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ACCUMULATION REQUIREMENTS
FOR A BOTTLING OPERATION

by

Kimberly Jae Carswell

A THESIS

Submitted to
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ABSTRACT

ACCUMULATION REQUIREMENTS FOR A BOTTLING LINE

by

Kimberly Jae Carswell

Productivity has recently received increased attention in the packaging industry. The use of accumulation, once considered a necessary evil is now being considered as a way to increase productivity. This thesis proposes the use of accumulators as a way to increase packaging line productivity by decreasing the labor requirement of a packaging line, while maintaining the same level of production.

Time studies, statistical analysis, and plant space considerations were employed to determine the optimal size of accumulator for a bottling line. It was determined that installation of an accumulator would make it possible to eliminate one position from the line crew. This labor saving justified the cost of the accumulator. The incorporation of an accumulator in the line will reduce the labor requirement of the line thus increasing packaging line productivity.

This thesis is dedicated to my parents, Mr. and Mrs. James R. Carswell. Without their continual support and effective encouragement, this thesis would not have been possible.

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INTRODUCTION

Productivity continues to gain greater prominence in the packaging industry. One way to increase productivity is through the use of accumulation on the packaging line. Application of accumulation is the subject of this thesis. It is proposed that through the use of accumulation the productivity of a packaging line can be increased by a reduction in the labor requirement, while maintaining the same level of production. An investigation was carried out to demonstrate this concept.

The purpose of the thesis is threefold. First, it is a compilation of the scattered information on packaging line accumulation and its effect on packaging line productivity. Secondly, the information is organized in such a way to be used as an educational tool at the undergraduate and graduate level in the School of Packaging. The final purpose in the thesis is to design and carry out one application of the principles of accumulation on a real installation and to estimate its effect on productivity. This application will serve to illustrate packaging line efficiency and productivity instruction to undergraduate and graduate students.

A DEFINITION OF PACKAGING LINE PRODUCTIVITY

Productivity has gained greater prominence in the packaging industry over the last few years and its importance continues to grow. The purpose of this discussion is to investigate this increasing importance, examine the range of definitions of productivity, and determine an effective definition for use in this study.

The words productivity and efficiency bring to mind many different connotations. However, a broad description can encompass both of these words and all the variables that come to mind. According to Hine:[13] Efficiency = $\frac{\text{achievement}}{\text{expectation}}$. Hine continues by saying that expectation is "the best estimate of what you anticipate producing based on calculation or accumulated experience....Achievement is an evaluation of actual production performance." Kealey[17] describes productivity as the ability to produce on time, within the lowest cost, and at the required capacity. Other definitions of productivity and efficiency are similar to these general descriptions.

Productivity has gained and continues to gain importance in the packaging industry for one primary reason. Economically, increasing productivity increases a firm's operational capacity and reduces its per unit operating costs. With the high cost of money (seventeen to twenty percent interest) and the high cost of building a new plant (increasing at the rate of ten percent per year) these factors become increasingly more important.

One economic benefit of increasing productivity is that it allows for an increase in output or capacity with minimal increases in input. Increasing capacity can imply a corresponding increase in input. However, through increased efficiency or greater productivity, increased outputs can be achieved which may in turn satisfy capacity requirements. This idea is clearly illustrated by Kealey[17] who considers a capacity problem an opportunity to improve efficiency. Another benefit of increasing capacity with minimal increases in inputs is the chance to avoid the expenditures of expansion. This is a key advantage in today's economic environment. A recent article in Package Engineering[27] supports this by stating, "Along with the vestigial remains of prior affluent years, industrial floor space has become a precious commodity." Another economic benefit of increased productivity is the chance to reduce operating costs. These savings are direct benefits to the firm that involve no risk. According to Frank Paine,[26] "any work which is able to improve the efficiency of the process, its productivity...is potentially capable of massive savings to the manufacturer (and) lower costs to the user..." Gillete, a major American firm, aims to "improve productivity because it lowers costs and improves the profitability of (their) organization."[17] For the past few years Gillette has been able to offset 25 percent of its yearly costs by increasing productivity.

There are innumerable factors which are directly related to productivity. It is not the intention of this paper to attempt to discuss all of them, but rather to mention the major components that have definite quantitative bearing on packaging line productivity and its measurement. Briefly, these include the quality of the output, the packaging material, the product, the human element, and the mechanical element.[14] These factors are affected by countless other inputs as well as by each other. This situation makes it difficult to determine one singular and effective method to measure productivity. One way to measure productivity is to monitor per worker output as suggested by Kealey. Gorton and Smith[11] propose mechanical output or the number of units a machine will produce per hour as a viable measurement. One can derive several other types of productivity measurements from this method by incorporating allowances for material tolerances, operating conditions and quality. The productivity of an entire line can be determined by its final output which considers each individual machine and the effects they have on each other. Another method used to quantify productivity is simply: Productivity = $\frac{\text{Output}}{\text{Input}}$. The output can be defined as the final product and the inputs can vary. Typical inputs include material, energy, and labor. According to Hine[13] packaging line efficiency can be defined in four ways: the use of machine time, the use of packaging materials, the production of an efficient pack, and the use of labor in the operation. Hine suggests that line personnel, their training, their positions on the line, and the number of operators employed, all influence the efficiency of the line. If it is possible to decrease the number of operators on a line and maintain the same operational capacity, a higher productivity can be achieved. Inputs have been reduced while the output has remained at the same level. To serve the purpose of this paper, productivity will be considered as line efficiency and line efficiency will be measured as the use of labor in a packaging line. Expressed another way: $\text{productivity} = \frac{\text{final output}}{\text{labor input}}$. This is the relationship that will be considered for evaluation of productivity later on in the paper.

The Effect of Machine Interaction on Productivity

According to Dennis Hine[13] "most of the literature on machine efficiency concentrates on the measurement of machine running time, that is achievement, and the analysis of the duration and causes of lost production time." The running time of a packaging machine can be measured as reliability or the probability that a machine will be operating. A machine with a 90 percent reliability rating indicates the machine will operate 90 percent of the time it is supposed to operate. Hine says reliability is determined by taking into account the duration and frequency of downtime. Downtime is the actual time a machine is not functioning during operating time. As downtime increases for an individual machine or entire line, the reliability of that machine or line decreases. Since a packaging line is a linkage of machines, the overall line reliability is determined in part by each individual machine's reliability. According to Muramatsu,[23] a machine in a line cannot yield its individual reliability because it is dependent on the preceding machine(s) to operate. This non-productive time is defined as idle time, the time a machine has to wait for input to operate. Therefore one machine's downtime will result in idle time in the succeeding machines. Muramatsu continues with the suggestion that "because of this idling time the operational efficiency (reliability) of the entire line has to decrease." This phenomenon is referred to as machine interaction. To serve the purpose of this investigation, machine interaction will be considered as a negative condition because it reduces the overall line reliability and therefore reduces the total line efficiency. This is evidenced by Domke's[9] statement that the efficiency of a packaging line is impaired by the number of linkages in the line. Machine interaction increases with the number of machines in the line and overall line efficiency decreases. Metamatic,[15] the container handling division of Metal Box, Ltd. has demonstrated through analyses that low efficiencies are often caused by the inability of the line to compensate for the inevitable short stoppages of one component. Each machine is dependent on the preceding machine for its own input, which in turn determines its own output. If the first machine is down, the second machine will not reach its own rate of output or reliability simply because there is no input.

According to a Pira study[13] output is affected in six ways. These are: machine inefficiency, machine-material interaction, faulty packaging materials, inadequate maintenance, poor operation of the line and machine mismatching. As problems arise in all of these areas the machine interaction increases, leading to lower line efficiencies.

Machine mismatching is an imbalance in the line due to machine speeds. Each machine has an individual speed and if these speeds are not closely matched in the line the faster machine may experience more downtime. It may have to wait for input from a slower operating machine. Closely matched speed indicates the same speed throughout the line or a progressively higher speed at each succeeding work station in the line. This increase is not large enough to create an imbalance in the line. Its purpose is to avoid the building up of units between machines. One American brewery progressively increases the machine speeds by 10 percent.[12]

As mentioned previously low reliabilities of machines and correspondingly lower line reliabilities increase downtime. This results in losses of production and increased operating costs per unit. These costs are attributed to idle labor and machine time. Briston[3] emphasizes this point by suggesting that small periods of downtime may result in the loss of hundreds of units. An article in a recent issue of Package Engineering[27] stated that, "the costs of downtime will leapfrog as packaged products increase in dollar value and machinery runs faster." An example of this is a candy bar packaging operation in which line speeds can be 1000 packages per minute. If the line is down for three minutes, a loss of 3000 units is the result.

Another negative consequence of downtime is the problem of restart. Certain products require constant product flow. Kidd and Company[31] experiences this problem with their Marshmallow Creme.

> Continuous uninterrupted production might seem no great feat except for what happens to product consistency if the manufacturing and flow in the production and flow of Marshmallow Creme may trigger a weight variation among jars - as a result of the interruption causing a variation in the air content of the Creme.[31]

The presence of a gluing operation in an operation can result in another problem of restart. Once a line stops, the gluing process is interrupted and the consistency of the glue changes. This sometimes leads to insufficient tack and unacceptable results. Labels may not adhere properly to a bottle or cartons may not remain closed. Machine warm-up time is another negative effect of restart. This is the time required to start up a machine and allow it to reach operational capacity. This time is costly in terms of lost production time and idle labor.

