SYSTEMS RELIABILITY

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Today more systems are being installed and are operating reliably than in the past. Is that comforting to know when your system has poor reliability? When you made your justification, your presentation was based upon an operating system. How much downtime was planned in? How much deterioration was there in the ROI (Return On Investment) with 5% downtime, 10%, or 15%? If not planned properly those small numbers may destroy the justification!

The reliability of Automated Material Handling Systems is higher than many other material handling systems. Why then, are there not more automated systems? How can all of the manual or mechanized systems be the operating backbone of manufacturing and distribution? Remember that they were there first. Another reason is that the frequency of malfunctions has been sufficient enough that the user mans his system to overcome the shortcomings and, as a result, gains the productivity desired.

Why haven't we all learned to do this with the Automated Material Handling Systems? Some users have. One factor is that with higher reliability of their Automated Material Handling System the problems are infrequent and "what to do" training is forgotten. There are many other factors. This paper will discuss a number of the factors and suggestions for gaining reliability in the more sophisticated system.

When your new system performs to your reliability expectation, the popular expression, "How sweet it is," is a truism.

For over 15 years I have been very interested in "System Performance" of which reliability is one factor. I am pleased that "System Reliability" was my assigned task for this Advanced

System Conference. But, to establish a better prospective for the subject, let's first recognize that System Performance is based upon 3 key Parameters:

- Capability
- Availability
- Manageability

"Capability" is the parameter we all have been guilty of—spending most of our planning time and attention on. Capability is the capacity to meet all of the physical and corporate objectives. Capability is the first parameter for all successful systems.

"Availability" is the parameter which is a broader term than "Reliability." It includes Reliability as a significant factor. To simply state: Reliability is the lack of an item or system to break down. Availability is the system performing its function.

"Manageability" is the parameter often overlooked in planning and design. Manageability is the ease of operation and the ease of managing the system. Developing a system, assuming it can be operated and managed without design iteration, causes poor beginning performance or lasting performance.

This System Availability paper will concentrate upon realistic objectives, improved understanding, suggestions of how to improve, and why more planning and attention must be spent.

I recommend for our future predictable and successful Automatic Material Handling Systems, that the overall planning and implementation effort be one half toward Capability and one fourth each toward Availability and Manageability.

Economics play a heavy role in today's Systems. It requires management to have an appreciation of the major trade-off in System Availability. Management should provide the project team with overall performance objectives as to capacity, availability, and manageability. To do so, ideas of what availability to expect and broad cost guidelines may help.

I will start with what to expect, offer suggestions on how to improve, reinforce ideas with examples, and conclude with some estimated cost guidelines.

<u>Reliability and Availability</u>

Before discussing "What to Expect," we should be sure we know, by definition, what Reliability is and what System Availability is.

I off a definition of "Reliability" as:

> RELIABILITY is the PROBABILITY of an item PERFORMING its purpose without failure for the period of TIME intended under the operating CONDITIONS encountered.

I offer a definition of "System Availability" as:

> SYSTEM AVAILABILITY is the TIME a SYSTEM or SUBSYSTEM is PERFORMING; its intended capacity (or fraction thereof) compared to the TOTAL TIME and capacity it is EXPECTED to be operating.

Availability is usually measured in percent as shown in the following formula with the terms defined:

$$\% \text{ System Availability} = \frac{MTBF}{MTBF + MTTR \times (1-SCF)} X100$$

Where MTBF (Mean Time Before Failure)
MTTR (Mean Time to Repair)

Summation of Times for:

1. Error Detection
2. Maintenance Man to Site
3. Diagnosis
4. Repair Parts to Site
5. Repair
6. System Restart

SCF (Sustained Capacity Factor)
An addition to the component availability formula to realistically measure systems.

To measure availability first, the system or subsystem shutdowns for preventive maintenance are not defined as lost time. Secondly, during a breakdown, availability is not zero if only one of two parallel systems is down because availability of half the design capacity is still sustained. The 1-SCF (Sustained Capacity Factor) is a modifier on downtime (MTTR). This produces a more realistic System operating value of availability.

<u>AVAILABILITY – WHAT TO EXPECT</u>

Because this is an advanced Materials Handling Seminar, most of you have a mechanized or Automated Material Handling System. You may be looking for 100% availability! Or, you may feel that you have to live with poor availability because of circumstances. Neither is correct. However, your planned system availability must be a factor in the initial justification.

I will not say that our Materials Handling Industry knows all about system reliability and availability, nor to indicate that there is extensive data on machines or conveyor components.

Availability is being diligently addressed by some system suppliers and subsystem suppliers. There has been some broad experience gained over the last 10 years. The following table represents what I believe is a consensus of minimum recommended availability values per type of subsystem. The Table also provides values of probably achievable and values for design objective.

Physical System Effect

The best approach to designing availability into a system is first to justify it on a minimum recommended value. Secondly, design for the design objective value, and thirdly, work with your system in operation to obtain the probably achievable values.

Table 1 lists five subsystem functions of which your system may involve two, three, or more.

TABLE I – AVAILABILITY GUIDE

SUBSYSTEM	MINIMUM RECOMMENDED	PROBABLY ACHEIVABLE	DESIGN OBJECTIVE
Automated Storage	95%	98%	99.5%
Pallet Conveyor	95%	98%	99.5%
Package Conveyor	97%	98.5%	99.7%
Automated Recognition & Data Input	98%	99.5%	99.9%
Computer/Control	97%	99%	99.8%

By a proper modularity approach to the material flow and the information system, the result can be forecasted. A typical system may consist of one automated storage subsystem, three pallet handling conveyor subsystems, seven automated recognition and data input subsystems, and one computer/control subsystem. The way the design integrates these subsystems will influence the overall system availability.

