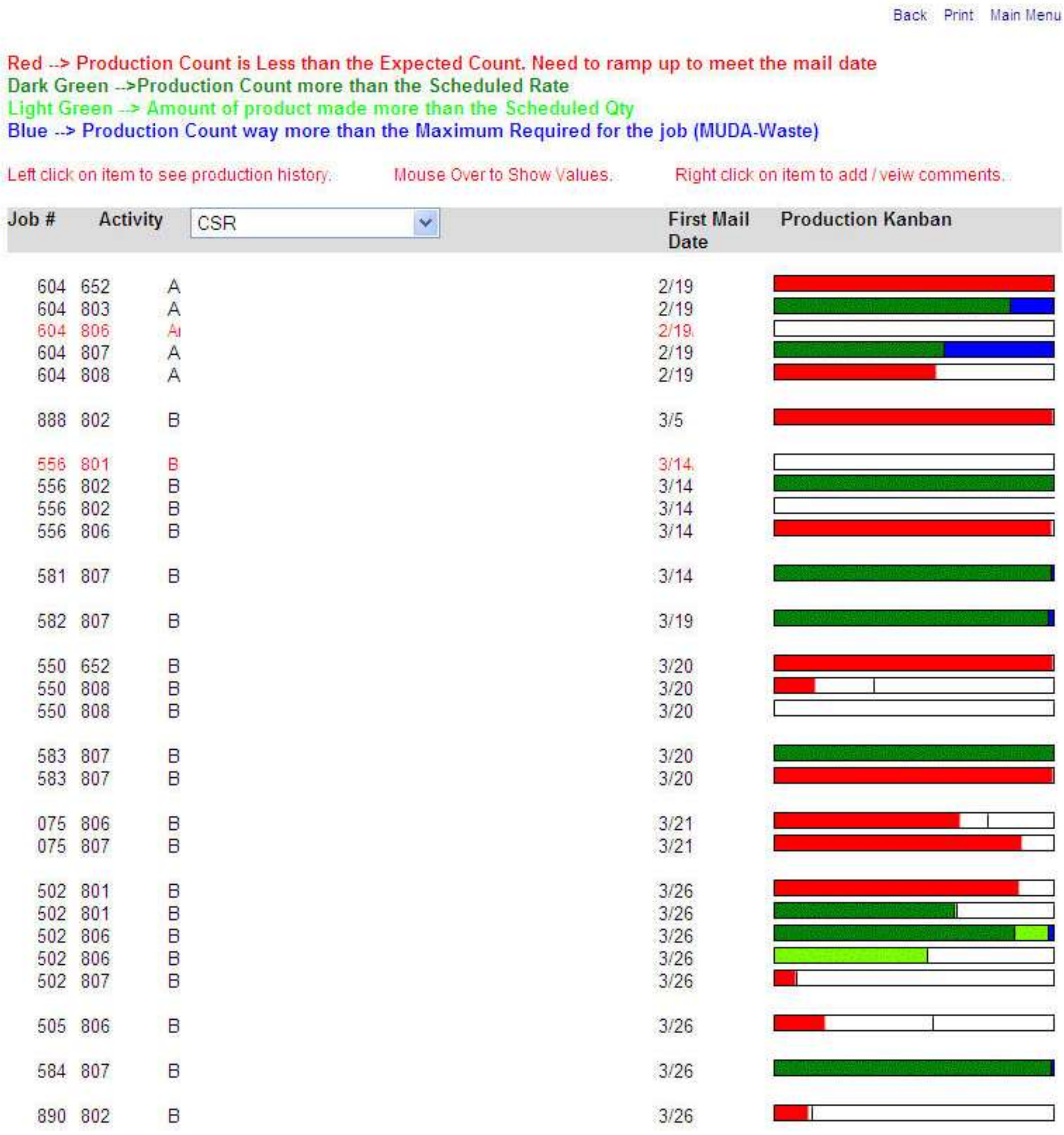


Figure 74 Kanban display sorted by CSR

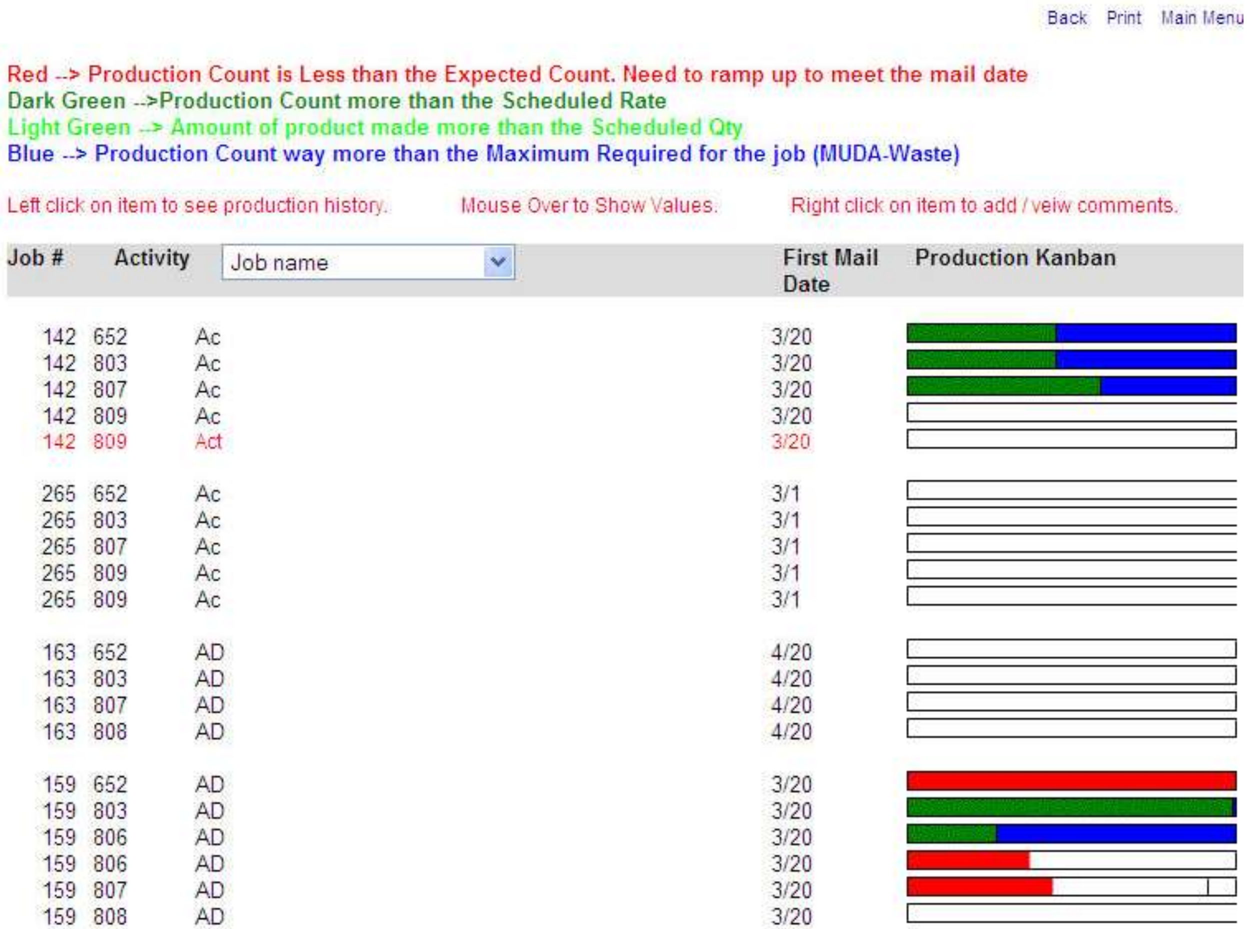


Figure 75 Kanban display sorted by Job Name -Activity Name

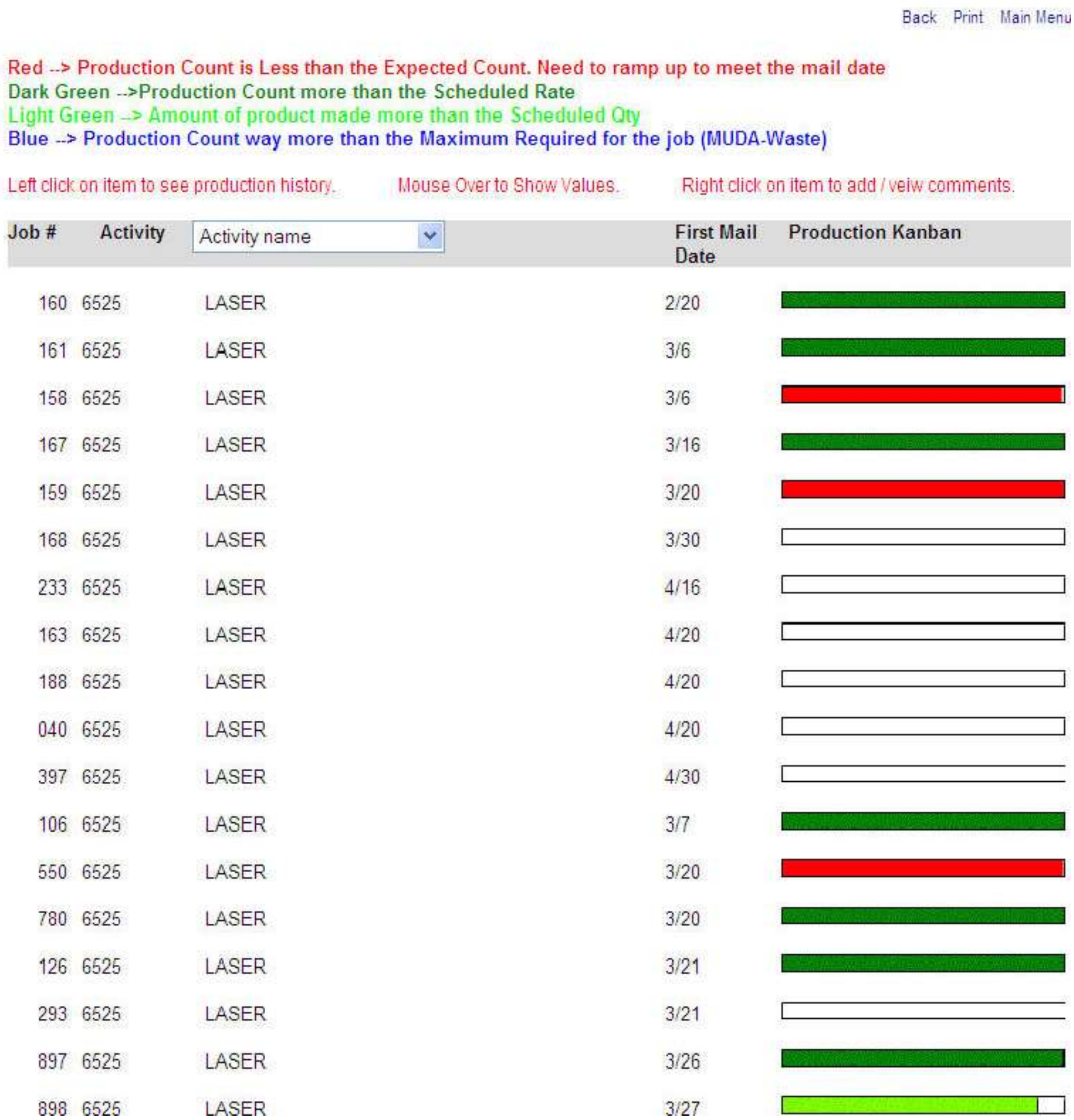
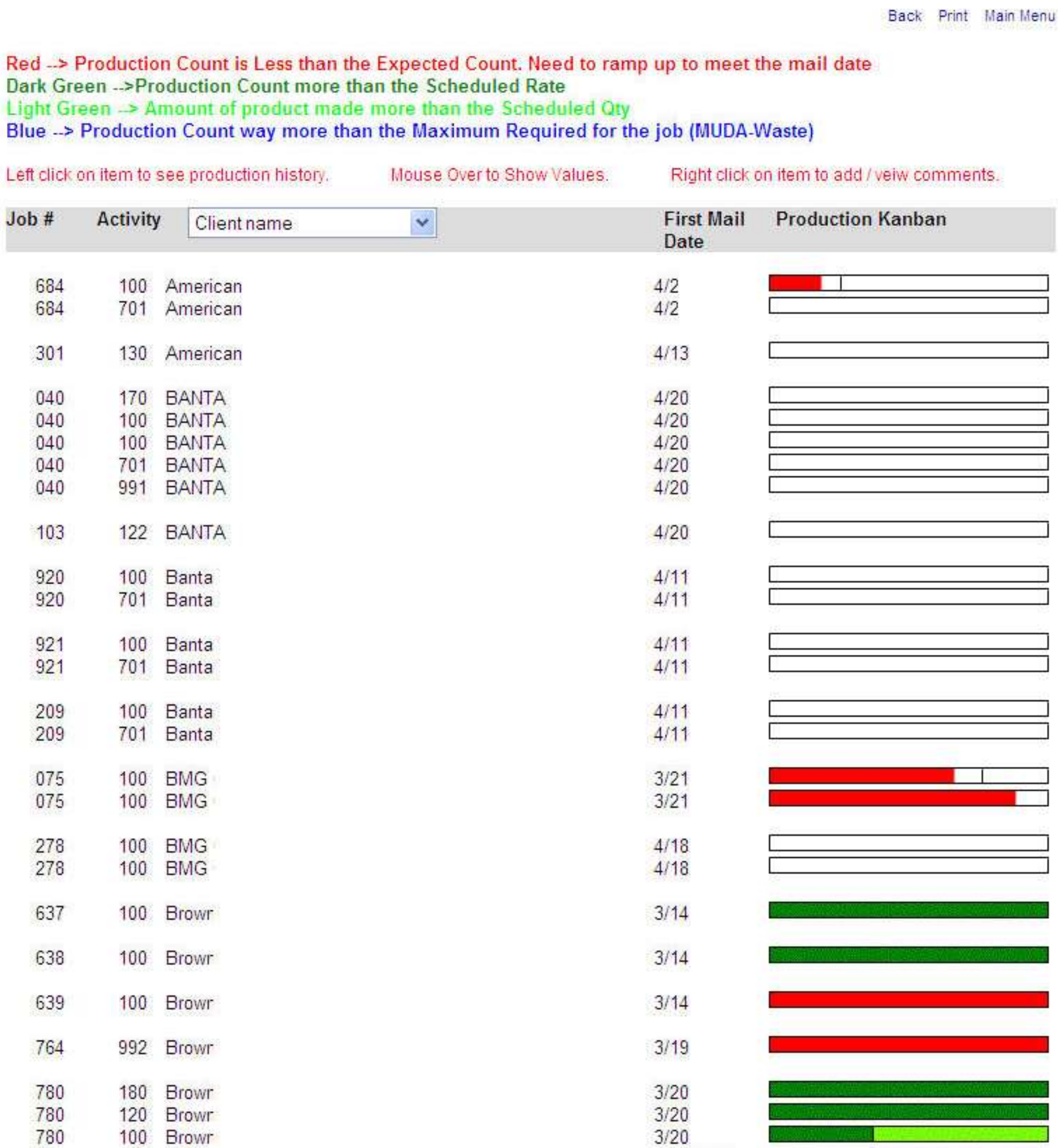


Figure 76 Kanban display sorted by Activity Name

Figure 77 Kanban display sorted by CSR



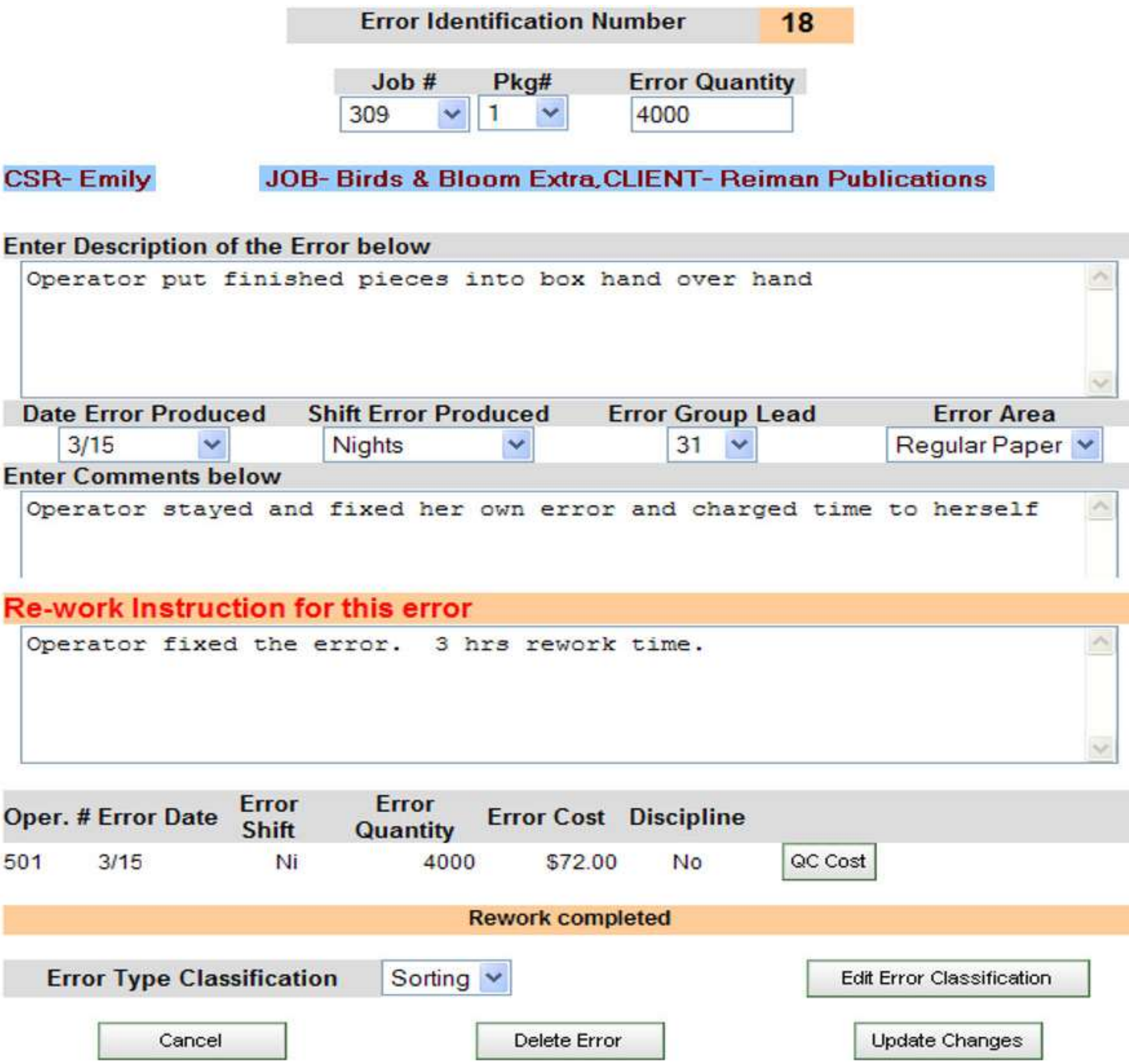
Back Print Main Menu

Red --> Production Count is Less than the Expected Count. Need to ramp up to meet the mail date
Dark Green -->Production Count more than the Scheduled Rate
Light Green --> Amount of product made more than the Scheduled Qty
Blue --> Production Count way more than the Maximum Required for the job (MUDA-Waste)

Left click on item to see production history. Mouse Over to Show Values. Right click on item to add / veiw comments.

Job #	Activity	Client name	First Mail Date	Production Kanban
684	100	American	4/2	
684	701	American	4/2	
301	130	American	4/13	
040	170	BANTA	4/20	