Downtime is an inevitable occurence in any manufacturing and packaging operation. However, its duration and frequency can be monitored and steps taken to reduce downtime. One American brewery attributed 70 percent of its production loss to high frequency, short duration machine failures.[24] This loss can be alleviated with proper line design to decrease machine interaction. Gorton and Smith[11] mention the fact that design factors can ensure efficiency by increasing overall line reliability. These include line layout considerations and the use of conveyor and accumulator units.

STATE OF THE ART:
ACCUMULATORS IN THE PACKAGING INDUSTRY

Definition and Purpose

An accumulator is a device designed to permit the gathering of objects. According to Buckminster[5] it is a device installed in a packaging line to fulfill one of three functions. First, an accumulator retains items in a specific area for a specific purpose. Second, an accumulator may collate items for a specific purpose such as casepacking. The third function of accumulation and the subject of this paper is to provide a time cushion in the packaging line. Gorton and Smith[11] define an accumulator as a sponge or buffer in the line to cover inevitable stoppages in the production process. This time cushion increases the opportunity for a machine to operate by minimizing machine interaction. The accumulation unit alleviates the repercussions of downtime by limiting the negative effects of downtime to the machine that is actually down. This increases overall line efficiency. This point is supported by Gorton and Smith's statement that, "the selection of machinery...is only of value if reservoirs and accumulators are correctly designed between the machines."

Computer simulation of packaging lines has suggested that a line without any reservoirs between machines can have a machine interaction rate of 100 percent.[30] This means that during every stoppage the entire production process stops, increasing costly downtime and decreasing overall line efficiency. Similar simulation has also demonstrated that accumulation is necessary for improved line efficiency.[19] Buckminster proposes that accumulators link the line together in such a way as to insure high efficiency and he substantiates this with an example of a pharmaceutical company that increased line productivity by 25 percent through the use of accumulators. Buckminster continues with the suggestion that "accumulators give the user the ability to produce more units in a given time period in the most efficient way so that benefits are directly related to dollars and cents savings."

Types of Accumulators

There are two major types of accumulators. These are in-line and off-line. Each functions in a different way and each has specific types.

In-line

In-line accumulators are part of the line and items must travel through the entire accumulator to reach the next station in the line. An example of this type of accumulator is a serpentine conveyor. The stacked serpentine (Figure 1) moves units vertically and horizontally. By elevating and lowering the product, this type of accumulator allows the user to achieve greater capacity through maximum use of surface area and ceiling height. The other type of serpentine accumulator moves the product horizontally only. An example of this type of in-line accumulator is a long conveyor that winds back and forth hence the name "serpentine". The capacity of such an accumulator is partially determined by the size of the package as this size dictates the radius of the turns in the conveyor. Larger containers will jam in tight corners.

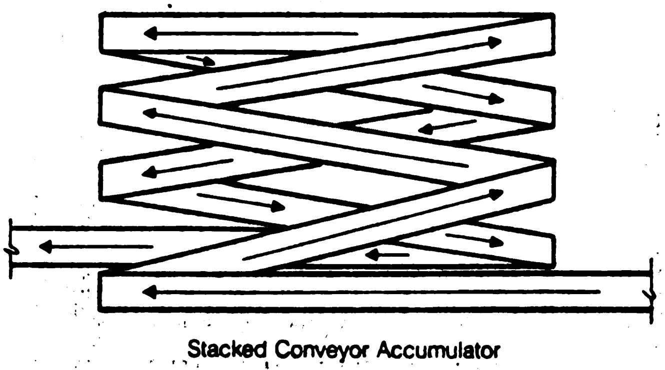

Figure 1. Stacked Conveyor Accumulator

SOURCE: William Buckminster, "Accumulating," The Packaging Encyclopedia (Chicago: Cahners Publishing, 1981), p. 240.

Therefore they require larger corner radii than packages of smaller dimensions. In-line accumulators are best suited for unstable packages and where package orientation is important. This system provides for first-in, first-out dispensing. The density of containers in the accumulator is dependent on the conveyor speed, conveyor width, and package size. Density is defined as the number of units that can be in the accumulator at any given time. This definition differs from the conventional definition of density as mass per unit volume as it considers mass (number of units) per unit surface area. Density increases with slower conveyor speed, greater conveyor widths and smaller packages.

Off-line

Off-line accumulators are not part of the actual packaging line. They are an addition to the line that is used only when the line is full. An accumulation table is a prime example of an off-line accumulator (Figure 2). The table is attached to the line but items are not required to travel through the accumulator to reach the next station in the line. The items

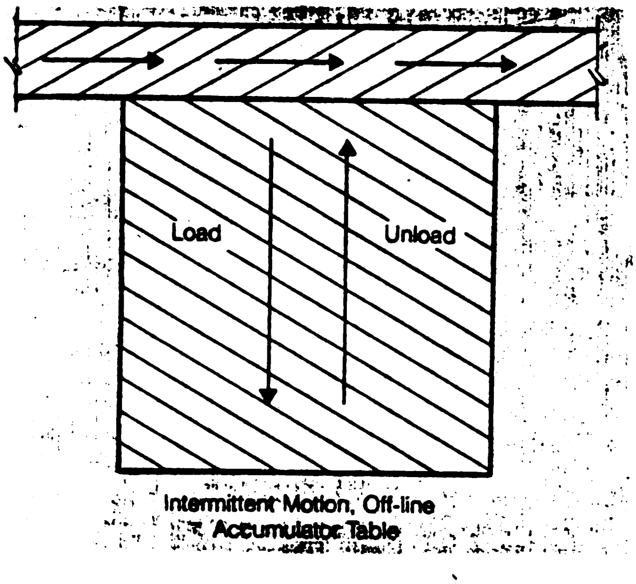

Figure 2. Intermittent Motion, Off-line Accumulation Table

SOURCE: William Buckminster, "Accumulating," The Packaging Enclycopedia (Chicago: Cahners Publishing, 1981), p. 240.

will enter the table only when the upstream machines are operating and the downstream machines are not operating. In this situation the items will back up on the line and enter the accumulation table until the downstream machines are running again.

Other examples of off-line accumulators include rotary and multi-lane. A rotary accumulator collects items on a rotating disc. Products enter the accumulator in one direction and continue in that direction until they enter the line again (Figure 3).

Multi-lane accumulators consist of additional conveyors on each side of the main line conveyor. One runs in the direction of the line while the other runs in the opposite direction (Figure 4).

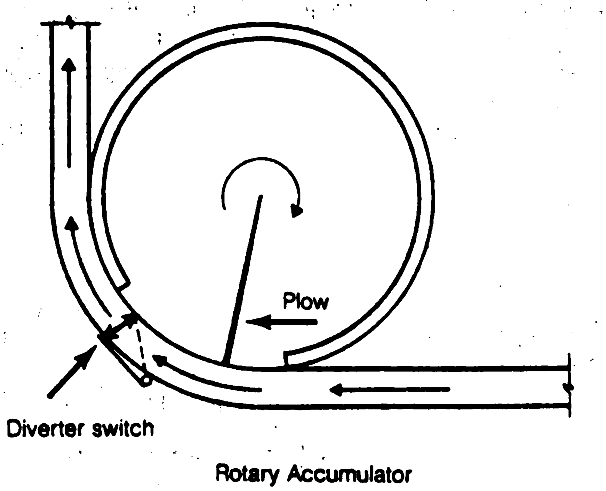

Figure 3. Rotary Accumulator

<u>SOURCE</u>: William Buckminster, "Accumulating," <u>The Packaging Encyclopedia</u> (Chicago: Cahners Publishing, 1981) p. 240.

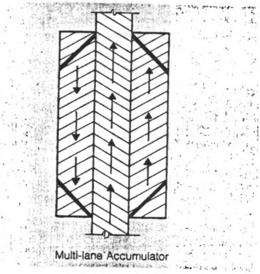

Figure 4. Multi-lane Accumulator

SOURCE: William Buckminster, "Accumulating," The Packaging Encyclopedia (Chicago: Cahners Publishing, 1981) p. 240

These accumulators allow the product to travel back up the line (similar to a counterclockwise holding pattern) on the one conveyor and enter the line again when it is sufficiently empty to do so. This results in minimal scratching of the package by reducing the pressure on the products. This pressure reduction is the result of the counterclockwise pattern flow of the packages.

The Factors Involved in Determining Accumulation Needs

The capacity, line position, and type of accumulator are determined by several product and line factors. The first and foremost factor is the space available in the plant. This factor frequently prevents the accumulator from being its optimum size, in the optimum location or of the optimum type. According to one supplier of accumulators, this situation occurs because accumulation is rarely given consideration at the design level.[6] The needs is usually realized after the line has been designed, installed and is currently running. This opinion was supported by conversations with four major users in the food, pharmaceutical, and beverage industries.[1, 12, 21, 28] Until very recently the majority of users in the packaging industry had considered accumulators a "necessary evil." They did not want to install an accumulator unless they saw a definite need for one. In other words, an accumulator was usually installed only after there was a proven line deficiency without accumulation. This need usually has been realized only during production. At this point in time the problem of space becomes critical and it appears to be the primary limiting factor in the determination of accumulation needs in the packaging industry today.