Simply stated, if all subsystems must be operating at design capacity at one time, the System availability is the product of all of the values and may provide a poor result. If all the subsystems do not have to be operating at design capacity at one time, the System Availability may be equal to only the poorest of the subsystem values.

The system availability, due to the physical system, is not the only factor to consider.

People-Effect

In an Automated Material Handling System there are people involved and they may create reduced reliability or may be an asset to improved availability. An Automated Material Handling System uses less people than mechanized or manual systems providing the same function. They are not without people.

As one example of people-effect, the reliability of an Automated Material Handling System, using an operator for product identification, must recognize his errors. As such, an operator required to encode 2 to 4 digits at 30 to 60 units per minute will have an error rate of .1% to 1.5%. It makes a difference if the operator is male or female, old or young, trained or untrained. This may mean 50 errors per hour in a 60-unit per minute system that must be rehandled.

The opposite people-effect is an automatic remote reading scanning station for product identification that may use 1% of an area supervisor's time to pen scan or key enter no-reads. This raises the availability and maintains the require rate.

There is other operating people-effect. They may be from the workload planning, methods of batching orders, product quantities, timely replenishment of picking stock, maintenance personnel availability, etc.

Management-Effect

A third important area is the management-effect on availability. A particular management may establish and practice the "zero error" philosophy. Another management may choose not to train previous to shifting personnel and rely on "on-the-job" training. This may have worked with manual systems but will not on Automated Material Handling Systems.

Management's involvement at both the 1st level supervision and top management significantly affect system availability. Their involvement and commitment is a significant factor which can, and will, raises system availability.

Another management-affect is predicated on management's experience in managing.

WHERE TO LOOK FOR AVAILABILITY IIMPROVEMENT

System Availability must be a tradeoff of economy, technically and physically accomplishable, meeting of corporate objectives and time related.

In concepting material flow and information systems, the technique of seeking the "Ideal System" first has produced final concepts that were better than first concepting only a "practical" solution. This approach can work equally well in providing good system availability. This is what I term the "Design Objective Approach."

By striving for a "design objective" concepting approach with the justification based on conservative recommended availability values system anticipated results can be obtained.

When is the proper time to analyze a system solution for availability? Based upon the benefits of an iterative process, the proper time is after the first overall system concept. To try to factor availability in before there is a workable concept, will tend to tie up the process of getting workable concepts. Broad guidelines for the do's and don'ts of system design for availability will always affect some initial conception. These should be in the subjective mind.

To be most effective in advancing concepts, good planners must have an uncluttered mind to concept the "ideal solution." Today's competition and inflations demand that each user make quantum jumps in better systems solution.

Following preliminary evaluation considerations of a one or a number of concepts, the team should look at the reliability aspects of each. These should be relative to the subsystems. Then, maintainability of each must be evaluated to arrive at availability. Also, the manageability of the system should be evaluated.

The concept availability values should be compared against the systems and the subsystems objective values. The system use, the dependency of other functions on the cost of downtime, and the management's previous experience will provide judgements for this first concept evaluation.

After a preliminary analysis, reconcepting the system will permit improving the overall system availability or provide a more economic solution for the acceptable value. The process will take several reiterations but a very effective solution will arrive.

In manufacturing or distribution a basic objective should be to remove throats or bottlenecks. This is not always possible but many times is. Throats may be defined as single points of material flow, single critical control devices without backup, or single points of required instantaneous information flow.

Life Cycle Cost Approach

Before we discuss some of the do's and don'ts of design for system availability, I believe the future of material handling and information systems will be to look at the "life cycle cost approach."

A quick review of chapter one of Professor Benjamin Blanchard's book on "Design and Manage to Life-Cycle Cost" would help gain an appreciation of future product and project analysis. System reliability plays an important part in the true prediction of "life cycle cost." As stated, the current dilemma is that the "total cost" of systems and products has been increasing at an alarming rate. This is due primarily to a combination of inflation and cost growth from causes such as the:

a) engineering changes

b) production or construction changes

c) schedule changes

d) logistics support

e) estimating inaccuracies

f) program documentation

g) unforeseen problems

I am not recommending that each major system must have the detail of life cycle costing. I am stressing that certain factors and the effect thereupon will make us all more aware of wants rather than needs. Also, it may be better to raise the capital investment to greatly reduce the future operating expense.

Do's and Don'ts of Availability

In planning a major system, the analysis must have a design objective but today without contractual values. If a system supplier is forced to contract for availability and something uncontrolled happens, "the user may then own a material handling company." That is neither of benefit to he user, the industry, or the unfortunate supplier. This "Design Objective Approach" produces a strong team effort and results in higher systems availability.

The following is a review of some of the do's and don'ts of design for availability. They may provide a reference and/or check list for future planning.

Do's

- Provide two or more flow paths where possible, especially in critical areas.
- Use multiple storage modules or aisles where possible.
- Use S/R machines at 75% maximum utilization for systems with 4 or less machines and 85% maximum for larger systems.
- Use S/R Transfer Unit with systems having only one unit load per many SKU/s.
- Use modular mechanized flow rack systems for dynamic storage systems.
- Use random assignment of storage aisles, picking lines, packing lanes, accumulation lines vs fixed.
- Use of multiple PC's (Programmable Controllers) or relay logic panels per section of system.
- Backup protection of PC for each critical throat.