040	100	BANTA	4/20	
040	100	BANTA	4/20	
040	701	BANTA	4/20	
040	991	BANTA	4/20	
103	122	BANTA	4/20	
920	100	Banta	4/11	
920	701	Banta	4/11	
921	100	Banta	4/11	
921	701	Banta	4/11	
209	100	Banta	4/11	
209	701	Banta	4/11	
075	100	BMG	3/21	
075	100	BMG	3/21	
278	100	BMG	4/18	
278	100	BMG	4/18	
637	100	Browr	3/14	
638	100	Browr	3/14	
639	100	Browr	3/14	
764	992	Browr	3/19	
780	180	Browr	3/20	
780	120	Browr	3/20	
780	100	Browr	3/20	

Figure 78 Kanban display sorted by Client Name



Error Identification Number **18**

Job #	Pkg#	Error Quantity
309	1	4000

CSR- Emily **JOB- Birds & Bloom Extra,CLIENT- Reiman Publications**

Enter Description of the Error below

Operator put finished pieces into box hand over hand

Date Error Produced	Shift Error Produced	Error Group Lead	Error Area
3/15	Nights	31	Regular Paper

Enter Comments below

Operator stayed and fixed her own error and charged time to herself

Re-work Instruction for this error

Operator fixed the error. 3 hrs rework time.