Capacity

Accumulation "speeds and capacities are tailored for individual products."[4] Capacity is primarily determined by space available, frequency and duration of downtime, product size, and the speeds of the line.

Since accumulation is incorporated in a line to reduce machine interaction, the frequency and duration of downtime can be analyzed and the most frequent duration will determine the required capacity of the accumulator. Capacity is measured in time. A line with a machine experiencing frequent downtime periods of 5 minutes would require an accumulator with a capacity of 5 minutes. The accumulator can be placed before and/or after the machine to isolate it and its effects from the line. This would allow the line to run while the machine is attended to. The 5 minutes of accumulation together with the differences between the ingoing and outgoing conveyor speeds will determine the number of items that will accumulate in 5 minutes. This amount and the product size will determine the optimum dimensions of the accumulator.

A similar method can be used that considers the average number of units that will be in the accumulator. The number is determined along with the standard deviation. An accumulator can be designed with a capacity of the average plus 3 standard deviations. This capacity will insure that the accumulator will prevent machine interaction 99.73 percent of the time by providing sufficient accumulation 99.73 percent of the time.[23] However, according to Gill[10] 3 standard deviations may not be adequate. This point will be discussed more specifically later in the paper.

[According to one supplier of accumulators[6] a packaging line with a speed of 400 packages per minute typically has accumulation capacities of one to two minutes. A line speed of 75 packages per minute frequently has an accumulation capacity of three to five minutes. The faster line has a lower capacity due to spatial limitations. Cosmair, Incorporated uses five minute accumulation units at critical points in a line that runs 230 cartons per minute and this has increased productivity by creating a non-stop operation.[16] These accumulation units were considered at the design level and thus are more effective than units of lesser capacities that may have been the result of not considering accumulation until the line has been installed and running.

Even optimal capacities have limits. This is verified by Buckminster,[4] "anything more than the designed time interval will usually require shutting down the line for repairs and is considered to be outside the normal capabilities of a properly designed accumulator." The designed time interval is the length of the most frequent downtime of the machine before or after the accumulator. Accumulation is not designed to "compensate for a poorly designed line but it will help bridge the short machine stoppages that inevitably occur."[33]

Position

An accumulator is usually placed before and/or after a sensitive machine to isolate it from the line. A sensitive machine is defined as the machine in the line that experiences the most downtime in terms of frequency and duration. According to Van Rootselaar[33] the ideal locations for accumulation are before the filler, between the filler and labeller, and between the labeller and packer. In effect, this segments the line into several independent portions. This drastically reduces machine interaction. It is common to place an accumulator after the filling machine to keep it running if the line stops downstream.[4] In bottling operations the filler is the center of the operation and often the most costly piece of equipment on the line. Therefore it appears to be beneficial to keep it running at all costs. This is achieved by placing an accumulator before the most sensitive machine toward the end of the line. Since the machines in a line usually run progressively faster, this allows for the machines downstream of the accumulator to catch up by virtue of their higher speed, when they are operating.

Type

The type of accumulator is determined primarily by the product. Its weight, size, shape, and orientation requirements determine the optimal accumulator. Round objects work well with multi-lane or rotary accumulators, while rectangular objects work best with a serpentine conveyor.[5]

Current Methods Used in Determining Accumulation Needs

According to Buckminster, "packagers are just beginning to understand accumulators, how they work, where they work best, and how to best apply them...(and it)...is extremely difficult and costly to predetermine the size of accumulation in assessing its greatest impact on productivity." To select the best accumulator for a packaging line Buckminster says the entire line must be understood and it must be accepted that the machines will all stop at one time or another. Serchuk[29] suggests that the questions that should be considered include: how long and how often the downtimes are, how much accumulation will be needed to accomodate those stoppages and how the accumulated amount will be emptied. This amount must be disposed of quickly enough so that the accumulator will be ready for the next stoppage.

The current methods used to determine accumulation needs range from natural insight and previous line experience to computer simulation. Some units are installed without any prior planning or consideration as to the optimum option. Other units are installed only after extensive use of formulas or computer decision models.

One supplier uses an efficiency calculation to determine the best location in the line to place an accumulator.[5] They use a mathematical progression to calculate line efficiency. (For a complete discussion of this calculation refer to Appendix A.) By placing an accumulator in the line, the line is divided into independent segments with independent reliabilities. A line with four machines with reliabilities of 70, 80, 60, and 90 percent would have an overall line reliability of 30.24 percent (.70 x .80 x .60 x .90.) However, by placing an accumulator in the middle of the line, the line becomes two separate lines with two separate reliabilities. These are 56 percent (.70 x .80) and 54 percent (.60 x .90). If the accumulator is of the proper capacity it will prevent any machine interaction between the second and third machines. The overall line reliability is the lower of the two rates or 54 percent. This method considers the section of the line with the lowest reliability as the highest possible reliability of the line. The optimal locations for an accumulator can be determined by locating it in every possible position mathematically to find out all the possible effects of accumulation. The location or locations with the highest reliability are considered to be the optimum choice. *This method does not take into account the variability of machine speeds.

Computer models can be used to simulate the packaging line and its activities. Such models can be used to determine optimal locations and capacities. The current cost of one computer simulation program ranges from seventy-five to one hundred and fifty dollars. Currently these programs have restricted use because of the cost of collecting the required data and the limited ability of users to supply the computer with this required data. Some of the data that is required includes work station cycle times, line speeds, capacities of accumulators, frequency of downtime, duration of downtime due to failure, machine warm-up time, length of a typical production period, and the number of production periods.[16] The GALS program or Generalized Assembly Line Simulator has been used in the packaging field to determine accumulation needs. According to Buckminster this program also determines when extra work stations are necessary and where excess capacity exists. Another computer program, P.L.U.M. or Production Line Uprating Methods has been used by Pabst Brewery to evaluate line performance.[24] This particular program has saved Pabst over one million dollars. These programs not only allow the packaging engineer to evaluate current performance, they also are capable of changing the inputs to investigate other possible options.

Another factor considered when designing accumulation units is an equation that determines the best conveyor width for round objects (Appendix C). The optimal width allows the bottles to accumulate in a pattern that avoids jamming and package damage.[8] Many suppliers of accumulation units have developed their own in-house formulas to aid in the quantification of accumulation requirements. These formulas take into account product size, incoming and outgoing conveyor speeds, and accumulation area. (Appendix C).

The literature available and conversations with users and suppliers indicate that the most common and valued method to determine accumulation requirements are the thoughts and ideas of the people who actually need the accumulator. The user knows the line and why accumulation is required. When this knowledge is combined with the spatial limitations of the line and the product characteristics, the accumulations unit is already delineated. According to one supplier, the customer's experience and insight are more valuable than any equations they currently use. One major American food company determined their own requirements and designed and installed an accumulation unit based on their knowledge of the line and the spatial limitations. They have reduced the effect of downtime in this particular line by 37.5 percent.[2] This reduction could have been even higher but the firm was critically restricted by space. The installed accumulator alleviates the negative effects of downtimes up to ten minutes. Anything longer than this stops the line.

In conclusion, the current state of the art is diverse and discrepencies exist. Exact methods are available to determine accumulation needs. However, these methods require precise data and are limited to specific applications to function successfully. The technology of the user in the packaging industry is not as advanced as the technology of the supplier who attempts to use the computer decision models. According to Gene Harris,[12] a packaging engineer at Carling Brewery, computer programs are only "after the fact." He explains this by saying that the results of the program only verify what is already accepted. Another problem with the simulation is that it does not consider all the inputs that affect the line and therefore cannot give the user an accurate prediction of what to expect. The P.L.U.M. system is too specific at this point in time to be successfully applied to industries other than the beverage industry. Hence the technology is available but is not widely used. The industry as a whole still seems to rely on intuition and the actual space available to determine accumulation needs, capacities, line positions and types. An example to demonstrate that the use of accumulators is still in the art stage and has not reached the science stage is a comment by a pharmaceutical packaging engineer, who says that he will put an accumulator wherever he can and continually used one half hour as the capacity of the unit.[21]

Up until this point in time accumulation units have been installed primarily to increase productivity by decreasing the negative effects of downtime. One major supplier of accumulators claims that 80 to 90 percent of accumulators are bought for this reason, i.e. to avoid the situation where one machine's downtime stops the entire line or a major portion of the line. Another application of accumulation to increase productivity is to use accumulators to balance a line. In this application the line may be running smoothly but opportunities still exist to increase its productivity. In this specific investigation it is proposed that balancing the speeds of machines in this line will increase productivity by reducing the total labor requirement of the packaging line.

STATEMENT OF THE PROBLEM

The object of this study is to determine how accumulation can increase the productivity of a packaging line. For the purpose of this investigation, productivity will be measured as the number of workers on a packaging line. It is proposed that through the use of accumulation the number of operators on a packaging line can be reduced, thus increasing productivity. A specific investigation will be used to exemplify this procedure. We will see that in the relationship productivity = $\frac{\text{final output}}{\text{labor input}}$ the labor input can be reduced by use of accumulation while maintaining the same final output, thus increasing productivity.

