Logistics Management System (LMS): Implementing the Technology of Logistics with Knowledge Based Expert Systems

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Abstract

The Logistics Management System (LMS) is a real-time imbedded transaction-based integrated decision and knowledge based expert support (RITIDES) system which serves as a "dispatcher" (monitor and control) for the manufacturing flow or logistics of IBM's semiconductor facility in Essex Junction, Vermont. Its purpose is to help improve manufacturing performance in tool utilization, serviceability, and cycle time. Significant success has been achieved in all areas. LMS is now a critical component in running major areas of the manufacturing facility. LMS was developed by the Advanced Industrial Engineering department as part of its mission to improve decision making through improved decision support.

Introduction

The problem of scheduling a semiconductor fabrication facility is difficult for at least two reasons. Ther first is the high job degree of inherent combinatorial complexity. Given the number of processes and products, pieces of manufacturing equipment, and personnel in a typical fab, there are a very large number of assignments of individual lots to specific machines at particular instants in time which are possible. Building a complete set of assignments that lowers work-in-progress, raises machine utilization, lowers process throughput times, and meets product output deadlines is a non-trivial task. The second reason is the high degrees of inherent practical complexity. In the longer term, fabs ramp processes and products up and down, replace old machinery with new, reassign experienced personnel. and so on, all of which alters the scheduling problem at the fab. In the shorter term, Murphy strong enforces his laws on the fab floor. The delicate nature of both the process and the equipment gives more than ample opportunity for scheduling surprises to occur on all too frequent basis (Kempf, Chee, and Scott 1988).

Logistics Management System (LMS) regulates the complex manufacturing tasks of an entire plant. It automatically picks up data and, using the knowledge that has been given to it by scores of human experts, it reasons so thoroughly about manufacturing production, and makes corrections and changes based on that reasoning so quickly, that no individual or group of individuals can match its performance (Edward Feigenbaum 1988).

LMS is a new kind of entity. It's a *community* intelligence, born from the collective wisdom of various disciplines, experiences, and points of view, which dynamically disseminates the new intelligence around the same community that engendered it, solving problems that are "too tough for us humans to figure out" (Edward Feigenbaum 1988).

Overview

An ongoing organization goal in manufacturing (Goldratt and Cox 1986) is to improve tool utilization, improve serviceability (delivering product on schedule), reduce cycle time, and improve quality. As the complexity of manufacturing increases, additional emphasis has been placed on manufacturing logistics as a technology important to achieving these goals. The successful use of application information systems to implement the technology of manufacturing logistics to achieve these goals dates back to the early 1900's (Wrege, Greenwood, and Peterson 1986).

The Logistics Management System (LMS) is a real-time imbedded transaction-based integrated decision and knowledge based expert support (RITIDES) system which serves as a "dispatcher" (monitor and control) for the manufacturing flow or logistics of IBM's semiconductor facility in Essex Junction, Vermont. Its purpose is to help improve manufacturing performance in tool utilization, serviceability, and cycle time.

Significant success has been achieved in all areas. LMS is now a critical component in running major areas of the manufacturing facility. It is broadly distributed across the Essex Junction site, and is used to fill a wide range of user needs. The process operator on the manufacturing floor receives advice on scheduling. The manager receives messages relating alert conditions that have, or are about to emerge. The maintenance technician is able to assess the impact of tooling outages, and is alerted to their occurrence. Priorities are established by LMS and communicated to the person best able to deal with the situation.

To achieve this success, we implemented and extended the "technology of logistics" by using and integrating the technologies of knowledge based expert systems, decision support, industrial and manufacturing systems engineering, computer networking, window interfaces, data engineering, operations research, statistics, and rule, object, and function based programming paradigms. The basic design guide of LMS is the stimulus based cognitive model and the associated principles of attention, characterize, select, execute, and follow-up. LMS made use of two key Gene Woolsey rules: (1) the first step is to secure reliable and timely data sources, and :2) a manager would rather live with a problem he can not solve, than accept a solution he can not understand.

Success was achieved because the coherent integration of techniques from various disciplines permitted LMS to counter entropy in logistics. Entropy is a measure of disorder or uncertainty originally used in thermodynamics and statistical mechanics to describe the equilibrium state of a closed system. Entropy in a closed queueing system implies: the system will become as chaotic and disorderly as possible, subject only to the restraints imposed upon it by its own structure. The purpose of LMS is to impose an additional level of flexible structure to improve system performance.

The Basics of Producing Wafers

The basic wafer building process can be described as follows.