Oper. #	Error Date	Error Shift	Error Quantity	Error Cost	Discipline	
501	3/15	Ni	4000	$72.00	No	QC Cost

Rework completed

Error Type Classification Sorting | Edit Error Classification

Cancel | Delete Error | Update Changes

Figure 79 Quality Error and Cost entry

Appendix C: Case 2 ODSS Features

Table 7 ODSS Report Matrix

Role/Menu	Production Data Entry	Area Reports	Quality Performance	Operator Performance	Project Performance	Machine Performance	System Setup	Custom Reports	Performance Charts	Planning & Budgets	ODSS Usage Chart
Lead, Senior, Ops Rep	x	x	x	x	x	x			x		
General User											x
Manager	x	x		x		x		x		x	
Human Resources				x					x		
Performance Scoring Center								x	x	x	
Learning Assessment Team				x					x		
Architect	x	x	x	x	x	x	x	x	x	x	x
Administrator	x	x	x	x	x	x	x	x	x	x	x
Director, VP			x	x				x	x	x	x
Master Scheduler								x	x	x	
Program Team					x			x			

Operations Decision Support System-ODSS Summary of Plan Hours, People or Shifts

Back Print Main Menu

Click here for Line Hours | Click here for Plan Shifts | Click here for Plan Labor Hours | Click here for Plan People | Click here for Plan Quantity

Plan Quantity

Week	AO	Final	Inkjet	Manual	Pre	Tab	Total
2			5,218.00	54,926.00			60,144.00
3		8,076.00	6,849.00	27,463.00		10,100.00	52,488.00
4	344,918.00	599,358.00	1,652.00	65,118.00		1,073,678.00	2,084,724.00
5			20,961.00	58,712.00			79,673.00
6	344,918.00	680,023.00	21,304.00	78,236.00		1,133,058.00	2,257,539.00
7	344,918.00	1,551,624.00	79,359.00	189,303.00		1,073,678.00	3,238,882.00
8		488,509.00	45,139.00	57,370.00		49,280.00	640,298.00
9	30,761.00	293,103.00	20,944.00	104,555.00			449,363.00
10							0.00
11	188,231.00	1,066,154.00	82,292.00	183,557.00		51,215.00	1,571,449.00
12		20,869.00	60,930.00	247,442.00			329,241.00
13	78,735.00	184,009.00	140,796.00	523,500.00		1,935.00	928,975.00
14	78,735.00	171,216.00	80,696.00	271,379.00		10,100.00	612,126.00
15	30,761.00	313,972.00	63,621.00	321,076.00			729,430.00
16	30,761.00	418,442.00	75,806.00	105,619.00		49,280.00	679,908.00
17		72,589.00	15,412.00	13,118.00		49,280.00	150,399.00
18							0.00
19			3,410.00	4,679.00		1,935.00	10,024.00
20							0.00
21							0.00
22							0.00
23							0.00
24							0.00
25			3,410.00	4,679.00		1,935.00	10,024.00
26		72,589.00	15,412.00	13,118.00		49,280.00	150,399.00
27		72,589.00	15,412.00	13,118.00		49,280.00	150,399.00
28		120,426.00	63,019.00	4,760.00	3,765.00		191,970.00
29							0.00
31		8,076.00	4,240.00			10,100.00	22,416.00
32							0.00
33							0.00
34			1,710.00	56,382.00			58,092.00
35	78,735.00	142,271.00	15,526.00	23,937.00			260,469.00
36	78,735.00	142,271.00	15,526.00	23,937.00			260,469.00
37			47,950.00	57,519.00			105,469.00
38		8,076.00	22,493.00	30,921.00		10,100.00	71,590.00
39		72,589.00	15,412.00	13,118.00		49,280.00	150,399.00
40			18,253.00	30,921.00			49,174.00
41		125,339.00	73,115.00	31,985.00		49,280.00	279,719.00
42			18,253.00	30,921.00			49,174.00
43							0.00
44	157,470.00	284,542.00	31,052.00	47,874.00			520,938.00
45							0.00
46		52,750.00	57,703.00	18,867.00			129,320.00
47							0.00
48		3,305.00	2,967.00		5,740.00	7,402.00	19,414.00
49							0.00
50							0.00
51							0.00
52							0.00
53							0.00
0	1,787,678	6,972,767	1,145,842	2,708,110	9,505	3,730,196	16,354,098.00

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Figure 80 ODSS - Weekly Plan

Operations Decision Support System-ODSS- Monthly Performance

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Change 'Area' Drop Down to refresh the page

Month: January | Year: | Area: Final

Sub Task	Amount	Labor Hours	Rate	Month
1 Sca	5,863	9.50	617.16	1
10 Sc	16,549	292.50	56.58	1
2 Sca	84,173	97.25	865.53	1
3 Sca	17,311	110.00	157.37	1
4 Sca	34,531	306.00	112.85	1
5 Sca	67,529	566.50	119.20	1
6 Sca	57,299	400.25	143.16	1
Total/ Average Rate	**283,255**	**1,782.00**	**158.95**	

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Figure 81 ODSS - Department Monthly Performance

Operations Decision Support System-ODSS - Department YTD Performance

Back Print Main Menu

Change 'Area' to refresh the page

From Year: | To Year: | Area: Final

Amount	Labour Hours	Rate	STD Amount	% to STD	Month
27,545	199.90	137.79	185,310	15%	2
707,857	5,686.20	124.49	2,472,856	29%	3
874,000	4,644.29	188.19	4,644	18,820%	4
126,106	815.14	154.70	815	15,473%	5
7,984	119.00	67.09	119	6,709%	7
57,390	370.20	155.02	370	15,511%	8
125,636	627.90	200.09	628	20,006%	9
64,977	333.90	194.60	334	19,454%	10
41,056	222.00	184.94	222	18,494%	11
302,750	1,823.80	166.00	1,824	16,598%	12
283,255	1,782.00	158.95	1,782	15,895%	1
2,618,556	**16,624.33**	**157.51**	**2,668,904**	**98%**	**Totals/Rate**

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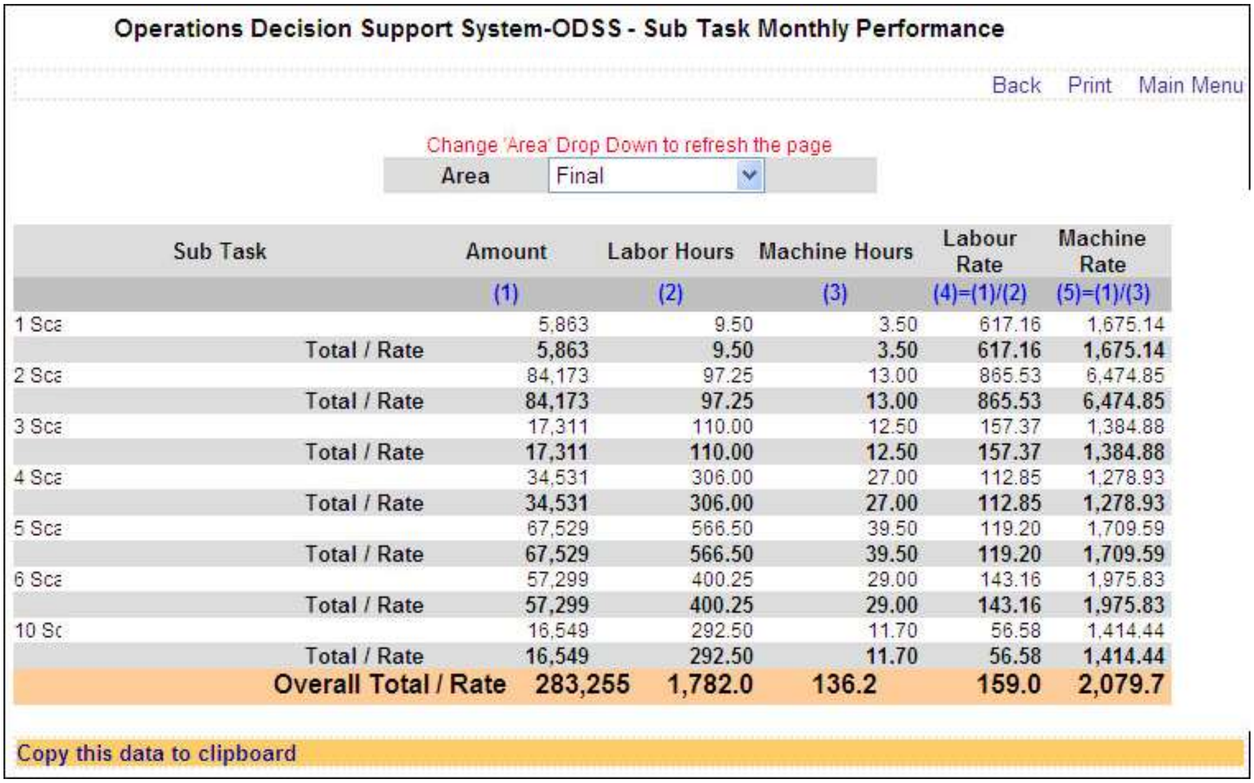
Figure 82 ODSS - Department YTD Performance


Operations Decision Support System-ODSS - Sub Task Monthly Performance

Back Print Main Menu

Change 'Area' Drop Down to refresh the page

Area: Final

Sub Task	Amount (1)	Labor Hours (2)	Machine Hours (3)	Labour Rate (4)=(1)/(2)	Machine Rate (5)=(1)/(3)
1 Sca	5,863	9.50	3.50	617.16	1,675.14
Total / Rate	**5,863**	**9.50**	**3.50**	**617.16**	**1,675.14**
2 Sca	84,173	97.25	13.00	865.53	6,474.85
Total / Rate	**84,173**	**97.25**	**13.00**	**865.53**	**6,474.85**
3 Sca	17,311	110.00	12.50	157.37	1,384.88
Total / Rate	**17,311**	**110.00**	**12.50**	**157.37**	**1,384.88**
4 Sca	34,531	306.00	27.00	112.85	1,278.93
Total / Rate	**34,531**	**306.00**	**27.00**	**112.85**	**1,278.93**
5 Sca	67,529	566.50	39.50	119.20	1,709.59
Total / Rate	**67,529**	**566.50**	**39.50**	**119.20**	**1,709.59**
6 Sca	57,299	400.25	29.00	143.16	1,975.83
Total / Rate	**57,299**	**400.25**	**29.00**	**143.16**	**1,975.83**
10 Sc	16,549	292.50	11.70	56.58	1,414.44
Total / Rate	**16,549**	**292.50**	**11.70**	**56.58**	**1,414.44**
Overall Total / Rate	**283,255**	**1,782.0**	**136.2**	**159.0**	**2,079.7**