- Use of individual controls per S/R machine vs a common control.
- Use of alternate data entry means for automatic scanning by backup scanner or keyboards.
- Use of non-contact, solid state sensors vs contact or moving part type.
- Use of dual drives and controls where throats can't be eliminated.
- Use of backup computers either cold, warm or hot depending on permissible downtime.
- Use of backup equipment, mechanical or controls to permit reduced manpower on 1 or 2 of multiple shifts.
- Use of limited accumulation between critical functions to eliminate or reduce impact of stoppage.
- Use common in-process storage between multiple machine functions.
- Design controls and computer system for limited operation without next level computer supervision available.
- Provide diagnostics to indicate most all known possible material handling failures and internal control failures.
- Use of communication center for the system for more rapid breakdown response.
- Use of closed circuit TV for monitoring critical areas.

Don'ts

- Design special equipment when standard is as good and available.
- Don't centralize entire control in one computer for entire system.
- Don't use one storage aisle and one S/R machine at maximum capacity for critical functions.
- Don't design with one vertical lift at maximum capacity.
- Don't design <u>every</u> element and subsystem at its maximum capacity and without accumulation between functions.
- Don't plan to run without adequate and trained maintenance personnel.

It is a mistake to consider availability designing only for large systems. Large systems are made up of small subsystems. One subsystem that has poor availability will greatly affect the major system availability.

A subsystem of a large operation is like a small system in a smaller operation. An example of a small system availability improvement can be given in the following example.

A small conveyor system handling appliances uses a moving beam scanner for automatic data entry and sortation information. The moving beam scanner may be very reliable itself but if the label is periodically damaged the sortation and transportation system throughput will frequently stop. The problem was solved by simply adding a pen scanner and a conveyor stop alarm. The supervisor could pen scan the label to enter the data which restarts the system.

As an effective secondary backup, a keyboard is provided for data entry if none of the bar code portion of the label is available.

This was a very low cost solution to provide a higher system availability.

Another small system example is the solution using one mini load machine and associated storage aisle to handle 75 ins and 75 outs per hour, Figure 1. By designing a special mini load machine that is essentially 20% faster than any existing but within our space age technology this system could be produced.

Contrast that with the reliability gained by using two S/R machines and two aisles providing the same amount of storage but using the more conventional 45 loads in and 45 loads out per hour per machine, Figure 2. The 75 input and outputs per hour required for the production parts to feed the assembly area would afford a much greater system reliability to keep up with demand. One operator will easily handle two aisles for normal operation.

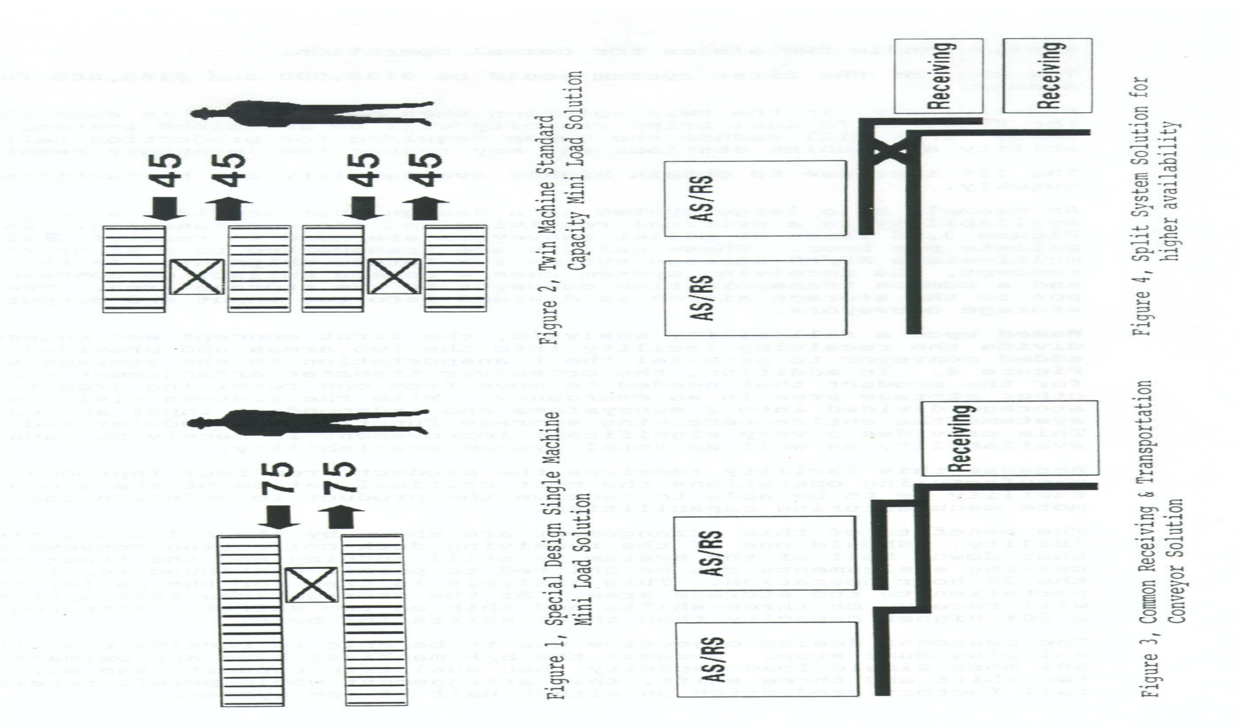

Figure 1, Special Design Single Machine Mini Load Solution

Figure 2, Twin Machine Standard Capacity Mini Load Solution

Figure 3, Common Receiving & Transportation Conveyor Solution

Figure 4, Split System Solution for higher availability

The cost of the first system would be $135,000 and $165,000 for the second.