The firm involved in this investigation is a bottling plant which bottles carbonated beverages. The firm employs twenty-five people of which eight are line operators. The annual output of this company is approximately 500,000 twenty-four bottle cases. The line handles ten and sixteen ounce returnable glass bottles with a size changeover time of thirty minutes. Bottles are stored in wooden cases in a warehouse which is in the same building as the bottling line. They are transported to the line by forklift truck. The bottles are washed, filled, capped, casepacked, and then returned to the warehouse for storage until delivery to local outlets. The bottles are uncased prior to washing and the wooden cases are repaired and placed onto a conveyor which runs under the line to the casepacker (Figure 5). The washer is capable of handling 144 bottles per minute (twelve cycles of twelve bottles per cycle). The bottles are washed in a caustic solution at 150°F. They then travel single file down a flat chain conveyor to a starwheel. Once properly positioned by the starwheel, these bottles travel through a light beam which detects foreign objects in the bottles. The device automatically rejects bottles that obstruct the beam of light. The bottles then travel to a rotary filler that also has a starwheel to position the bottles prior to filling. The filler has thirty-four heads and fills to level by pressure-gravity. The bottles move on to a fifteen head rotary capper where crown caps are applied. The filler and capper are synchronized to operate at 142 bottles per minute. Therefore, the overall speed of the line is 142 bottles per minute.

After being capped the bottles travel to the casepacker on a 31 foot long flat chain conveyor. They are mechanically counted and dated on this conveyor. The conveyor widens ahead of the casepacker to collate the bottles in four rows for casepacking. The bottles are channeled through guide rails and are properly aligned for casepacking. The casepacker fills one case at a time by

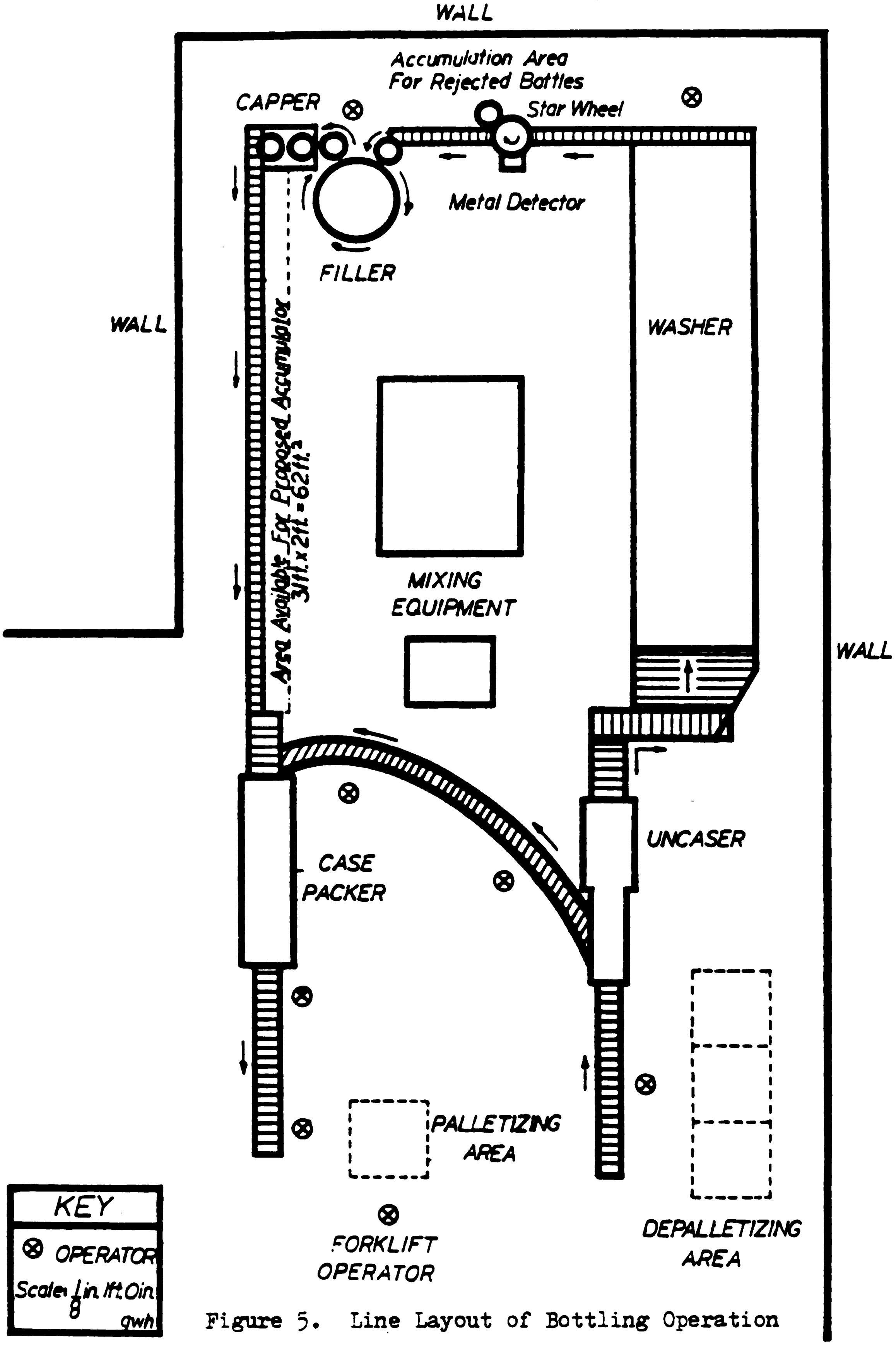

Figure 5. Line Layout of Bottling Operation

dropping the bottles through a grid of thin metal fingers into a case that has been elevated to receive the bottles. This casepacker has a "no case-no packing" feature. The machine is capable of handling 24 bottle cases. According to the supplier, Lodge and Shiply, the rated speed of the casepacker is 20 cases per minute, this translates to 480 bottles per minute. This is much faster than the overall line speed of 142 bottles per minute.

The cases are stacked on conventional wooden pallets and taken to the warehouse by forklift truck. A pallet holds 720 sixteen ounce bottles (30 cases) or 864 ten ounce bottles (36 cases). Operators are located at the case unloader, washer, filler-capper, and at the casepacker. (Figure 5).

Through extensive analysis and machine timings it was determined that a wide range of machine speed was present in this particular packaging line. The widest range exists between the filler, at a speed of 142 bottles per minute and the casepacker at 480 bottles per minute. This creates an imbalance in the line which results in the fastest machine running well below capacity. This discrepancy in machine speeds prevents the faster machine from operating automatically. Thus an operator is required to run this machine at a semi-automatic speed of six to nine cases per minute.

Presently three men are required to operate this machine, load the pallet, and transport the pallet to the warehouse by forklift truck. One operator runs the casepacker and pushes the full cases to the end of the conveyor. The second operator takes the cases from the conveyor and stacks them on the pallet. The third drives the forklift truck and participates in various activities between runs to the warehouse. These activities include helping repair cases, loading the pallets, unloading the cases, and monitoring the washer. However, this operator is idle a significant amount of the time and there seems to be no specific job for him to do between his trips to the warehouse.

Through the use of an accumulator, located ahead of the casepacker, the labor requirement at this work station may be reduced to two operators. The accumulator will accumulate bottles while one operator is away from the line on the forklift truck. During this time the casepacker will not operate. The operator will start the casepacker when he returns from the warehouse. At this time the casepacker will run automatically and the forklift driver along with another operator will load the pallet. The accumulator will allow the casepacker to run at its automatic speed by providing enough bottles and sufficient pressure to activate the automatic device.

Limits of the Investigation

The purpose in this investigation is to increase the productivity of a bottling line by the use of accumulation and to determine the optimal capacity of such an accumulator. In conducting the investigation, it is assumed that the determined line speed will be maintained at about 142 bottles per minute, and that the casepacker is capable of operating at its automatic speed. It is also assumed that the forklift truck is capable of transporting two pallets at once to and from the line. Factors that will not be considered include the net output of the line based upon bottle breakage and rejection, variances in the timings of the forklift operation due to additional transportation of pallets within the warehouse or to delivery trucks.

The factors that are considered are factors that were determined to have direct bearing on the forklift operation. Any factors which are not a part of the regular production process are considered outside the scope of the investigation.

METHODOLOGY

The purpose of the accumulator is to reduce the labor requirement of a packaging line, thus increasing its productivity. To accomplish this, the accumulator will be placed immediately before the casepacker because its purpose is to reduce the labor requirement at the casepacker. To function successfully, its capacity must be defined as accurately as possible.

The required capacity of the unit was statistically determined through stopwatch time study. The subject of these timings was the forklift operation, in order to determine how long the operator was away from the line. It was deemed necessary to the analysis to define each element of operation of this line and of the forklift transport to the warehouse and return. This was done using the Process Flow Charts displayed in Appendices E and F. Charting for the packaging line was not particularly useful, but the charting of the forklift operation was. The forklift operation consists of the operator walking from the casepacker to the forklift truck, getting on the truck, starting it, picking up a loaded pallet, driving to the warehouse, depositing the load, picking up a loaded pallet of empty bottles, returning to the line, depositing the new load of empty bottles near the uncaser, returning to the casepacker, parking the truck, and walking back to the casepacker. After charting the forklift operation, it was decided that it would not be necessary to time the elements of this operation because doing so would not add any valuable information for the purposes of the study. The purpose of collecting the timings was to determine how long the casepacker would be unattended. It was not the purpose of the timings to evaluate the forklift operation in itself.