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Figure 83 ODSS - Subtask Monthly Performance

Operations Decision Support System-ODSS- Quality Errors by Project

Back Print Main Menu

PGM 755

Machine Name	Error Type	Bad Amount	Month
Final	Entered Non Contiguous Serial Number	30	1
Final	Wrong Materials	38	1
	Total	**68**	
Inkjet	Barcode Unscanable (Smeared Prints / book printed on wrong side)	237	1
Inkjet	Duplicate Barcodes	6	1
Inkjet	Machine Damage (inkjet process)	72	1
Inkjet	PrintHead Issues (Inkjet Print Shorts)	123	1
Inkjet	Rework Bad Seals (paper(no glue/missing) or vinyl (removed and replaced))	21	1
Inkjet	Seals, nonconformed (torn or OPEN)	210	1
Inkjet	Setup Damage Scrap	167	1
Inkjet	Stained during Inkjet Process	30	1
Inkjet	Stained/Damaged during sealing process	142	1
Inkjet	VENDOR (Supplier) Document Printed/Collated wrong/bond issues	4	1
	Total	**1,012**	

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Figure 84 ODSS Errors by Project

Operations Decision Support System-ODSS - Project Summary Performance

Back Print Main Menu

PGM 016

Sub Task	Amount	Actual Hours	Team Size	Team Hours	Rate	Standard Amount	% to STD
	(1)	(2)	(3)	(4)=(2)x(3)	(5)= (1)/(4)	(6)	(7) = (1)/(6)
Answer Doc/Folder	800	2.6	1.0	2.6	307.7	1,274	63%
IJ	5,200	1.3	1.0	1.3	4,000.0	5,850	89%
Total / Rate	**6,000**	**3.9**		**3.9**	**1,538.5**	**7,124**	**84%**

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Figure 85 ODSS - Project Performance Summary

Figure 86 ODSS - ISO Productivity Metrics

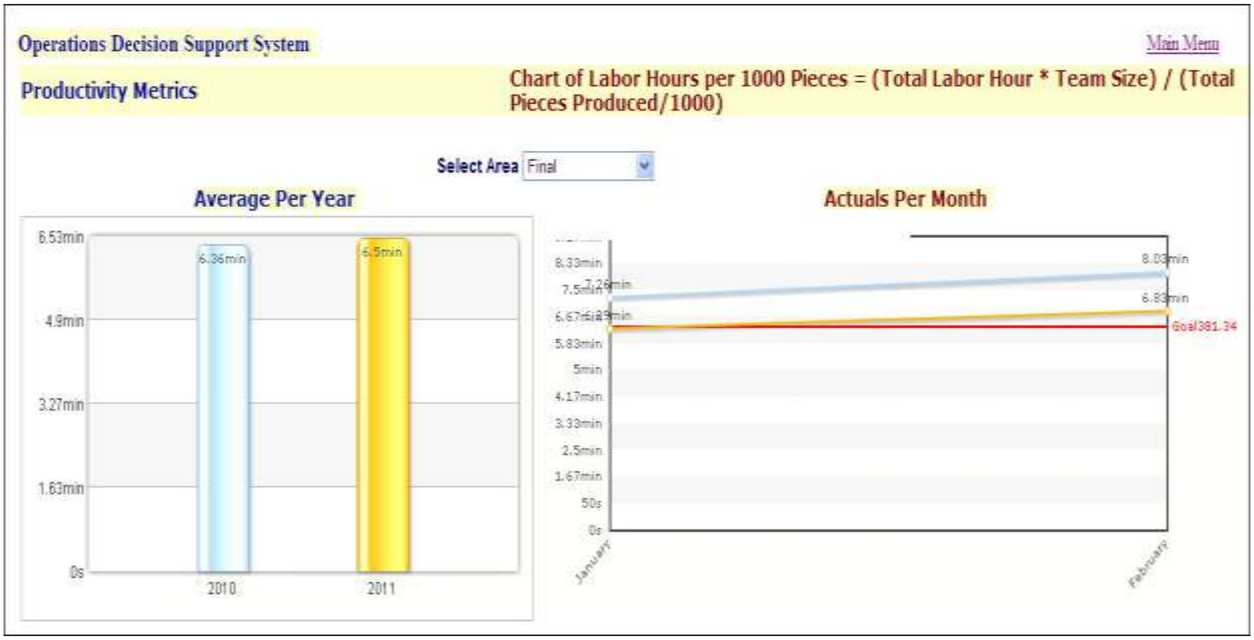


Figure 87 ODSS - ISO Labor Hours/1000

Figure 88 ODSS - ISO Productivity Seals

Figure 89 ODSS -Sealing Hourly Performance

Figure 90 ODSS - Usage by Links

Operations Decision Support System-ODSS **Total Seals YTD Performance**

Back Print Mai

Change 'To Year' to refresh the page

From Year To Year

Task Type	# of Seals	STD Rate	Amount	Total Seals	Hours	STD Amount	% to STD	Month
	(1)	(2)	(3)	(4)=(1)x(3)	(5)	(6)=(2)x(5)	(7)=(3)/(6)	
Tab-1	1	5200	70,000	70,000	28.0	145,600	48%	2
Seal-3	3	200	52,629	157,887	345.9	69,180	76%	2
Tab-1	1	5200	161,991	161,991	95.7	497,484	33%	3
Seal-2	2	300	118,870	237,740	677.5	203,235	58%	3
Seal-3	3	200	309,134	927,402	1,441.1	288,226	107%	3
Seal-5	5	120	49,530	247,650	438.4	52,608	94%	3
Tab-1	1	5200	30,761	30,761	21.3	110,760	28%	4
Seal-2	2	300	331,829	663,658	763.0	228,912	145%	4
Seal-3	3	200	229,455	688,365	689.4	137,882	166%	4
Seal-2	2	300	69,488	138,976	103.6	31,080	224%	5
Seal-5	5	120	61,141	305,705	145.4	17,448	350%	5
Seal-1	1	600	3,390	3,390	31.0	18,600	18%	7
Seal-1	1	600	10,115	10,115	54.6	32,760	31%	9
Tab-1	1	5200	78,093	78,093	28.6	148,720	53%	9
Seal-2	2	300	45	90	0.3	90	50%	9
Seal-3	3	200	1,000	3,000	8.0	1,600	63%	9
Seal-5	5	120	111,492	557,460	305.8	36,696	304%	9
1 Tab	1	5200	145,041	145,041	60.4	313,820	46%	11
Tab-1	1	5200	373,998	373,998	320.3	1,665,300	22%	11
Seal-2	2	300	6,575	13,150	4.5	1,350	487%	11
Large Print	1	32	4,370	4,370	101.7	3,254	134%	12
1 sea	1	600	141,118	141,118	75.3	45,180	312%	12
Seal-1	1	600	60	60	0.4	240	25%	12
24 pages	1	5200	440,227	440,227	234.1	1,217,060	36%	12
32 pages	1	5200	39,560	39,560	26.3	136,500	29%	12
40 pages	1	5200	6,763	6,763	2.8	14,560	46%	12
56 pages	1	5200	81,318	81,318	55.0	285,740	28%	12
62 Pages	1	5200	17,961	17,961	16.5	85,540	21%	12
64 pages	1	5200	69,803	69,803	51.3	266,760	26%	12
32 pages	2	300	270,254	540,508	184.9	55,470	487%	12
40 pages	2	300	711,611	1,423,222	729.4	218,820	325%	12
48 pages	2	300	75	150	0.1	30	250%	12
80 pages	2	300	62,187	124,374	87.2	26,160	238%	12
Seal-2	2	300	193,900	387,800	340.7	102,210	190%	12
Large Print	1	32	5,622	5,622	131.0	4,192	134%	1
1 seal 8 pages	1	600	4,065	4,065	4.0	2,400	169%	1
Seal-1	1	600	45	45	0.6	360	13%	1
30 pages	1	5200	58,398	58,398	34.0	176,540	33%	1
32 pages	1	5200	156,000	156,000	74.7	388,440	40%	1
40 pages	1	5200	575,014	575,014	327.6	1,703,260	34%	1
48 pages	1	5200	44,958	44,958	51.0	264,940	17%	1
56 pages	1	5200	2,098	2,098	2.1	10,920	19%	1
62 Pages	1	5200	1,074	1,074	1.8	9,360	11%	1
48 pages	2	300	66,054	132,108	74.0	22,200	298%	1
56 pages	2	300	40,944	81,888	44.0	13,200	310%	1
68 pages	2	300	11,740	23,480	21.4	6,420	183%	1
72 pages	2	300	969,605	1,939,210	1,412.9	423,870	229%	1
8 pages	2	300	154	308	1.5	450	34%	1
80 pages	2	300	63,637	127,274	98.3	29,490	216%	1
132 Page	3	200	38,071	114,213	91.6	18,320	208%	1
140 pages	3	200	36,380	109,140	84.6	16,920	215%	1
148 page	5	120	67,001	335,005	171.5	20,580	326%	1
180 pages	5	120	18,211	91,055	61.8	7,416	246%	1
Total / Rate			**6,412,855**	**11,892,661**	**10,156.9**	**9,578,153**	**67%**	