- start with a very pure slice of silicon
- then modify it to turn it from an insulator to a conductor
- There are 65,000 part numbers, 13,000 are active
- There are three basic steps in the process
  - oxidation
  - photolithography
  - etch
- the steps must be done in the stated order
- within each step there are a number of operations which are performed.
- to complete a wafer requires 10 iterations through the three step process
- the activity at each iteration is far from identical
- one set of machines handles all the activity across all the iterations across all the different types of wafers at the oxidation step
- one set of machines handles all the activity across all the iterations across all the different types of wafers at the photolithography step
- one set of machines handles all the activity across all the iterations across all the different types of wafers at the etch step
- some processes are batch (ovens) and some are singe thread
- different parts at different steps require different levels of precision
- tools are reconfigured to appropriately handle the part at the specific iteration
- Given the part type and iteration step the service time is known within a small tolerance
- service time range from 15 milliseconds to 20 minutes.
- Service times as a function of the next arrival are exponentially distributed
- decisions made at one iteration impact the environment at future iteration steps

The LMS Base

During the 1960's and 70's Essex Junction built a set of tracking and data collection systems to record all activity on the manufacturing floor (movements of lots, down machines, change in operators, etc.), and handle key functions including process flow, process feedback, and accounting issues. These systems were supplemented with paper systems. In their time these systems were the state of the art.

The Pre-LMS decision support environment (and the LMS base) provided:

- A set of automated, but independent data systems that:
  - reliably (strong data integrity checks, wanding, hardware backup, etc.) recorded all transactions to lots, machines, and orders in manufacturing
  - recorded these events on a real-time basis
  - contained basic process flow checks
- A once a day (overnight) prioritization of lots
- Paper data systems or knowledge bases that contained process spec information, machine spec information, location of lots, operator ability, expected queue time, etc.

These systems were independent (limited coordination between them) due to

- historial development
- technical ownership and maintenance
- technical barriers to linking them

From a decision support point of view the data bases are not independent, but logically linked.
Some of the limitations of the existing systems included:

- limited reporting capability
- no real-time access to the data to support management, industrial engineers, or operators
- limited operator assistance on assigning lots to tools
- unable to adapt schedule to changes in operation real-time

Implementation of LMS

As the size, activity level, and product mix in the facility grew, the limited decision support provided by these systems were no longer sufficient to meet the needs of the business. The Essex Junction facility was becoming data rich, but information poor. LMS was missioned as a first step to reverse this trend.

The first requirement (step 1) was to tie into and integrate widely separated datasets and existing systems in real-time. This requirement drove the architecture to be transaction based. The present transaction rate is 240,000 per day.

The next requirement (step 2) was to provide to various users (customers: managers, operators, planners, and the industrial engineering department (which was building LMS)) with tools that quickly, flexibly, and in real-time convert the data to information. In this step "paper knowledge bases" were "computerized" and integrated with the data stream. This put the users into the decision support phase.

People quickly recognized: time to act to take advantage of an opportunity or take action to avoid a problem (decision window) time frame was small; the transaction rate generated cognitive overload on the human expert; and the existing "experts" had no well articulated underlying theory to improve logistics performance. Therefore more responsibility had to be moved to LMS and the Advanced Industrial Engineering (AIE) department, and the knowledge for LMS would come from a team of people with various "speciality" expertise.

The next step (step 3) was proactive intervention with alerts. Knowledge about what situations should be alerted to whom was incoded in a KBES, and these modules monitored the data stream. This knowledge did not come from a single expert, but from research into the problem with a team from industrial engineering, production, manufacturing engineering, and management.

Step 4 was extending pro-active intervention by having the system responding to anomalies and make the decision about what lot to run next. The knowledge for this activity had the same source as step 3.

In steps 3 and 4 work continued in fine tuning the collection and organization of the transaction stream and the paper knowledge bases. The LMS plan for success was to follow the general approach for building RITIDES Systems.

In a very real sense, LMS is imbedded in the stream of transactions coming from a variety of on-line, real-time control systems, developing and implementing recovery tactics without human involvement in the decision process. Its role is not cognitive replacement, but cognitive augmentation. There is not a single expert who can do what LMS does. Its underlying theme is: "bring the appropriate knowledge at the appropriate time to the appropriate place to capitalize on an opportunity before it disappears".

LMS Functions

The goals and associated decision support tool functions of LMS are:

- Goal 1: Reduce Time to Locate Lots
  Function: establish decision support tool(s) that assigns storage location for lot
- Goal 2: Insure EXPRESS Lots Are Processed Quickly
  Function: establish decision support tool(s) that track and report on the progress (alert) of these lots and attempt to minimize their waiting time (action)
- Goal 3: Serviceability (orders on books are met)
  Function: establish decision support tool(s) that manage lots that are plus / minus to schedule (alert and action)
- Goal 4: Improve Tool Utilization / Usability
  Function: establish decision support tool(s) (alert and action) to
  - manage retooling time
  - set up trains (lots with requiring identical machine setup for bottleneck machines)
  - appropriately mix lots with different mask alignment test requirements
  - maintain appropriate buffers before and after pinch point tools
  - control preventive maintenance and prioritize repair actions