Beneficially, in the twin solution when one machine is down 45 of the required 75 dual trips capacity will be sustained instead of zero. This will reduce the queue required for production reliability at machine stations and may reduce the inventory required.

The 12% increase to obtain higher availability can be justified quickly.

An example of a large system is a design that provides a very high availability in a critical receiving and storage function. In Figure 3, 8 lanes of pallet conveyors are used to receive 348 pallet per hour. These pallets are transported to a highrise, multi-aisle AS/RS storage system for future shipment. In the first concept, the receiving system uses a common collection conveyor and a common transportation conveyor to the storage area. The input to the storage aisles in divided into two input and output storage conveyors.

Based upon a reliability analysis, the first concept was changed to divide the receiving facility into the two areas and provided the added conveyor to parallel the transportation to the storage area, Figure 4. In addition, the crossover transfer arrangement was made for the product that needed to move from one receiving area to the other storage area in an emergency. With the sixteen aisles of storage divided into 2 subsystems and independent input and output systems the entire receiving storage function was modularized. This provides a very significant improvement in receiving capacity availability as well as total system availability.

Because this facility receives the product from four inprocess manufacturing operations the most critical nature of the storage facility is to be able to receive the product to maintain the remote manufacturing capabilities.

The benefits of this arrangement are shown by the following flexibility. Should one of the receiving dock-collecting conveyors shut down, half of the system is still running and the truck receiving assignments can be shifted to permit continued receipts in the 24-hour operation. This analysis is true for the pallet transportation to the storage area. At the storage area this system will receive on three-shifts and ship on two shifts. This requires a 50% higher capacity than three shifts for both.

The customer design objective was to be able to receive even if the shipping must stop. Because the S/R machines have approximately 50% more single load capacity than dual trip capacity and sized for two shift and three shift, this arrangement would permit receiving full factory production on either half of the system.

If the availability of each subsystem is 95% the selected arrangement has a reliability of 99.75%. This is obtained by realizing that 95% availability of each half means 5% downtime. The likelihood of both halves being down is only 5% of 5%.

This is an excellent example of a reliability analysis providing excellent performance. The added cost to obtain the second solution was only 3.2%. Seldom can you receive so much benefit for such a little cost.

HOW TO OBTAIN AVAILABILTY WITH ECONOMY

Today's technology, system planning methodology, project management, systems structured programming, and advanced system configurations obtain better availability with economy.

Modular Approach

The modular approach to designing material flow system is a key element. The idea of using six modules in a given distribution center is a quick example. Each module has storage, picking capacity, transportation capacity, accumulation, automatic scanning, automatic sortation, and mechanized palletization at the dock. The economy in this modular system is obtained by economy of engineering, better learning curve for manufacturing, better learning curve for installation cost, and better overall system sustained capacity. A stoppage affects only 1/6 of the total system capacity.

Pre-Engineered Highrise

Using pre-engineered highrise storage modules has been a step toward obtaining greater availability with economy. This is only in its beginning but has been much more fruitful in 1000 systems in Japan.

Subsystem Exercising

The use of automatic sequencing controls for exercising the mechanical subsystems with loads has been very beneficial in removing infant mortality failures before a total system is called to operate.

Distributed Control

By providing distributed control in Automated Material Handling Systems, a significant step can be made towards more reliable systems. They are the conveyor and sortation, the vertical travel for greater floor usage, and storage machines for queuing. Each of these material handling functions may be stand-alone systems with a local logic control. The use of PC's (Programmable Controllers) for vertical lifts or other conveyor logic. The use of microprocessor PSC's (Programmable Sort Controller) provide the standardized and reliable solution to most sorting situations. The use of standardized microprocessor control for S/R machines for on-board logic performing a reliable function.

Why are these logic elements more reliable? They become more reliable because they are repeatedly manufactured hardware; smaller software programs; predictable table-driven software for ease of application and commissioning; repeated application permits standardized diagnostics for operations and maintenance; familiarity by the supplier and the user maintenance people due to better documentation; and the repeatability of systems due to flexibility of the application. This produces the tendency toward more standardized applications. These elements would stand alone but are, also, with proper planning, able to be tied into a distributed control now or in the future.

Spare Parts Considerations

Having the proper spare parts is a key element in obtaining availability with economy. The proper level of spares will prevent the catastrophic failure. As a guideline, the following Table may be used in budgeting spares. It was compiled from some conveyor, storage, and combination systems.

TABLE II – SPARE PARTS GUIDELINES
(% of System Cost)

Operation (Shifts)	Mechanized	Automated
1	1.5%	2.2%
2	1.7%	2.5%
3	2.0%	2.9%
Continuous	2.6%	3.8%
	*	*

*Generally small systems are higher and large systems may be lower.

Spare parts such as keyboards and computers have been used as training aids for economy.