Determination of Sample Size

In this study the critical factor is not the average number of bottles in the accumulator at any one time, but rather an accurate determination of the standard deviation to be added to the average in order to achieve suitable capacity. The standard deviation is important because the accumulator must be able to accomodate the varying numbers of containers that are the result of longer trips to and from the warehouse. An accurate standard deviation will allow for adequate capacity for the longer trips.

Based upon a pilot study sample size of nine timings and an eighty percent level of confidence, the sample size for the full study was determined to be 200 timings.[10] The statistical power of this test is determined by the accuracy of the standard deviation of the sample. With a sample of 200 this test has an approximate 80 percent confidence level of finding the true population standard deviation within 5 percent.[10] This means the standard deviation of the sample will be less than or equal to 1.05 times the standard deviation of the population (see equation 1).

$$S_{\text{sample}} \leq (1.05)\,\sigma_{\text{population}} \qquad (1)$$

The power of the test increases to 90 percent when the standard deviation of the sample is less than or equal to 1.10 times the standard deviation of the population.[10] (See equation 2).

$$S_{\text{sample}} \leq (1.10)\,\sigma_{\text{population}} \qquad (2)$$

Samples were collected on different days, at all times of the day, and with different products and bottles sizes. A conventional stopwatch was used in this study and time was computed in minutes. If an apparent reason could be determined for an uncharacteristically long timing it was not included in the sample. These reasons included: the forklift operator having to wait to drive through a passageway because of repair work being done, changing of drivers in the warehouse, stopping on the way to or from the warehouse or when the operator returned on a different forklift. All of these situations were determined not to be part of the regular production operation or not a specific work element of the forklift operation. Therefore, they do not represent a typical timing. Atypically short runs were not included in the sample either. These timings were primarily due to the operator taking a load to the warehouse or bringing one back to the line but not both in the same run. This occurred during start up when the first bottles were being brought to the line and during shutdown when the last bottles were taken back to the warehouse.

Determination of Capacity

After collecting the data, the mean and standard deviation of the sample were calculated. The maximum expected range of expected results (trip time) is approximately 6.5 standard deviations. According to Gill,[10] the expected range of timings for a sample of 500 would be about six times the standard deviation (6 x s). To compensate for the fact that the number of trips over a period of one year is much greater than 500 the maximum expected range has been increased to 6.5 times the standard deviation (6.5 x s). This is close to the value given by Gill for 1000 observations (6.477 x s). The value of the ratio of range to standard deviation increases very slowly with larger sample sizes. This expected range of times was centered on the average timing of the operation to determine the minimum and maximum accumulation levels necessary to provide uninterrupted production. The maximum level is the most critical factor in determining the capacity of the accumulator. By adding one half of the range to the average time, the maximum capacity of the accumulator can be defined (see equation 3).

$$T = t + 3.25s_t \qquad (3)$$

Where: T = design time for accumulation

t = average trip time

s_t = standard deviation of the trip time

This time value was then multiplied by the line speed to determine the maximum number of bottles that are expected to accumulate over long term production periods. This number of bottles was then multiplied by the conveyor surface area occupied by one bottle to determine the size of the accumulator. The conveyor surface area occupied by one bottle was determined by calculating the surface area occupied by twelve nested bottles. The twelve nested bottles formed a parallelogram (see Figure 6 Appendix C for an illustration of the nested bottle pattern). Therefore the total conveyor surface area occupied by twelve bottles equals the base times the height of the quadrilateral ($A = bh$). Once this figure was calculated, it was divided by twelve to determine the surface area per bottle. This resulted in 4.75 square inches for the ten ounce bottle and 6.10 square inches for the sixteen ounce bottle. Once the capacity of the accumulator was determined, the optimal type was investigated based upon the required capacity, package shape, and the space available in the plant. The method of emptying the unit was also considered to assure that it would be emptied quickly enough not to interfere with the next accumulated amount of bottles.

RESULTS/DISCUSSION/CONCLUSION

The average time of the forklift operation was determined to be 3.92 minutes. The standard deviation of the sample was .568 minutes. To determine the maximum value of the range 3.25 standard deviations were added to the average. This increased the value to 5.77 minutes or 3.92 minutes + 3.25 (.568 minutes). At a line speed of 142 bottles per minute this time results in the accumulation of 820 bottles (5.77 minutes x 142 bottles/minute). This would be the maximum number of bottles that would accumulate at the casepacker while the operator is away from the line.

Determination of Capacity

To determine the size of the accumulator, the time required to empty the accumulator must be considered. At a rated speed of 20 cases per minute, the time required to casepack the accumulated amount would be 1.7 minutes (see equation 4).

$$\frac{\text{820 bottles}}{\text{20 cases/minute x 24 bottles/case}} = \text{1.7 minutes} \qquad (4)$$

This assumes that the operator will maintain this speed in loading the cases onto the pallet. However, to be more realistic 80 percent of the rated speed will be used in this investigation. This results in a time of 2.13 minutes to empty the accumulator (see equation 5).

$$\frac{820 \text{ bottles}}{20 \text{ cases/minute} \times 24 \text{ bottles/case} \times .80} = 2.13 \text{ minutes} \tag{5}$$

This increases the required capacity of the accumulator to 7.9 minutes (5.77 minutes + 2.13 minutes). This results in an accumulation of 1,122 bottles (see equation 6).

$$(7.9 \text{ minutes of accumulation}) \times (142 \text{ bottles/minute}) = 1{,}122 \text{ bottles} \tag{6}$$

The 1,122 bottles result in a total surface area of 37 square feet for the 10 ounce bottle and 47.5 square feet for the 16 ounce bottle (see equations 7 and 8).

$$1{,}122 \text{ bottles} \times 4.75 \text{ square inches/ten ounce bottles} = 5{,}330 \text{ square inches} = 37 \text{ square feet} \tag{7}$$

$$1{,}122 \text{ bottles} \times 6.10 \text{ square inches /sixteen ounce bottle} = 6{,}844 \text{ square inches} = 47.5 \text{ square feet} \tag{8}$$

To accomodate both bottle sizes, the accumulator must have a spatial capacity of 47.5 square feet.

The capacity of the forklift operation must also be considered. One pallet is capable of holding 30 cases or 720 sixteen ounce bottles (24 bottles/case x 30 cases/pallet). To maintain an efficient operation, only full pallets will be taken to the warehouse. The accumulated amount of 1,122 bottles will require one loaded pallet and one partially loaded pallet. Therefore the operator will take two loaded pallets to the warehouse every other time. This arrangement will avoid a long term build up of bottles but simultaneously allow for the transport of full pallet loads to the warehouse. The 1,122 bottles converts to one full pallet of 720 bottles and one partially full pallet of 402 bottles (see equation 9).

1,122 accumulated bottles (9)
- 720 capacity of one pallet (16 ounce bottles)
402 remaining bottles (partially full pallet)

The operator would take the full pallet to the warehouse. Upon returning to the line, he would fill the partially full pallet and entirely fill another pallet and transport both to the warehouse at one time. The partially full pallet would have the capacity of 318 bottles (see equation 10).

720 capacity of one pallet (16 ounce bottles)
-402 partial load from previous operation (10)
318 capacity of partially full pallet

This capacity is not enough to accomodate the predicted accumulation of 1,122 bottles (see equation 11).

1,122 predicted amount of accumulated bottles
- 720 capacity of one pallet (11)
- 318 capacity of partially full pallet
84 bottles (overflow)

However, while collecting the data for this project, it was noted that the filler stopped frequently during a typical production period. These stops were recorded (Appendix H) and the average frequency and its duration were calculated. This value is approximately 5.2 minutes of downtime per hour (see equation 12).

29.7 seconds average downtime x 10.8 downtimes/hour =

321 seconds of downtime/hour or 5.3 minutes of downtime/hour (12)

When the filler is down the entire line stops running and no bottles will accumulate in the proposed accumulator. These occurrences of downtime reduce total production and therefore the required capacity of the pallets to empty the accumulator is also reduced.

In one hour 8,520 bottles travel through the line, (142 bottles/minute x 60 minutes/hour). However with 5.3 minutes of total line downtime (from the filler downtime) the total production in one hour is predicted to be 7,767 bottles (142 bottles/minute x 54.7 minutes of running time/hour). In one hour approximately eight trips are made to the warehouse. If the operator takes two pallets every other time he will take twelve pallets to the warehouse per hour.

Twelve pallet loads result in 8,640 bottles (720 bottles/pallet x 12 pallets). This capacity exceeds the expected number of bottles produced per hour (7,767). Therefore the expected downtime of the filler will allow the accumulation system to handle the capacity of the line while simultaneously maintaining the practice of transporting full pallets to the warehouse.