- match the lot with the tool best able to handle the lot

- Goal 5: Insure Unnecessary WIP Levels Are Not Generated
  Function: establish decision support tool(s) (alert and action) to
  - control the launching of lots into the next sector
  - remove lots
  - watch buffer levels
- Goal 6: Coordination between Goals

Notes and Observations

Basic concepts and techniques from MS/OR/STAT like statistical estimations, risk analysis, resolving conflicting goals, decision analysis, etc play a major role. Especially pertinent was a view that humans had significant cognitive limitations that negatively impacted their decision making ability. Due to the complexity of the problem (generated by: time to produce results, data engineering, complexity of the product flow, number of products, short decision windows, etc.), traditional MS/OR/STAT structures like mathematical programming and multi-attribute where not insufficient for

- global structuring of the knowledge
- incremental steps in developing a solution.

KBES type heuristic model structures provided the only realistic vehicle for development of the "model". Real-time imbeded decision support was the only realistic vehicle for delivery. Four items should be noted:

A key feature of KBES structures is the ability for rapid prototyping and incremental evolution. These features permitted the LMS team of industrial engineers (IE) to add components to deal with the complex interdependencies between goals, production steps, and decisions made over time as they came to understand their nature and relative importance. These features also permit the IE's to adapt the system real-time as underlying conditions in Essex Junction change.

Much of the "knowledge" put into the system were the result of STAT/OR/IE kind of investigations by the Industrial Engineering department (called XSELL sessions). The managers and operators did not often articulate specific rules, but goals and relative tradeoffs. The IE's had access to the real-time flow of events on the line and could change rules within 30 minutes. Therefore, they could put in heuristics, watch their impact, do some analysis, and then repeat the process.

For a system to continue to survive, it must continue to evolve. To maintain a steady pace of evolution, LMS relies on "user friendly" programming tools like rules, views, menus, and fact tables to permit the end user to carry a significant portion of the burden of writing and updating the system. The enclosure and message passing concepts from object programming were key in permitting the system to evolve at a rate equal to customer demand.

Besides real-time scheduling, LMS is a key tool for understanding why certain measurement goals were not made, and determining the appropriate action from adding a tool to changing the measurement system. Like any other model, its purpose is insight.

The data engineering and networking is as difficult as the knowledge base development.

As work on LMS progressed, it became apparent "general KBES tools" would not suffice for this task. This type of tool puts the knowledge collected in rules and frames into a single bucket; and the inference engine (IE) determines which knowledge to use when. This type of tool does not permit explicit procedural control over the activation of knowledge, (we do not consider flag variables in a rule explicit control), does not provide for the addition of types of knowledge representation schemes, often require a lot of memory just for initilization, and are at best difficult to imbed.

This type of tool failed in two major areas: The ability to imbed. The ability to express the "natural" organization of knowledge (both storage of knowledge and determination of when it should be used). For example, we found the tabular representation of functions (relationship between input variables and output variables) particulary valuable.

As an example, the following table identifies the appropriate SETUP based on the CHIPTYPE and STAGE.

CHIPTYPE	STAGE	-> SETUP
tiger	1	3
tiger	2	2
lion	1	4
lion	2	4

LMS was developed using APL2, PASCAL, and Assembler to build our an expert system environment (XEN). APL2 is a particularly potent programming language for building RITIDES systems.

The LMS team was composed of:

- people with strong system thinking skills and a strong knowledge of manufacturing (either industrial engineers or people directly from manufacturing)

- strong programming skills
- strong skills in KBES and MS/OR/STAT

LMS was developed over two years with a team of four people. Only two of those people did programming. The two years includes the time to move the system from a limited implementation with a few users, to a full implementation with over 400 users.

The LMS team has now begun work on some significant additions and enhancements to LMS, and a capacity planning system.

LMS is not just a system. It is a team, a goal, management support, and appropriate tools.

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Appendix 1: Plan for RITIDES

The general approach for building RITIDES (Real-time Imbedded Transaction based Integrated Decision and Expert Support) Systems is:

- Build a gateway to collect real-time all transactions (events) captured by independent data systems, access static data systems (computer and paper based).
- use the gateway as the real-time data engine to feed the following support tools:
  - fast and flexible information view tools
  - imbedded knowledge based expert systems to provide cognitive augmentation
  - analysis tools used by industrial engineering, manufacturing engineers, manufacturing floor technicians, MS/OR, statisticians, problem investigator, etc.
- use the tools to drive decision makers through the follow support hierarchy
  - data
  - management information system
  - decision support system
  - pro-active intervention
    - alert
    - recommended action
    - action taken automatically
- DSIM
- the goal being:
  to improve the tools available to support decision making, which improves decision making, which improves organizational performance.