Preventative – Breakdown Maintenance

The user's management style is an important factor on availability. Both management's style of maintenance on a breakdown basis and maintenance on a preventative maintenance program can be made to work. The more Automated Material Handling Systems, the more successful managers are relying on the preventative maintenance approach.

One of the benefits in a computer controlled system is the availability of a breakdown information such that preventative maintenance can e more effective in focusing upon the proper cycle of each element's PM Program. Even with the most perfect preventative maintenance program breakdowns still will occur. The training and rapid response to the occasional failure and proper tools and spares are paramount in maintaining the lowest (MTTR) Mean Time To Repair.

Maintenance Method

This brings to mind a customer's question on who should maintain an Automated Material Handling System. Should it be maintained only by user personnel, maintained only by the supplier on a contract basis, or a combination thereof?

Many users believe in and implement their maintenance program for the material flow equipment. Simply stated, they maintain the conveyors, storage machines, transfer units, pallet stackers, packing equipment, palletizing equipment, and usually the conventional controls. For the computer control they often have a service contract with the computer equipment company. This has led to a trap in the computer field because of the software or special computer board content.

To have the supplier maintain the entire system usually means a significant increase in cost to the user but not so in all cases. The supplier must have resident people and may not be able to draw on other company personnel as the user can in an emergency.

Several combination efforts have been successful for maintenance. One of these is where the supplier has a contract to periodically visit and inspect the equipment, making an awareness list of items requiring attention for the supplier himself to remedy. This is a relatively low cost contract.

Another possibility is the system's supplier who provides field service for his computer control and sophisticated components such as scanners, electronic scales, and S/R Machine Controls. This service covers preventative maintenance and remedial service on a specified response time for both the computer hardware and software.

Computer Backup

Users who do not have a computer controlled material handling system are very concerned about the reliability of the computer or computers in their proposed system. Because few users feel they are qualified computer experts and the prominence of the computer, proper backup becomes an essential point of interest.

The computer CPU is probably the most reliable device in the system except the racks. Devices around the computer may not be so. Even so, computers should have backup.

One of four approaches will apply to your system:

1) Spare parts only 2) Cold backup 3) Warm backup, and 4) Hot backup

By using distributed control properly computer backup cost will be reduced for the same system requirements.

Hot backup is the most expensive approach requiring special electronic hardware and significant increase in software engineering. It is an automatic switch over scheme and is not normally required. It can increase the computer content, hardware and engineering, 25 to 80%.

Warm backup is the newer idea for critical systems. The backup computers are kept on line and up to date within the last second or so. Switch-over is by the operator. It requires mostly standard hardware and some extra software engineering. In a distributed control it would apply

to the Facility Director, System Director, or Subsystem Director level. The computer system cost increase may be 15 to 35%.

Cold backup uses a duplicate computer already in place with a switch or by changing plug-in cables to transfer to the backup unit. More time is required to switch but it is used on a number of large and small systems. Very little extra engineering is required. The extra system cost is from 5 to 25%. One reason for the low cost is the computer hardware is probably only 50% more than basic spare parts cost.

Spare parts only approach is adequate for many systems. They are the less critical small and medium computer systems and the individual function controllers of small systems and large distributed control systems alike.

Useful Life Contracting

Material handling is not ready for Useful Life Contracting. The military and some aero-space customers are. The concept is a single responsibility Life Cycle Cost Contract. The supplier designs, manufactures, services, and repairs all units or systems over the useful life.

We don't know enough to do so but may so in the future, perhaps 5 to 10 years.

Let's review two examples of how to obtain higher system availability with economy. The first one is a system layout arrangement and the second is the use of control practices.

Availability Economy by Layout Idea

The following example has become nearly a classic for an Automated Material Handling and Storage System Project. This particular example has a system with sixteen S/R machines in sixteen aisles. The flow to and from the storage area was 6 pallets per minute on a sustained peak basis. This rate is above normal guidelines for common input and output systems.

The first solution, Figure 6, shows a lower level input system and an upper level output system. This system configuration, relative to receiving and shipping, was good because they were on opposite sides of the storage. In analyzing the availability of this solution, the customer and the supplier were not satisfied. The receiving function had to have a higher availability than could be counted with one common conveyor.