Figure 91 ODSS - Yearly Activity Performance Report

Appendix D: CK Features

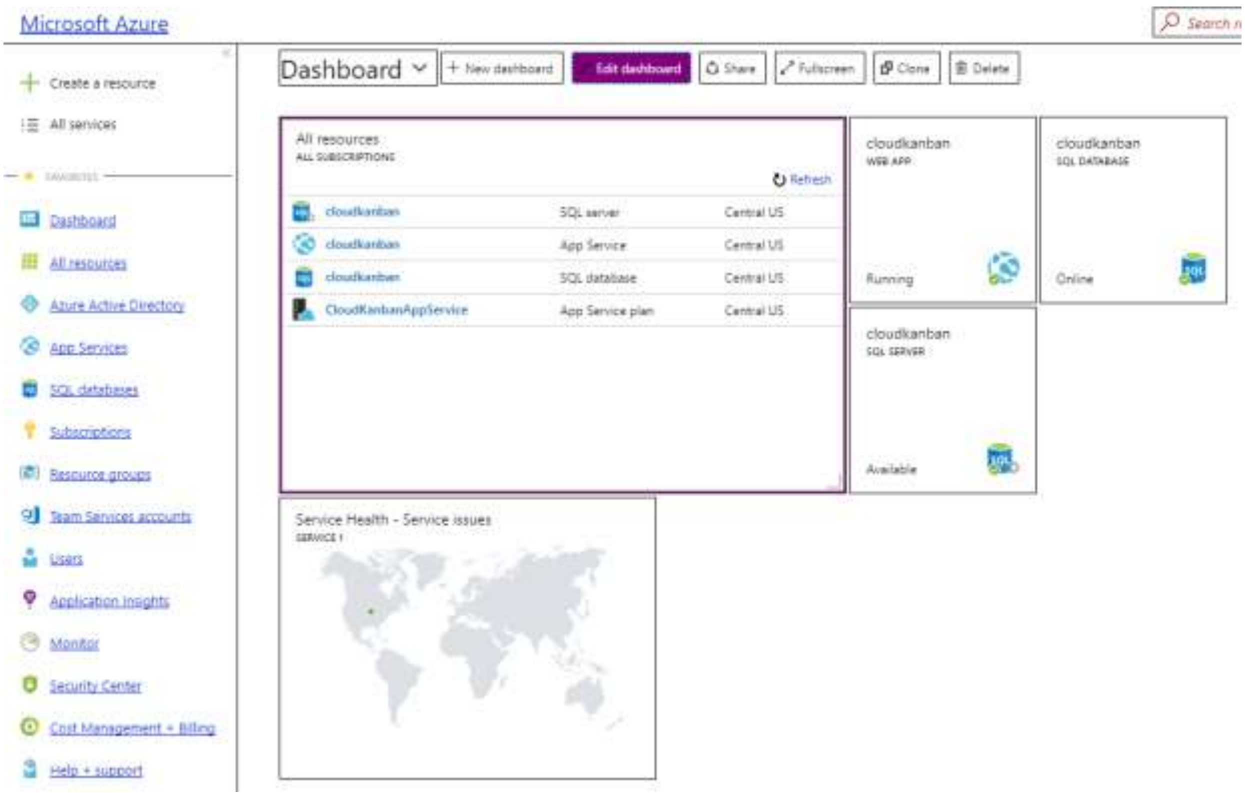


Figure 92 CK - Azure Resources

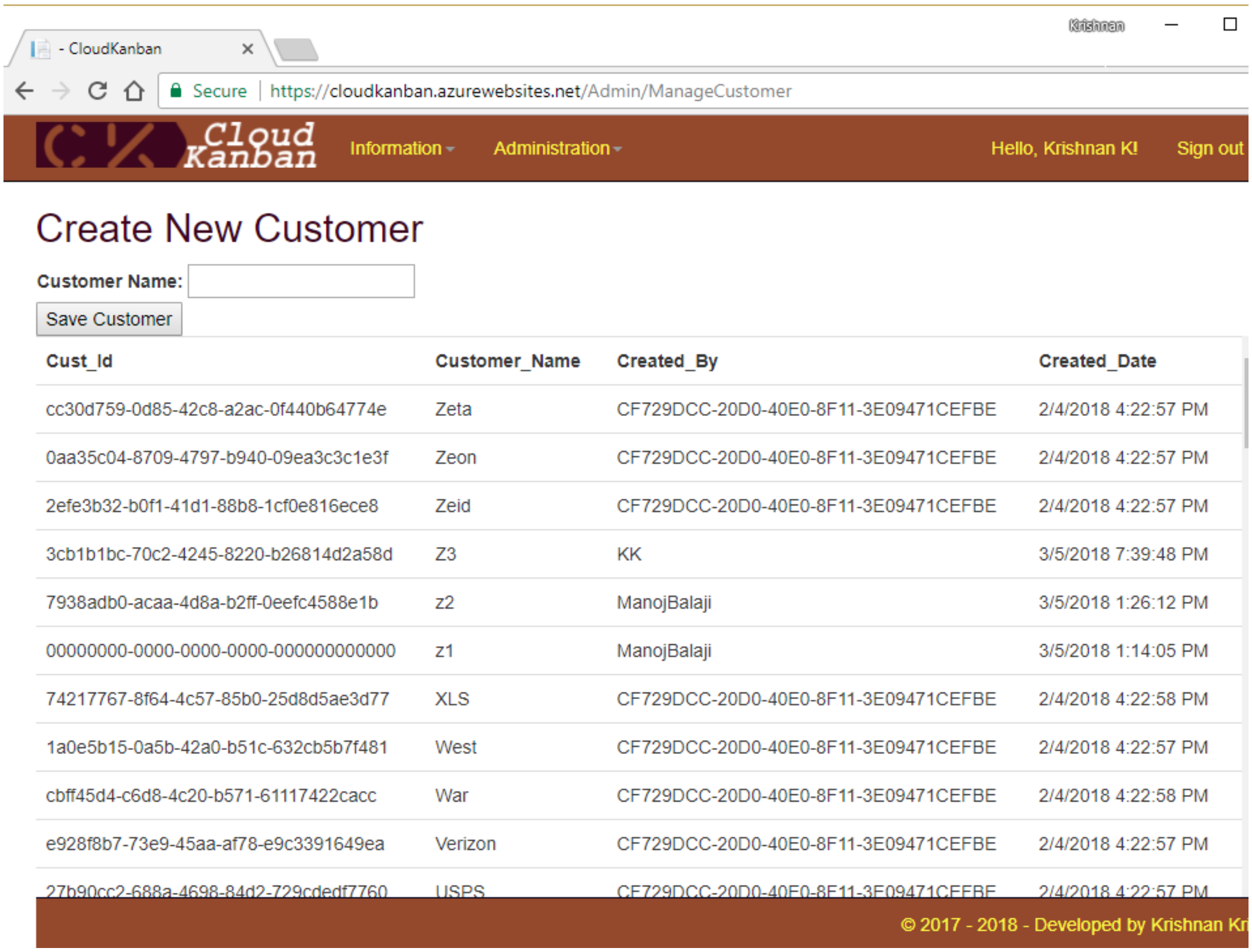


Figure 93 CK - Add New Customer

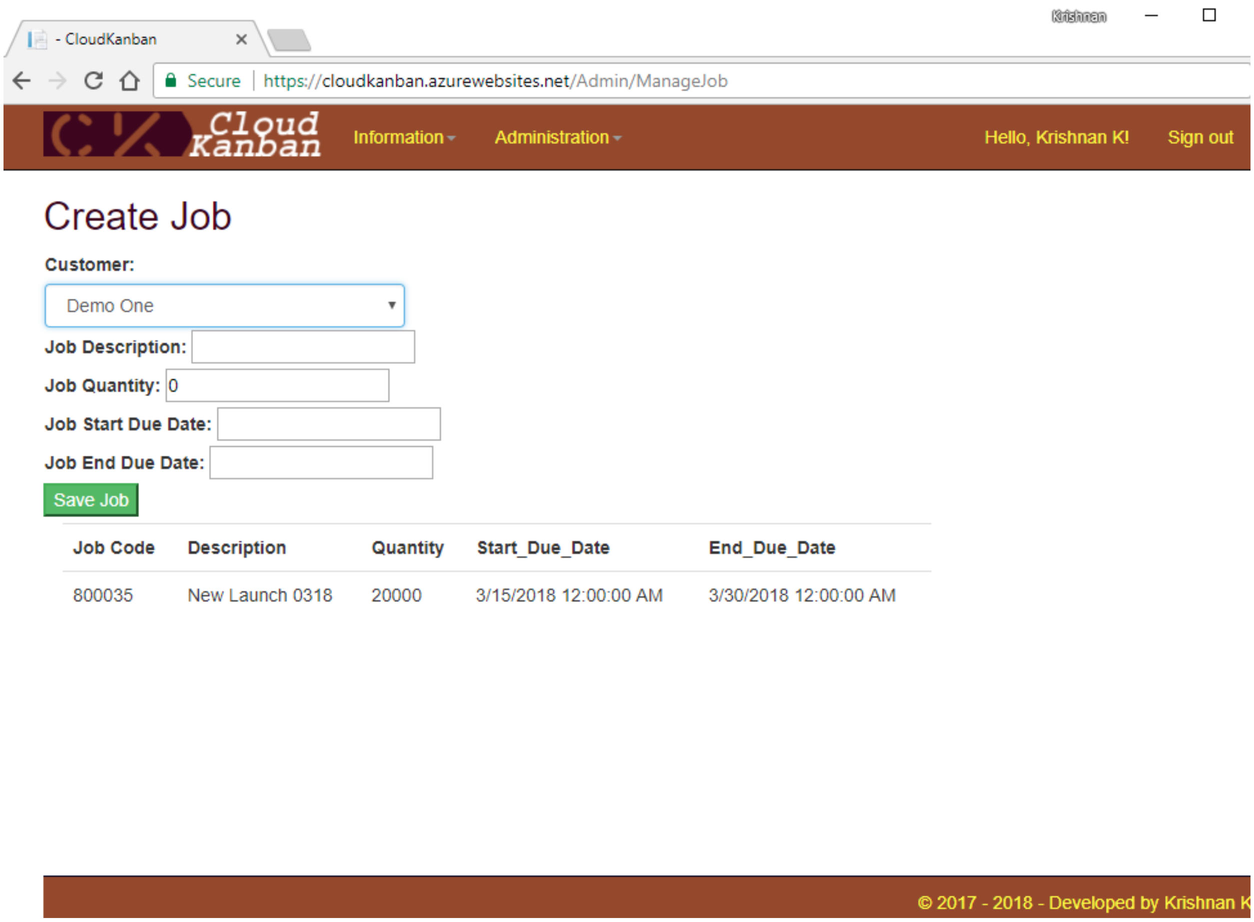


Figure 94 CK - Create New Job