When the line is running ten ounce bottles, the operator will take two pallets to the warehouse approximately every third trip. This is determined again by the capacity of the pallet and the practice of only transporting full pallets to the warehouse. One pallet holds 864 ten ounce bottles (24 bottles/case x 36 cases/pallet). It will take approximately 1.3 pallets to empty the predicted amount of 1,122 accumulated bottles (see equation 13).

$$\begin{array}{rl} 1{,}122 & \text{accumulated bottles} \\ \underline{-\ 864} & \text{capacity of one pallet (ten ounce bottles)} \\ 258 & \text{remaining bottles (partially full pallet)} \end{array} \qquad (13)$$

This pallet with 258 bottles is approximately one third full (see equation 14).

$$\frac{258 \quad \text{partial load of pallet}}{864 \quad \text{capacity of pallet}} = .30 \qquad (14)$$

Therefore the volume created by three accumulations would require approximately four full pallets (see equation 15).

$$\begin{array}{l} 3 \times 1{,}122 = 3{,}366 \text{ bottles (volume created by three accumulations)} \\ 4 \times 864 = 3{,}456 \text{ bottles (capacity of four pallets)} \\ 3{,}456 \text{ bottles} - 3{,}366 \text{ bottles} = 90 \text{ bottles (excess pallet capacity)} \end{array} \qquad (15)$$

With an expected hourly production of 7,767 bottles (142 bottles/minute x 54.7 minutes of running time per hour) the forklift operator will take approximately nine full pallets to the warehouse per hour. This translates into seven trips to the warehouse with the operator transporting two pallets in two of the seven trips. The pallets with an excess capacity of 90 bottles will remain at the casepacker until they are completely full before transport to the warehouse.

These predictions of pallet transportation are only generalizations. Various factors will change the daily pattern. The one thing that will remain constant is that only fully loaded pallets will be taken to the warehouse. Any partially full pallets will be left at the line until they are filled to capacity. Therefore, this discussion only attempts to describe the pattern that may be observed most frequently over time.

The Treatment of Filler Downtime

In the above calculations the treatment of the filler downtime varied. The purpose of this section is to explain why the downtime was not considered in the determination of accumulator capacity but was considered in the discussion on pallet transport. In collecting the filler downtime data no pattern could be found. The frequency and durations of the filler downtime were estimated by ten measurements which showed occurrence to be extremely irregular. Therefore it was deemed best not to include such a factor in the determination of accumulator capacity. The irregularity of downtime occurrence was such that at any time in the production day the filler could be expected to run uninterrupted for the full 7.9 minutes of accumulator capacity or more. If downtime was incorporated into the calculation to determine accumulator capacity, this would result in an accumulator of insufficient capacity. Such a situation defeats the purpose of the accumulator because once it is filled to capacity, the line would have to stop until the accumulator begins to empty.

The reason the downtime was incorporated in the description of pallet transportation is that it provided a more realistic situation and thus allowed for the prediction of a more accurate pallet transport schedule. Also, any error in the prediction of line downtime (due to the filler) is not as detrimental in determining the pallet transport schedule. As previously mentioned an error in predicting the capacity of the accumulator is very significant. However, with regard to the pallet transport schedule, any error in the prediction of filler downtime will only result in a change in the number of pallets taken to the warehouse at any one time. Any changes in this schedule will not affect the overall production of the line.

Determinations of Accumulator Dimensions

As previously determined, the spatial requirement of the accumulator is 47.5 square feet. The area available for accumulation is approximately 62 square feet or 31 feet x 2 feet (see Figure 5). To avoid problems of accessibility to the machines before and after the accumulator (the filler and casepacker) the length of the accumulator will be limited to 29 feet. The width of the accumulator is determined by the formula explained in Appendix C. Adjustable guiderails will be used to allow for optimal widths for both bottle sizes.

The minimum width is determined by dividing the total required area by the maximum length. This results in a minimum width of 19.7 inches for the sixteen ounce bottle (see equation 16).

$$\frac{\text{47.5 square feet of required capacity}}{\text{29 feet maximum length of accumulator}} = \text{1.64 feet or 19.7 inches} \tag{16}$$

To determine the optimal conveyor width for the sixteen ounce bottle a mathematical formula was used. For a complete explanation of the formula used in equation 17, refer to Appendix C.

$$\begin{aligned} W &= (N-1) \times D \times \sin 60^{\circ} + D + .15(D) \\ W &= (9-1) \times 2.594 \times .866 + 2.594 + .39 \qquad (17) \\ W &= 20 \text{ inches or } 1.67 \text{ feet} \end{aligned}$$

The value for N was determined by assuming a value of 19.7 inches for W (minimum required width to achieve a capacity of 47.5 square feet). Then the exact value for W was found by using 9 as the value for N. This allows for a smooth bottle flow by creating a leading row of 9 bottles which are at a 60° angle to the guiderail. Therefore a total capacity of 48.4 square feet is realized (1.67 feet x 29 feet = 48.4 square feet) exceeding the required capacity of the proposed accumulator (47.5 square feet).

To determine the minimum width for the ten ounce bottle the total required surface area is divided by the maximum length. This results in a minimum width of 15.4 inches (see equation 18).

$$\frac{\text{37 square feet of required capacity}}{\text{29 feet maximum length of accumulator}} = \text{1.28 feet or 15.4 inches} \qquad (18)$$

To determine the optimal conveyor width, the same formula can be used to find the optimal ten ounce width that was used to find the sixteen ounce bottle width (see equation 19).

$$\begin{aligned} W &= (N-1) \times D \times \sin 60^{\circ} + D + .15(D) \\ W &= (8-1) \times 2{,}406 \times .866 + 2.406 + .36 \qquad (19) \\ W &= 17.4 \text{ inches or } 1.45 \text{ feet} \end{aligned}$$

As with the sixteen ounce bottle, the value for N was determined by assuming a value of 15.4 inches for W. Then the exact value for W was found by using 8 as the value for N. This allows for a smooth bottle flow by creating a leading row of 8 bottles which are at a 60° angle to the guiderail. Therefore a total capacity of 42 square feet is realized (1.45 feet x 29 feet = 42 square feet) exceeding the required capacity of 37 square feet for the ten ounce bottle. Adjustable guiderails will be used to change from the 20 inch (1.67 feet) width to the 17.4 inch (1.45 feet) width and vice versa to maintain smooth bottle flow with both bottle sizes.

The type of accumulator proposed is simply a wider conveyor driven by a stainless steel flat chain. The required capacity of the accumulator was satisfied by widening the conveyor. It was chosen as the most likely option due to its relatively low cost and its minimal installation requirements.

Cost Determination and Analysis

The results of this investigation indicate that an accumulator with the capacity of 47.5 square feet would increase the productivity of the line by eliminating the need for one operator at the casepacker. A wider conveyor is proposed as the best choice of accumulator. The cost of such an accumulator is approximately $300 per square foot.[6] The installation charge is approximately $1,000. To be able to accommodate both conveyor widths at least 48.4 square feet must be installed. This results in an overall cost of $15,520. The annual cost of one operator to the firm is approximately $14,000. Therefore the accumulator could pay for itself in 1.11 years (see equation 20).

$$\frac{\$15,520 \quad \text{cost of proposed accumulator}}{\$14,000 \ (\text{cost of operator to firm/year})} = 1.11 \text{ years} \qquad (20)$$

Conclusion and Recommendation

Installation of this accumulator is recommended because the use of accumulation will balance the line with regard to machine speeds. This will allow the casepacker to run automatically rather than semi-automatically as it is currently doing. With the casepacker running automatically, the need for one of the three operators now stationed at this point in the line is eliminated, thus increasing productivity according to the relationship: productivity = $\frac{\text{final output}}{\text{labor input}}$. Since the accumulator is estimated to save $14,000 per year, it would pay for itself in 1.11 years while simultaneously increasing the productivity of the line by reducing the labor input and maintaining the same level of production.

Areas for Further Study

The proposed accumulator in this investigation was chosen by using time study, statistical analysis, and considering spatial limitations. Computer simulation could be used to predict and evaluate the accumulation requirements of the packaging line. However, sufficient data must be collected to provide the computer with the correct inputs.

The data collected in this investigation could be used as a basis for the development of a computer program of this type. This data would provide a real production situation on which a computer model could be based.

APPENDICES

APPENDIX A

LINE RELIABILITY CALCULATION

APPENDIX A

LINE RELIABILITY CALCULATION

The reliability of an entire packaging line is determined by the interaction among individual machines in the line. The reliability of a machine is a percentage measurement of the time a machine is actually operating during the time it is supposed to operate. A mathematical progression can be used to determine overall line efficiency. It works like this: a line consisting of eight machines each with an individual reliability rating of 95 percent has an overall line reliability of 66 percent. (.95 x .95 x .95 x .95 x .95 x .95 x .95 x .95). This means the first machine will run 95 percent of the time. The second machine will run 95 percent of the time it is supplied with input from the first machine or 90.25 percent (.95 x .95). The third machine will operate 95 percent of the time it is supplied with input from the second machine or 85.74 percent (.9025 x .95). This progression continues until the eighth machine is operating 66 percent of the time. This calculation assumes total machine interaction which results in the lowest reliability rating.

The highest theoretical rating is the reliability of the slowest machine in the line. If a line has three machines with reliabilities of 70, 80, and 90 percent respectively, 70 percent would be the highest reliability possible for that line, assuming no machine interaction. Under this assumption the downtime of the second two machines would coincide with the time the first machine is down. Therefore the downtime of the scond and third machine would be hidden by the downtime of the first machine. However, it is possible that the downtimes of the second and third machines would not coincide with the downtime of the first. It is even possible that the downtime of each machine would occur at a time when the other two would have been running. In this case there would be total interaction, and the efficiency of the line would be .70 x .80 x .90 = .504 or 50.4 percent.