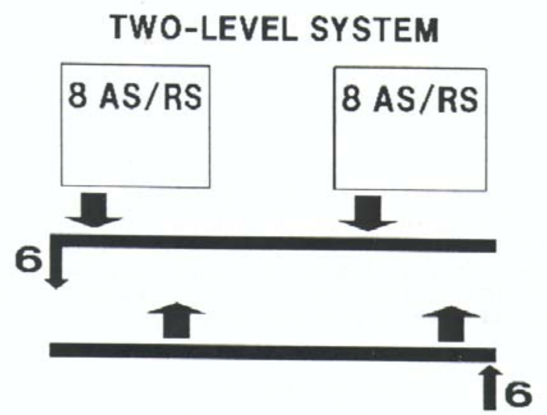

Figure 6, Two-Level AS/RS Input and Ouput Conveyor System

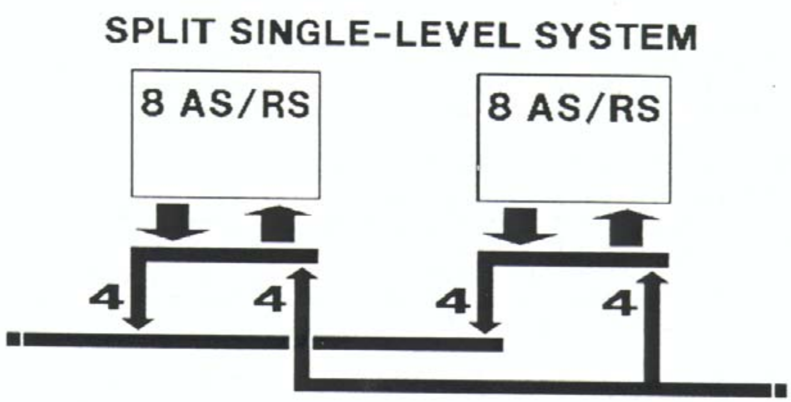

Figure 7, Split Single Load AS/RS Input and Output Conveyor System with greater availability than Figure 8.

In analyzing this, a second solution, Figure 7, was analyzed. It divided the storage system in half and used a single level common input and output front end conveyor system. The availability of the overall system receiving and shipping capacity is better. The conveyor systems, at no increase in equipment content, could handle 4 pallets per minute in each system. This eliminated the supported steel in the first solution.

The results of this example show that the system with the greater availability was actually more economical. The values are as follows:

- Two level - $1,500,000
- Split Single Level - $1,200,000
- a 20% reduction

Improved Availability With Control Idea

There are ways to improve the control system availability with economy. If we will let our engineers have the time and freedom to concept, given an overall objective, I find that they will provide us with excellent solutions. The following example is a use of simplicity for reliability or availability improvement.

This project was for a company purchasing the most demanding conveyor system I know of in the United States, or maybe the World. It is a 24-hour a day, 7-day a week, 365-day a year material handling, in-process project. In order to have the best reliability and availability from the control, PC's were chosen to handle the logic control for receiving, transportation, interim storage, demand routing to test, secondary and long-term storage, and delivery to the packaging area. For illustration purposes, we will simply show four PC's and how their reliability was improved, Figure 8.

Each PC was programmed to cover its area. Once the logic control size was established each PC's memory was doubled by a duplicate Unit B. This idea permitted each PC to contain its program in two independent units but in one cabinet.

The system reliability was obtained by being able to plug switch the inputs and outputs of any failed PC to its alternate.

Of the total controls equipment and engineering for this project, the increase cost was 2.8% increase for memory, wiring, and cabinets.

To complete the story, the distributed control was redundant at the System Director computer level above the PC's as well as the Flow Manager's computers level above the System Director. 2.8% increase shows how increased availability and reliability can be obtained with economy.

GENERAL QUANTITATIVE GUILDELINES FOR ADDED COST

In the beginning of this paper I recommended that management give availability guidelines to the project team as well as guidelines to the project team as well as guidelines for justifiable capital cost to obtain the increased availability. In analyzing a number of systems and subsystems, I have produced the following graph. It should be understood that each area of the business community has differences relative to return on investment and other asset justification guidelines. The purpose of these guideline charts is to present some of the considerations of what reasonable increased cost are to obtain increased availability.

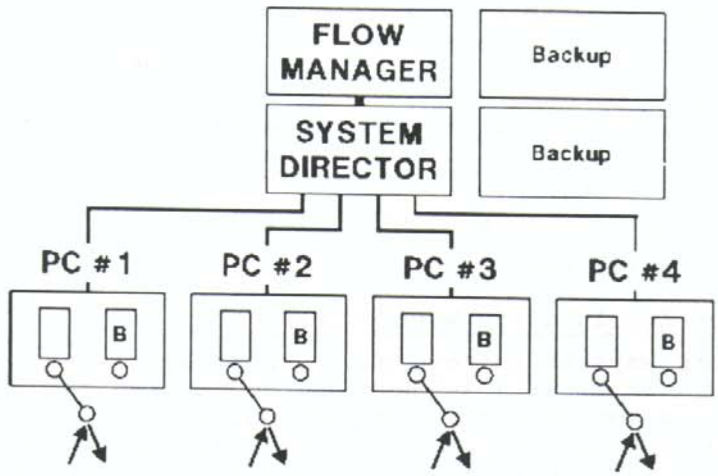

Figure 8, Effective Conveyor Control Backup for continuous operating, In-Process Handling System.

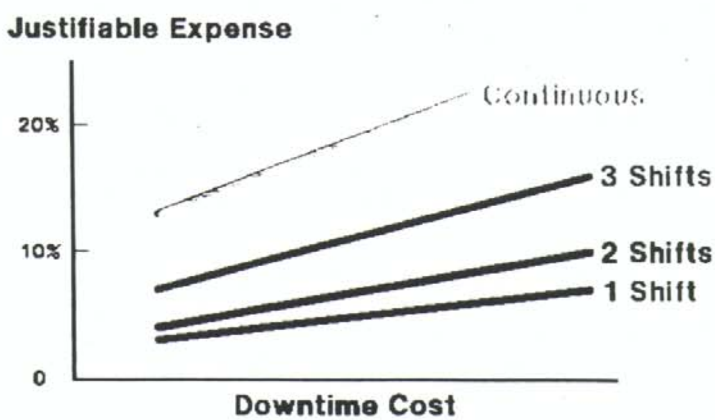

Figure 9, Justifiable Capital Expense relative to downtime consideration.