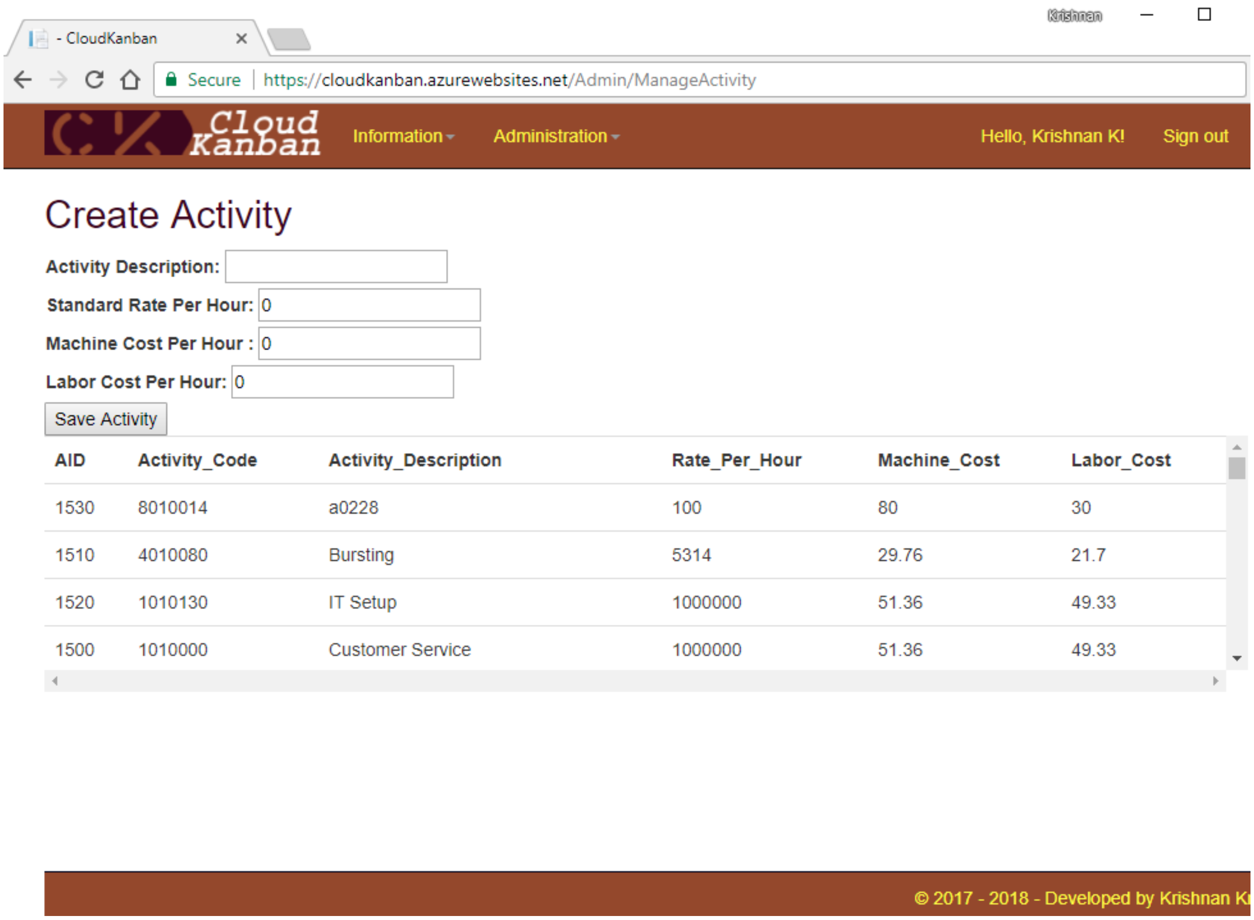


Figure 95 CK - Create New Activity

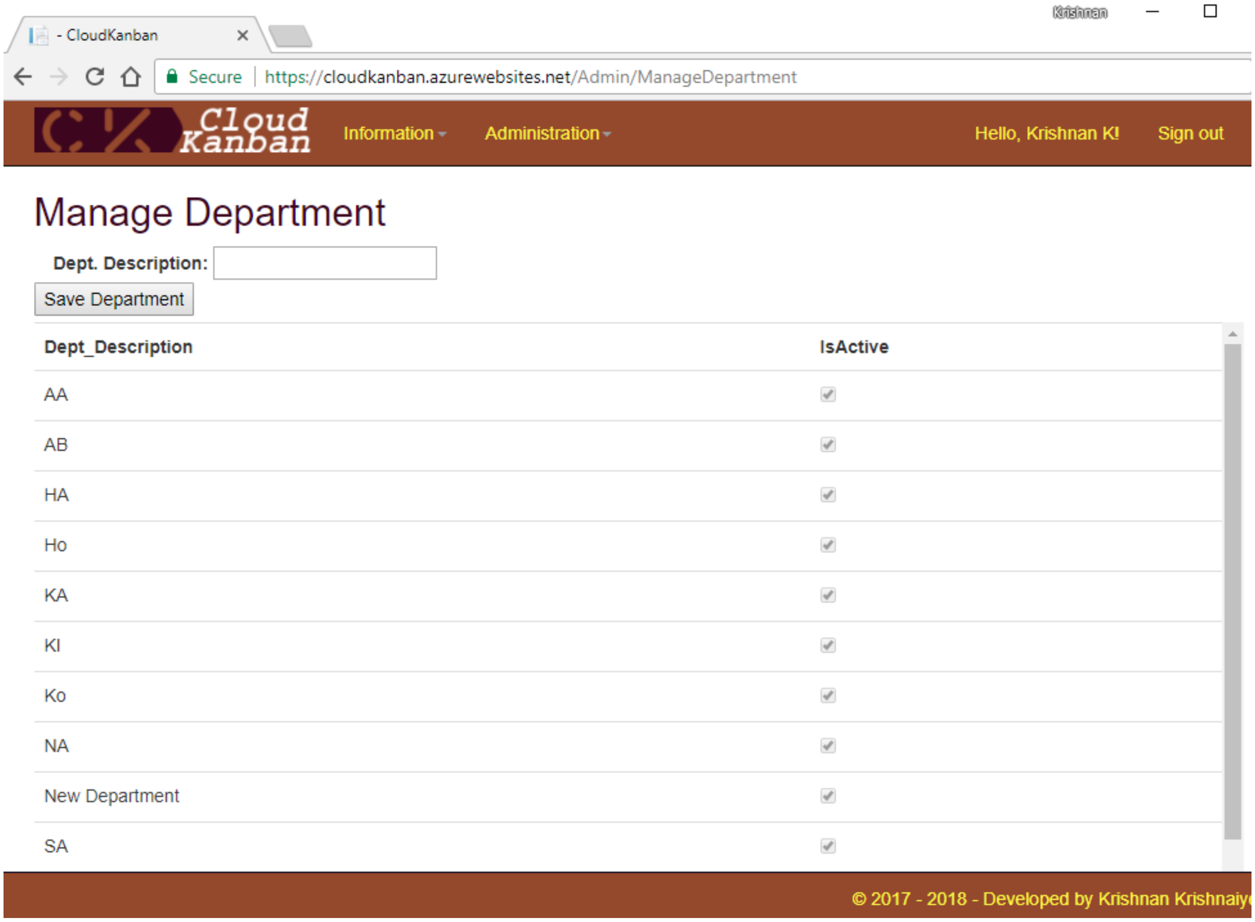


Figure 96 CK - Create New Department

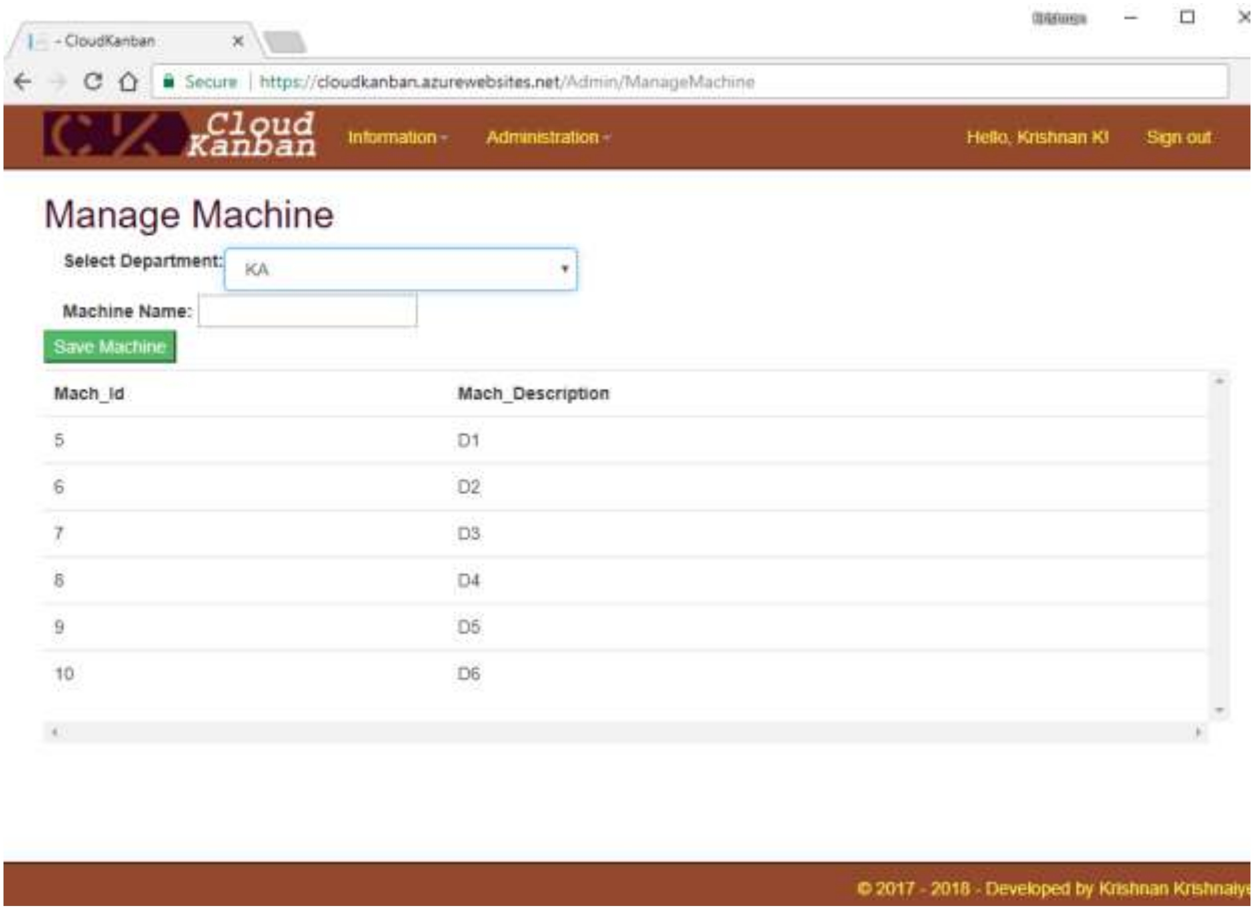


Figure 97 CK - Manage Machine for a Department

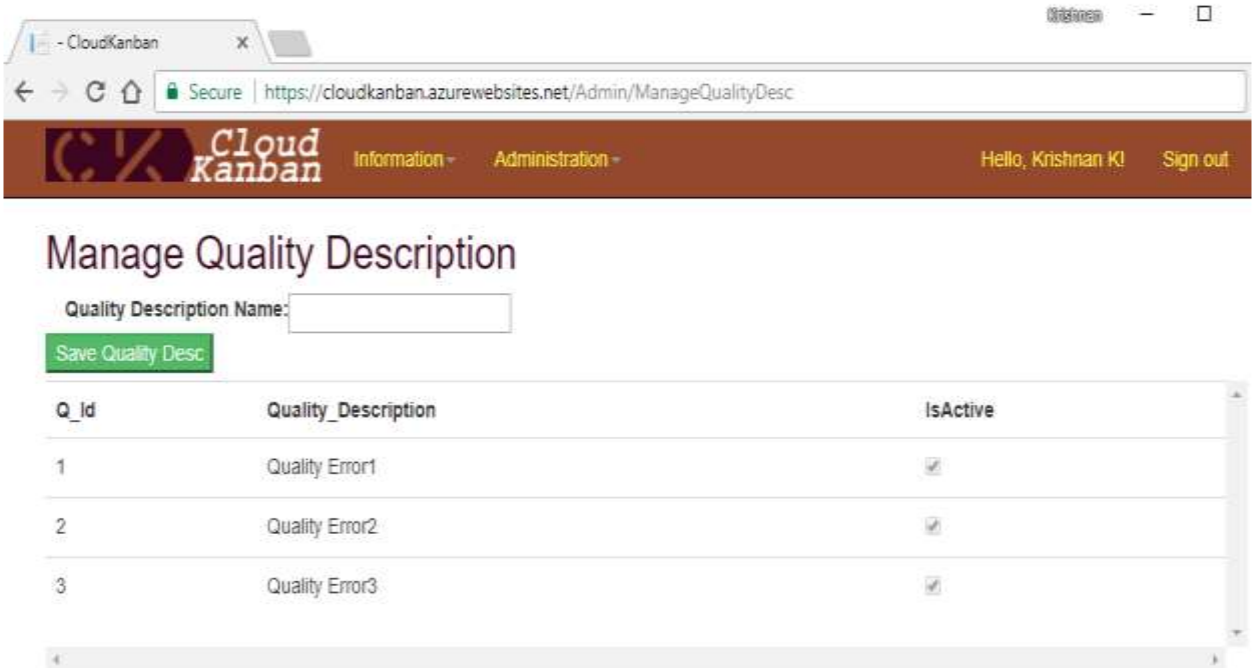


Figure 98 CK - Manage Quality Error Description