The guidelines are offered to provide a forecast of justifiable expense over the base cost of your Automated Material Handling System. Figures 9, 10, and 11 show the difference between justifiable expenses for single shift, two shift, three shift, and continuous operating systems. Figure 9 compares expense to downtime.

Figure 10 shows the effect of the size of the system and Figure 11 shows the effect of sophistication or complexity of the system. These are trend lines with only relative values. They are based on spare parts costs, increased equipment and engineering costs and training.

Another interesting consideration is shown for justifiable capital expense against cost with hourly downtime cost expressed in percent of system cost. Figure 12 shows results in attempting to raise availability from 95% to 97.5%. The more that other functions rely on this system, the higher the downtime cost. Therefore, the higher justifiable capital expense. Better availability analysis and design can save some of this.

CONCLUSION

This paper has presented System Availability design objectives; discussed the designing of a system; questioned how much backup is needed or recommended; examined management philosophies on maintenance and operations; examined mechanical and control functions relative to economic considerations; and, provided some guidelines for future system's reliability and availability improvements.

The three key system performance parameters discussed capability, availability, and manageability are paramount. We must, as system planners, maintain our high quality of interest and effort in the capability parameter but we must increase by a significant amount the planning and implementation effort towards a better availability and better manageability within the Automated Material Handling Systems. My recommendation of 50% of the effort towards capability, 25% towards improved availability, and 25% towards manageability will produce better systems with predictable payback.

A number of do's and don'ts in system planning have been suggested, and the effect of people involvement, and the effect management philosophy has on system availability, hopefully, will inspire your project team to improved concepts. It is appropriate at this time to make one additional caution about management's skills and how they affect a new Material Handling and Storage System. If their experience is only that of a manual system, it becomes almost impossible to manage a large automated system. It's like a "three dimensional chess game." This can be accomplished but management's skills must be learned before the system will be successful.

I would like to stress that the top management, middle management, and first level supervision involvement and understanding of the overall workability, capabilities, and flexibility of the new Material Handling System are keys to success.

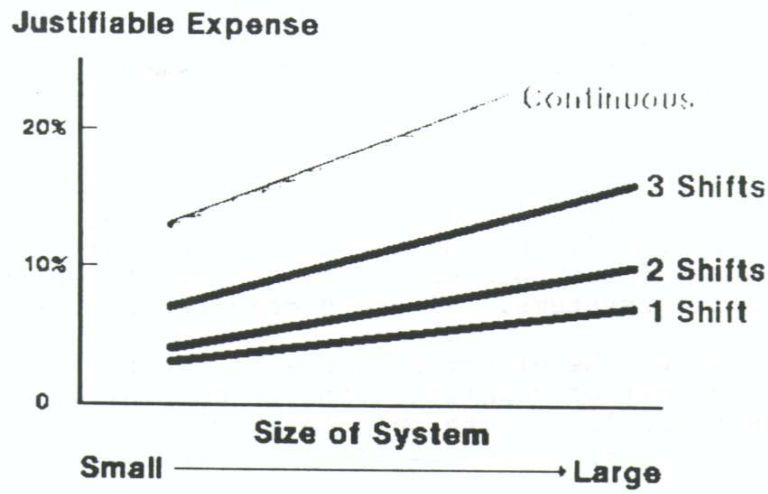

Figure 10, Justifiable Capital Expense relative to System size considerations.

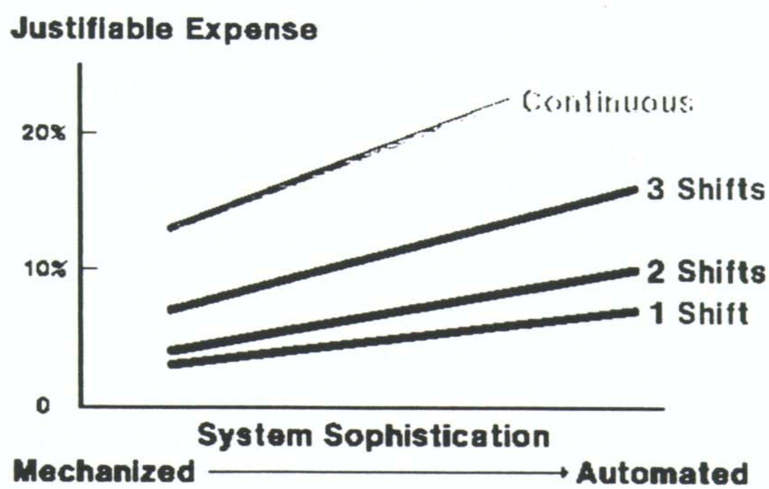

Figure 11, Justifiable Capital Expense relative to System sophistication.