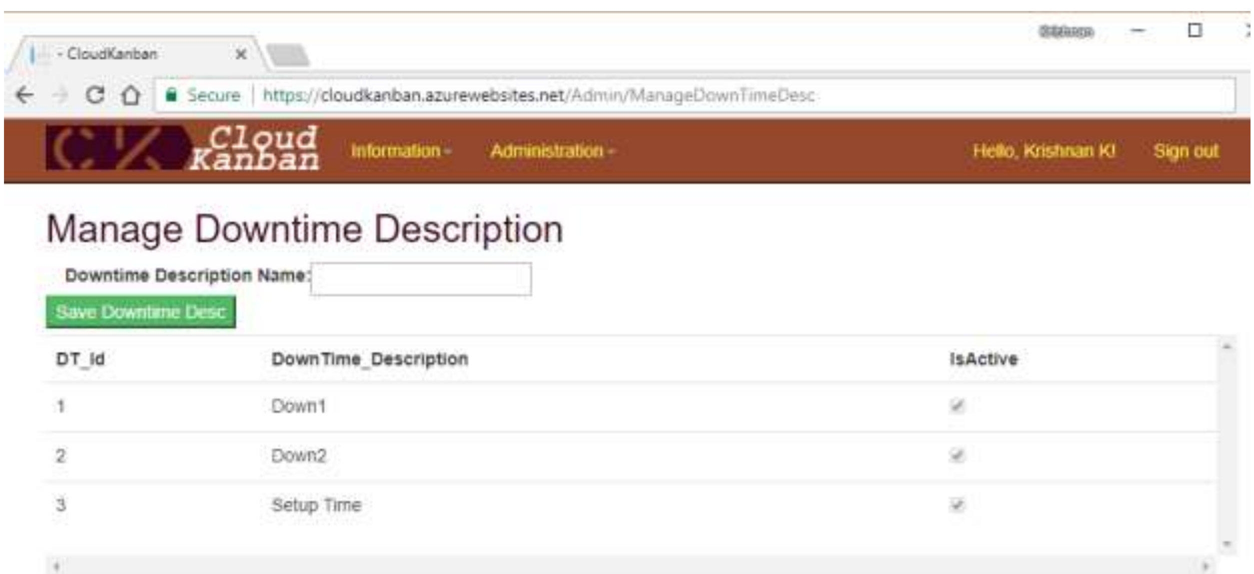


Figure 99 CK - Manage Downtime Description

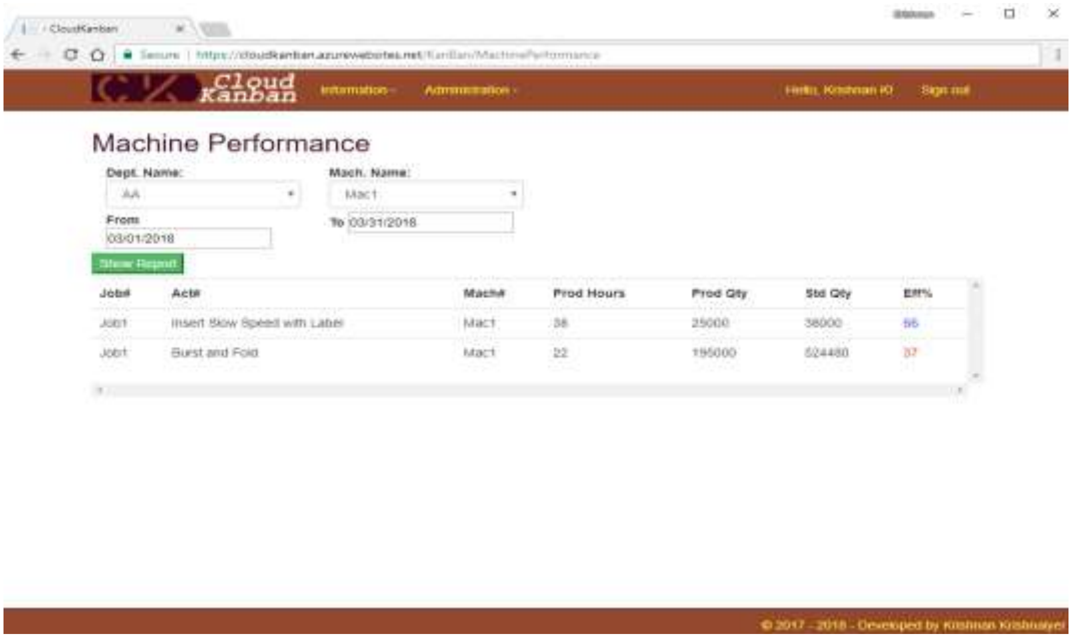


Figure 100 CK - Machine Performance

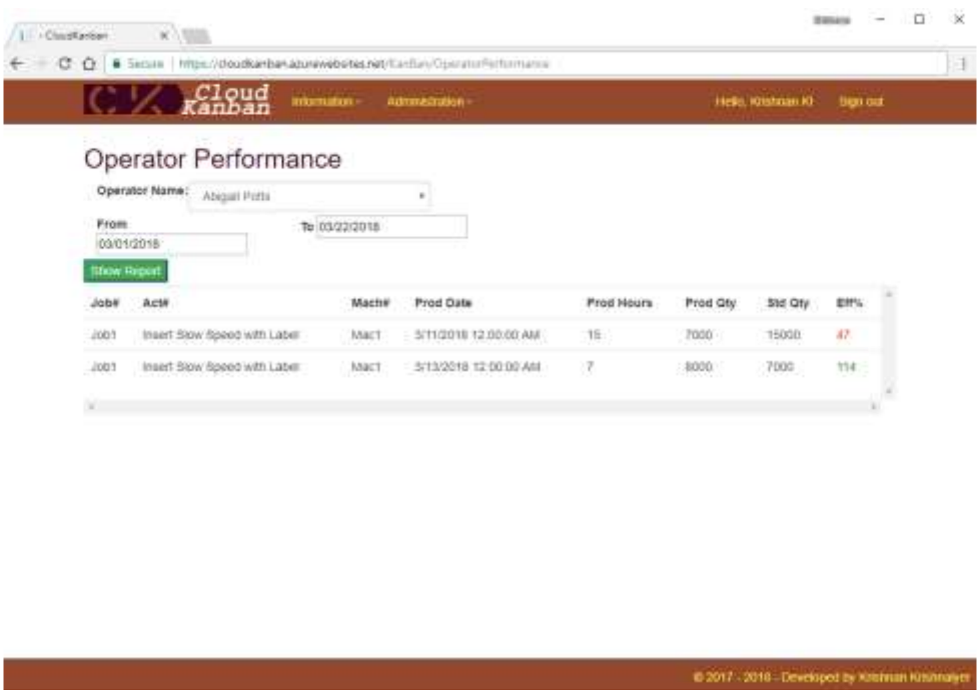
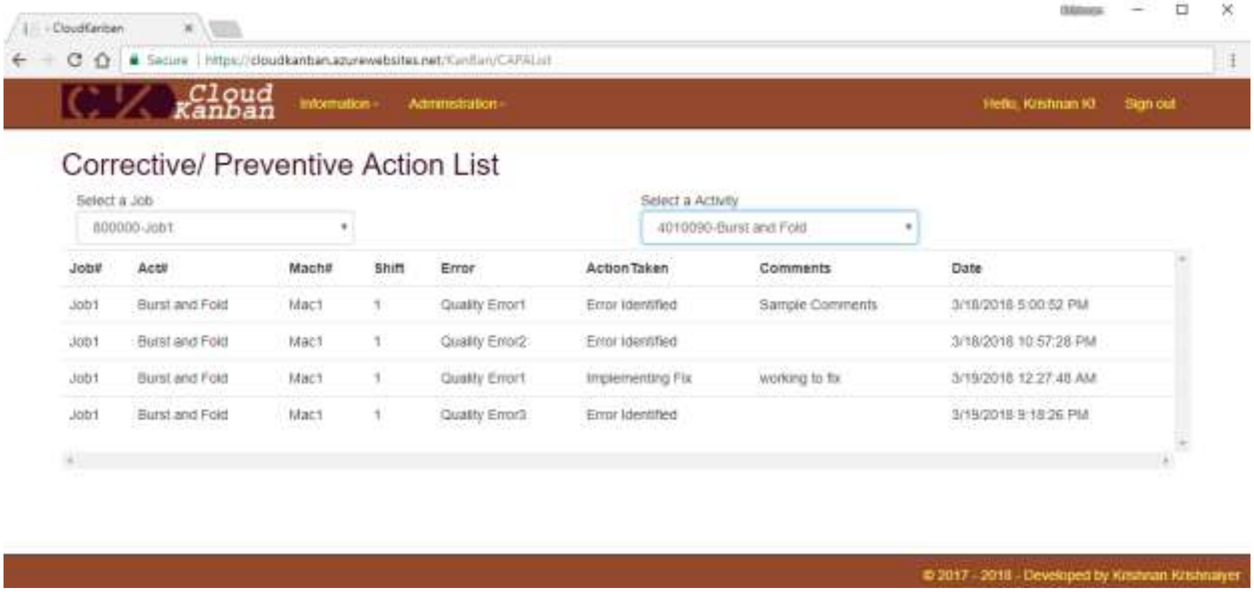
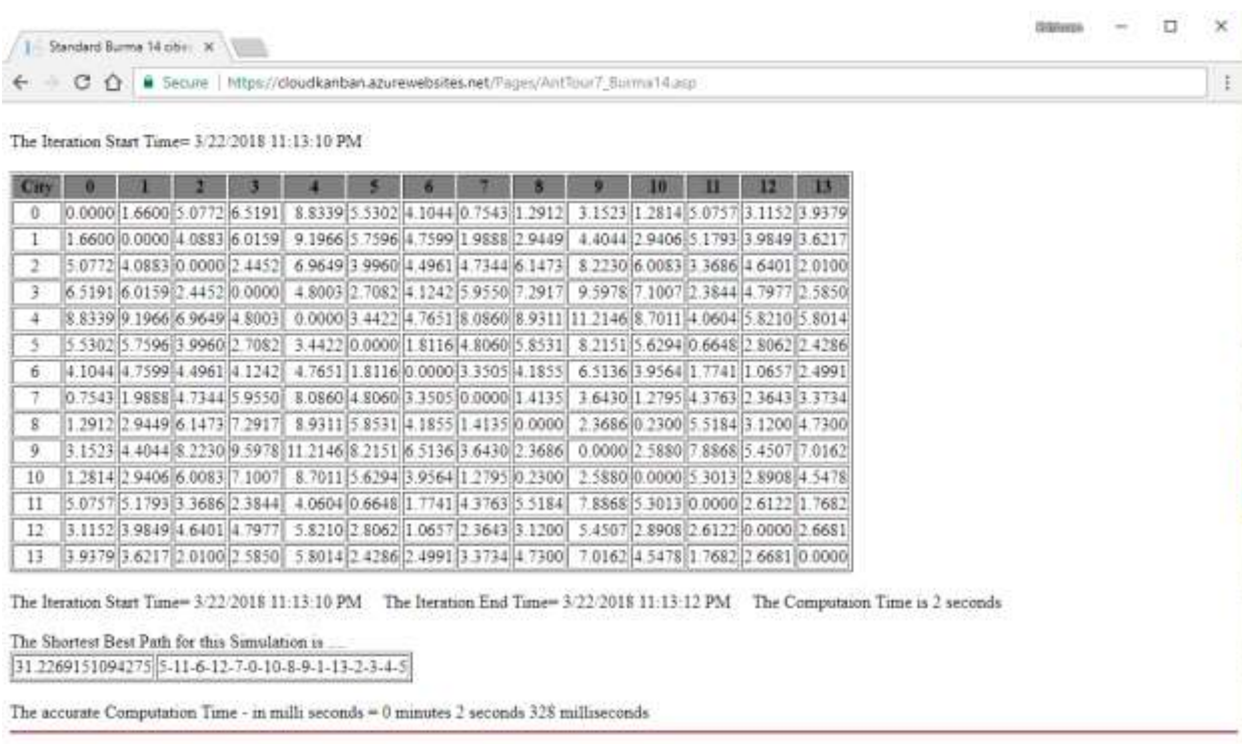


Figure 101 CK - Operator Performance



Job#	Act#	Mach#	Shift	Error	Action Taken	Comments	Date
Job1	Burst and Fold	Mac1	1	Quality Error1	Error Identified	Sample Comments	3/18/2018 5:00:52 PM
Job1	Burst and Fold	Mac1	1	Quality Error2	Error Identified		3/18/2018 10:57:28 PM
Job1	Burst and Fold	Mac1	1	Quality Error1	Implementing Fix	working to fix	3/19/2018 12:27:48 AM
Job1	Burst and Fold	Mac1	1	Quality Error3	Error Identified		3/19/2018 9:18:26 PM

Figure 102 CK - CAPA List



City	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.0000	1.6600	5.0772	6.5191	8.8339	5.5302	4.1044	0.7543	1.2912	3.1523	1.2814	5.0757	3.1152	3.9379
1	1.6600	0.0000	4.0883	6.0159	9.1966	5.7596	4.7599	1.9888	2.9449	4.4044	2.9406	5.1793	3.9849	3.6217
2	5.0772	4.0883	0.0000	2.4452	6.9649	3.9960	4.4961	4.7344	6.1473	8.2230	6.0083	3.3686	4.6401	2.0100
3	6.5191	6.0159	2.4452	0.0000	4.8003	2.7082	4.1242	5.9550	7.2917	9.5978	7.1007	2.3844	4.7977	2.5850
4	8.8339	9.1966	6.9649	4.8003	0.0000	3.4422	4.7651	8.0860	8.9311	11.2146	8.7011	4.0604	5.8210	5.8014
5	5.5302	5.7596	3.9960	2.7082	3.4422	0.0000	1.8116	4.8060	5.8531	8.2151	5.6294	0.6648	2.8062	2.4286
6	4.1044	4.7599	4.4961	4.1242	4.7651	1.8116	0.0000	3.3505	4.1855	6.5136	3.9564	1.7741	1.0657	2.4991
7	0.7543	1.9888	4.7344	5.9550	8.0860	4.8060	3.3505	0.0000	1.4135	3.6430	1.2795	4.3763	2.3643	3.3734
8	1.2912	2.9449	6.1473	7.2917	8.9311	5.8531	4.1855	1.4135	0.0000	2.3686	0.2300	5.5184	3.1200	4.7300
9	3.1523	4.4044	8.2230	9.5978	11.2146	8.2151	6.5136	3.6430	2.3686	0.0000	2.5880	7.8868	5.4507	7.0162
10	1.2814	2.9406	6.0083	7.1007	8.7011	5.6294	3.9564	1.2795	0.2300	2.5880	0.0000	5.3013	2.8908	4.5478
11	5.0757	5.1793	3.3686	2.3844	4.0604	0.6648	1.7741	4.3763	5.5184	7.8868	5.3013	0.0000	2.6122	1.7682
12	3.1152	3.9849	4.6401	4.7977	5.8210	2.8062	1.0657	2.3643	3.1200	5.4507	2.8908	2.6122	0.0000	2.6681
13	3.9379	3.6217	2.0100	2.5850	5.8014	2.4286	2.4991	3.3734	4.7300	7.0162	4.5478	1.7682	2.6681	0.0000

The Iteration Start Time= 3/22/2018 11:13:10 PM The Iteration End Time= 3/22/2018 11:13:12 PM The Computaion Time is 2 seconds

The Shortest Best Path for this Simulation is ....

31.2269151094275	5-11-6-12-7-0-10-8-9-1-13-2-3-4-5

The accurate Computation Time - in milli seconds = 0 minutes 2 seconds 328 milliseconds

Figure 103 CK - Ant Test Simulation

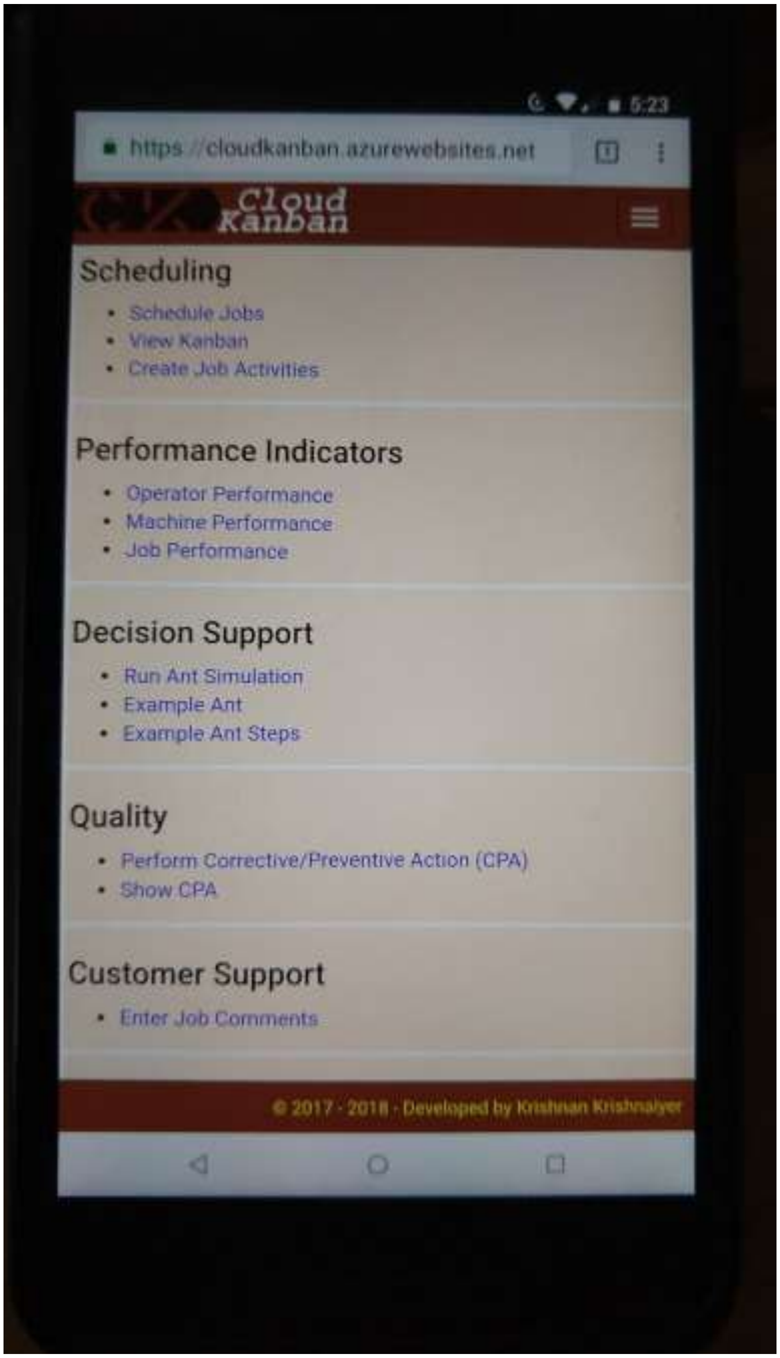


Figure 104 CK Mobile View

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VITA

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