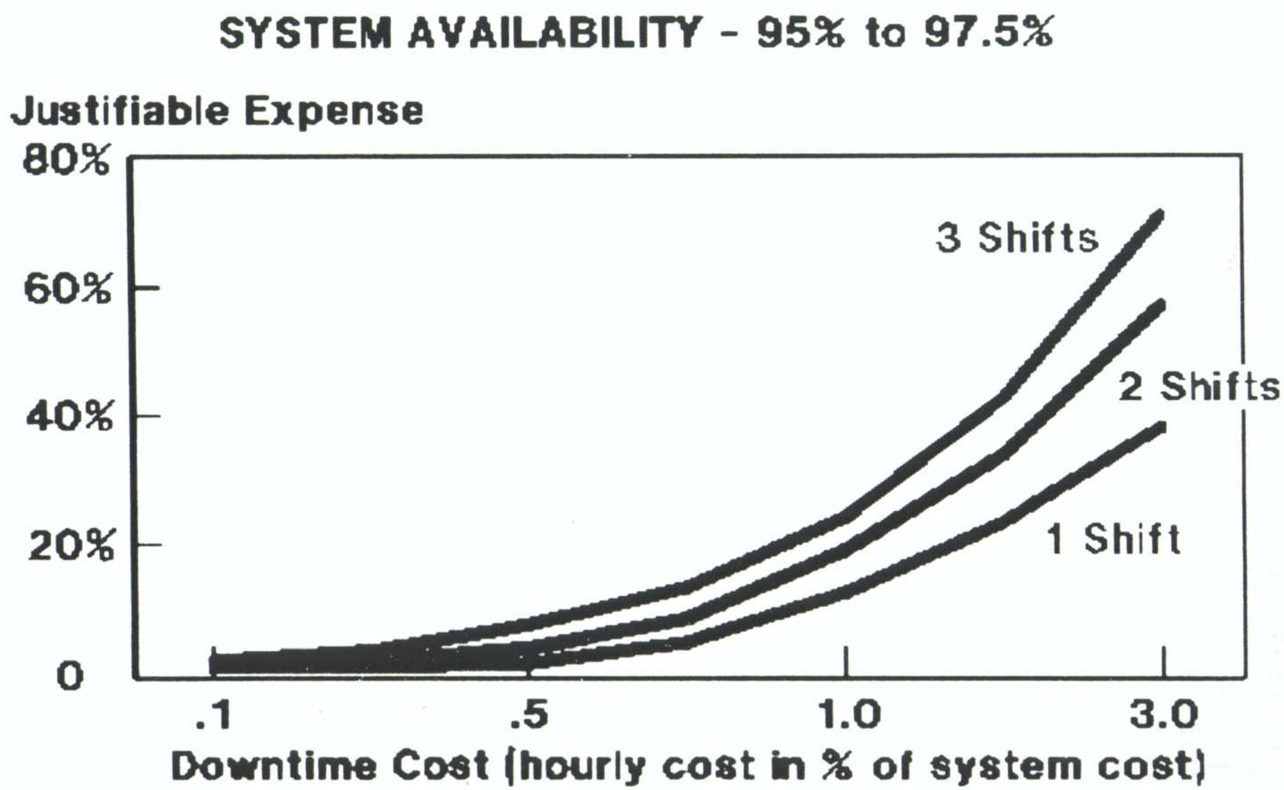

Figure 12, Effect on Justifiable Expense relative to down-time cost showing effect a single system may have on many other functions.

APPENDIX

Systems Reliability was my assigned subject for this conference. It is addressed in the joint session due to its importance to the Automated Material Handling Systems. Systems Reliability is not the only factor to consider for economic operation. Each project must consider System Availability of which Reliability is a major factor. Each term has been defined in the paper.

The other key factor is maintainability. Maintainability is a factor which takes into account the time to detect a down condition, the time required to obtain help, time required to analyze and determine the problem, the time to repair the problem, and the time to get back on stream.

Percent Availability, as defined earlier in the paper, is the ration of total hours for planned operation divided by the total planned hours minus the product of hours not in operation and the sustained capacity factor. The Sustained Capacity Factor (SCF) is an allowance for part of a system to be stopped while the remaining part is outside the planned hours except for a 356-day per year continuous operating system.

In order to see how you would calculate the Percent Availability, the following examples are given.

The first example is where a system stops once per hour but is back in full operation within one minute.

$$\text{\% System Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}\ (1\text{-SCF})} \times 100$$

$$= \frac{60}{60 + 1\ (1-0)} \times 100$$

$$= 98.36\%$$

Now compare this with a system that stops once in an 8-hour day and takes two minutes to realize the down condition, five minutes to get proper help, ten minutes to diagnose the problem, and three minutes to repair and put the system back on stream. The second system has poorer availability as shown in the following formula:

$$\text{\% Availability} = \frac{8 \times 60}{8 \times 60 + (2+5+10+3)\ (1-0)} \times 100$$

$$= \frac{480}{480 + (20 \times 1)} \times 100$$

$$= 96.0\%$$

Even though the second system has an MTBF (Mean Time Before Failure) eight times as long as the first, the fact that the maintainability factor of twenty minutes is proportionately higher, thereby lowers the percent availability. In each of these cases, they have been calculated as the sole capacity of the system.

Looking at a third example, let's take the second system and base the percent availability on one of two parallel systems that each have sixty percent of the required system capacity. As such, the percent availability of this example would be as follows:

$$\% \text{ Availability} = \frac{8 \times 60}{8 \times 60 + (2+5+10+3) \quad (1-60)} \times 100$$

$$= \frac{480}{480 + 20 \times .40} \times 100$$

$$= \frac{480}{480 + 8}$$

$$= 98.36\%$$

Because sixty percent of the system capacity is maintained, the percent availability is 98.36%.

Some percent availability calculations would give this condition a higher value but this appears to be realistic form an availability standpoint. It is important that systems be analyzed with a clear understanding between the user and the supplier as to how the percent availability calculation will be made.

In these last two examples, the effect of items that are under the user's control has been shown but they are conditional upon the diagnostic tools and fail-safe equipment provided by the supplier.