APPENDIX B

CALCULATIONS TO DETERMINE ACCUMULATION REQUIREMENTS: THE GARVEY CORPORATION

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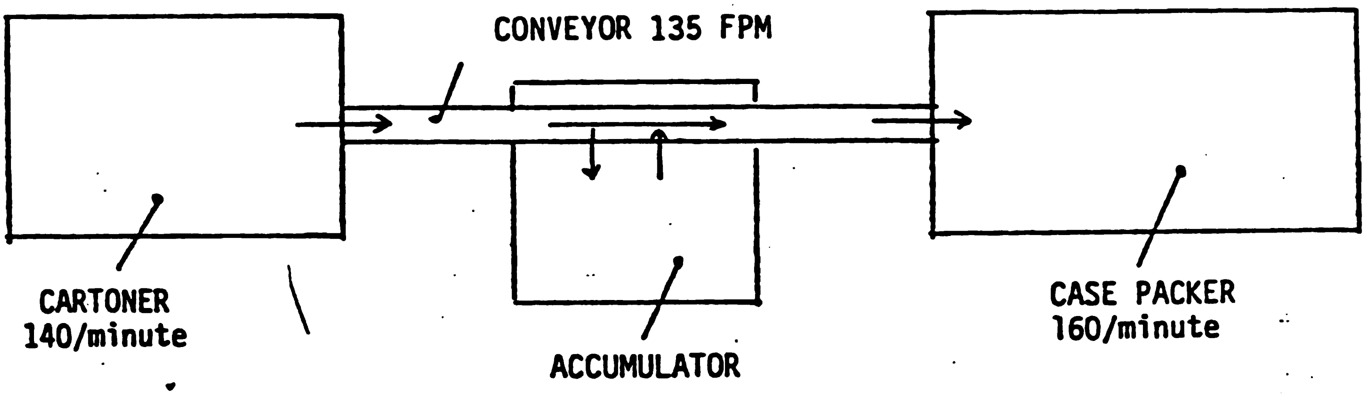
GARVEY®
CORPORATION
The Originators of Modular Conveyors™

[redacted] ACCUMULATOR XD-57427



PRODUCT SIZE:	LENGTH	5-3/4"
	WIDTH	7-1/4"
	HEIGHT	1-1/8"

ACCUMULATOR TRAY HOLDS 6 PRODUCTS = 34-1/2" LONG

PRODUCT ACCELERATION TIME: $\mu = .25$ V = 135 FPM = 2.25 feet/second = 27 in/second

$$V = \overset{0}{\cancel{V_o}} + at \qquad F = ma \; ; \; m = \frac{w}{g} \therefore F = \frac{w}{g} a \therefore a = \frac{Fg}{w} \; ;$$

$$\therefore t = \frac{V}{a} = \frac{2.25 \text{ feet/second}}{8 \text{ feet/second}^2} \qquad F = \mu w \therefore a = \cancel{\mu w}\left(\frac{g}{\cancel{w}}\right) = \mu g = \boxed{8 \text{ feet/second}^2}$$

$$\boxed{t = .28 \text{ second}}$$

FUNCTION TIMES:

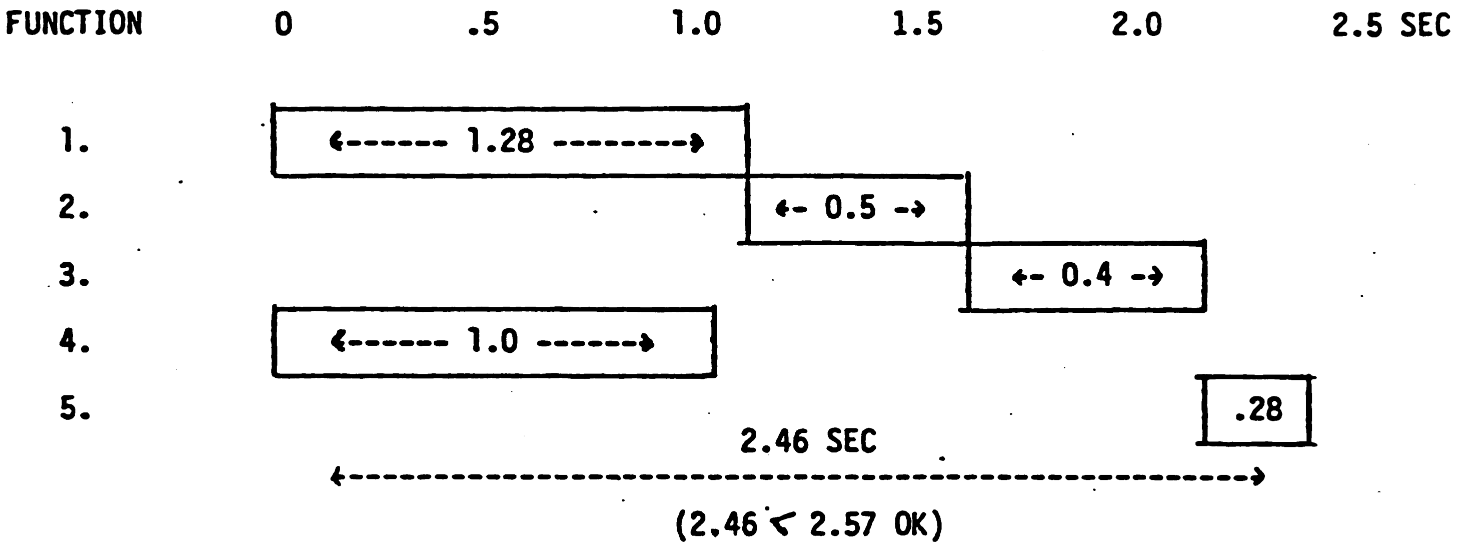
1. PRODUCT TRAVEL 1 TRAY LENGTH $\frac{34.5"}{27"/\text{seconds}}$ = 1.28 second*
2. ✓ PUSH PRODUCT TIME = .5 second
3. ✓ PUSHER RETRACT TIME = .4 second
4. ✓ TRAY INDEX TIME = 1 second
5. PRODUCT ACCELERATE FROM REST TIME = .28

* IGNORES DISTANCE TRAVELED DURING ACCELERATION

[redacted] ACCUMULATOR XD-57427

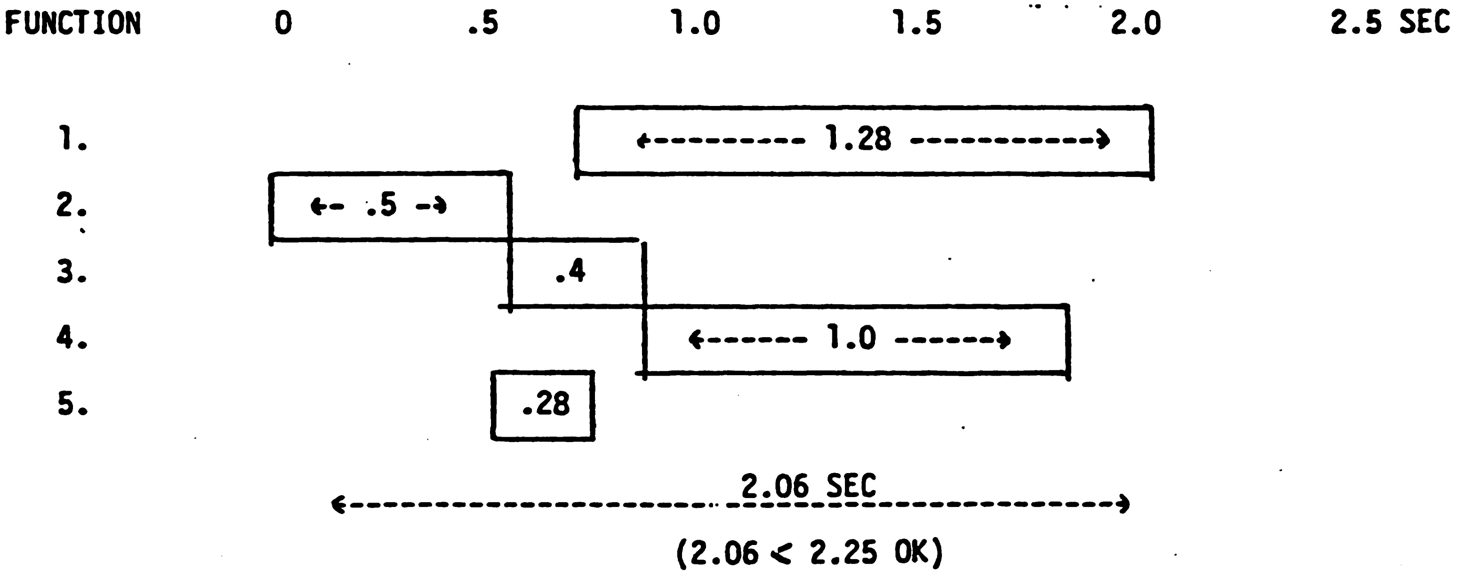
ACCUMULATE MODE CYCLE CHART:

140 CTN/MIN = 2.57 SEC/6 CTN TRAY



DISPENSE MODE CYCLE CHART:

160 CTN/MIN = 2.25 SEC/6 CTN TRAY



206 SEC/6 CTN TRAY = 175 CTN/MIN

GARVEY® CORPORATION
The Originators of Modular Conveyors™

[redacted] ACCUMULATOR XD-57427

RATE OF BACK UP CALCULATION

$$V_b = \frac{V_c\,(V_p \text{ in} - V_p \text{ out})\ l}{V_c - (V_p \text{ in} - V_p \text{ out})\ l}$$

$$\frac{135\,(140 - 0)\ .58\,\text{ft}/[illegible]}{135 - (140 - 0)\ .58} = 203.75\ \overset{\text{ft}}{\text{p[illegible]}}/\text{min}$$

$$135\,\text{ft}/\text{min})(140/\text{min})\,.58\,\text{ft}/ = 3.4\ \overset{\text{ft}}{[illegible]}/\text{sec}$$

RATE OF BACK UP @ 135 ft/min CHAIN SPEED WITH 140 PRODUCTS (.58 ft long) ENTERING AND NO PRODUCT EXITING = 3.4 prod/sec

CALCULATION FOR ON LINE ACCUMULATION

V_b = SPEED OF BACK UP (feet/minute)

V_c = CONVEYOR SPEED (feet/minute)

V_p in = RATE OF PRODUCT ENTERING SYSTEM (product/minute)

V_p out = RATE OF PRODUCT EXITING SYSTEM (product/minute)

l = PRODUCT LENGTH (feet)

T = TIME OF BACK UP (minute)

L = LENGTH OF BACK UP (feet)

SPEED OF BACK UP V_b (feet/minute)

$$\boxed{V_b = \frac{V_c\ (V_p\ \text{in} - V_p\ \text{out})\ l}{V_c - (V_p\ \text{in} - V_p\ \text{out})\ l}}$$

7.425

LENGTH OF BACK UP L (feet)

$$\boxed{L = V_b \times T}$$

TIME OF BACK UP T (minute)

$$\boxed{T = \frac{L}{V_b}}$$

APPENDIX C

FORMULA TO DETERMINE OPTIMAL CONVEYOR WIDTHS FOR ROUND OBJECTS

APPENDIX C

FORMULA TO DETERMINE OPTIMAL CONVEYOR WIDTH FOR ROUND OBJECTS

Ideal spacing of bottles on a conveyor can provide smooth bottle flow. This is achieved through optimal conveyor width and low speed mass flow of the objects. The benefits of this type of system include low noise levels, energy efficiency, minimal guide rail pressure, less bottle to bottle abrasion, and allows for in-line accumulation. A formula can be used to determine this optimal width.[8] The object is to form equilateral triangles of three bottles each and to continually repeat this pattern (Figure 6).

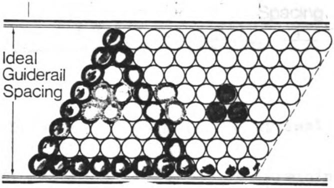


Figure 6. Diagram illustrating the equilateral triangle pattern of Round Objects on a Conveyor.

SOURCE: Rutherford Cooper, "Determining Guide Rail Spacing for Conveying Round Objects," Packaging Technology 10 (August 1980): 23-23.

To achieve this pattern the following equation is used:

$$W = (N-1) \times D \times \sin 60^{\circ} + D$$

Where: W = Optimal conveyor width

N = Number of round objects (bottles) in a 60° row

D = Diameter of the conveyed object

$\sin 60^{\circ} = .866$

A 60° angle is formed by the guide rail and an imaginary line drawn across the conveyor (Figure 7).

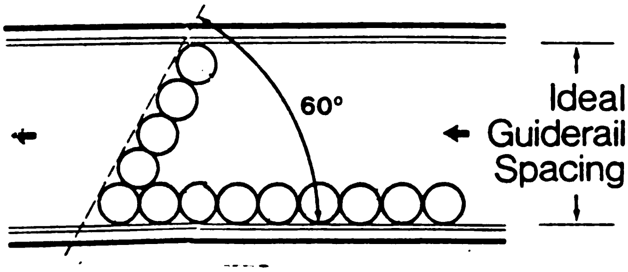


Figure 7. Diagram Illustrating the Optimal Conveyor Width for Round Objects.

SOURCE: Rutherford Cooper, "Determining Guide Rail Spacing for Conveying Round Objects," Packaging Technology 10 (August 1980) 22-23.

This equation provides for straight rows of bottles at a 60° angle to the guide rail. The number of bottles that fit in the 60° row is N. The 60° angle will preserve the basic pattern of three bottle equilateral triangles by allowing them to form larger equilateral triangles (Figure 6).

For example, in the preceding diagram (Figure 7) the number of bottles that fit in the 60° row or N is 5. If the bottle diameter is 2 inches the formula can be used to determine the optimal conveyor width.

$$W = (N-1) \times D \times \sin 60^\circ + D + .15(D)*$$

$$W = (5-1) \times 2" \times .866 + 2" + .30"$$

$$W = 9.23 \text{ inches}$$

---

* To compensate for variation in bottles diameter fifteen percent of the diameter is added as a safety factor.

APPENDIX D

MACHINERY INFORMATION

APPENDIX D

MACHINERY INFORMATION

Machine	Make and Model Number
Uncaser	Meyer HD-V ss-2055
↓	
Washer	Dostal and Lowey PEP D 12W 1283
↓	
Scanner	Meyer Mark IV D 79-1528
↓	
Filler/Capper	Meyer HP 2917 34-8
↓	
Counter	Durant 6-HF-41-R-CL 173
↓	
Dater	Ultra-Mark
↓	
Casepacker	Lodge and Shiply Climax DP3-1 5014

APPENDIX E

PROCESS FLOW CHART FOR BOTTLING OPERATION

PROCESS FLOW CHART

SUMMARY	Present Proposed	Saved
Operations ○		
Transportations ○		
Storages ▽		
Inspections ☐		
Total Details		
Total Distance		
Total Time		

Job R. C. Cola

Packaging line operation

Subject Charted 16 ounce bottles

Date 1-12-82 Charted by

	DETAIL DESCRIPTION (Present Proposed)	SYMBOL	Distance	Time	What?	Where?	When?	Who?	How?	NOTES	Eliminate	Combine	Chg. Seq.	Simplify
1	Bottles brought to into pkg area	○ ● ▽ ☐												
2	Unloaded by hand onto uncaser	● ○ ▽ ☐												
3	Automatically uncased	● ○ ▽ ☐												
4	Accumulate before washing	○ ○ ▼ ☐												
5	Washing	● ○ ▽ ☐												
6	Transported to filler/capper	○ ● ▽ ☐												
7	Electronically scanned	○ ○ ▽ ■												
8	Filling	● ○ ▽ ☐												
9	Capping	● ○ ▽ ☐												
10	Transported to casepacker	○ ● ▽ ☐												
11	Counted	● ○ ▽ ☐												
12	Dated	● ○ ▽ ☐												
13	Accumulate-Collate	○ ○ ▼ ☐												
14	Casepacking	● ○ ▽ ☐												
15	Loading onto pallets	● ○ ▽ ☐												
16	Taken to warehouse	○ ● ▽ ☐												
17	Storage until delivery	○ ○ ▼ ☐												
18		○ ○ ▽ ☐												
19		○ ○ ▽ ☐												
20		○ ○ ▽ ☐												
21		○ ○ ▽ ☐												
22		○ ○ ▽ ☐												
23		○ ○ ▽ ☐												
24		○ ○ ▽ ☐												
25		○ ○ ▽ ☐												
26		○ ○ ▽ ☐												
27		○ ○ ▽ ☐												
28		○ ○ ▽ ☐												
29		○ ○ ▽ ☐												
		○ ○ ▽ ☐												

APPENDIX F

PROCESS FLOW CHART FOR THE FORKLIFT OPERATION

Page ______

Of ______

PROCESS FLOW CHART

SUMMARY	Present Proposed	Saved
Operations ○		
Transportations ○		
Storages ▽		
Inspections ☐		
Total Details		
Total Distance		
Total Time		

Job R. C. Cola

Forklift operation - Labor analysis

Subject Charted 16 ounce bottles

Date 1-12-82 Charted by

	DETAIL DESCRIPTION (Present Proposed)	SYMBOL	Distance	Time	What?	Where?	When?	Who?	How?	NOTES	Eliminate	Combine	Chg. Seq.	Simplify
1	Operator leaves casepacker/line	○ ● ▽ ☐												
2	Walks to forklift truck	○ ● ▽ ☐												
3	Gets on forklift truck	● ○ ▽ ☐												
4	Starts truck and picks up load	● ○ ▽ ☐												
5	Takes load to warehouse	○ ● ▽ ☐												
6	Unloads pallet	● ○ ▽ ☐												
7	Drives to storage area for empties	○ ● ▽ ☐												
8	Picks up a load of empty bottles	● ○ ▽ ☐												
9	Drives back to packaging line	◑ ● ▽ ☐												
10	Unloads empties by uncaser	● ○ ▽ ☐												
11	Drives to casepacker	○ ● ▽ ☐												
12	Parks forklift truck	● ○ ▽ ☐												
13	Gets off	● ○ ▽ ☐												
14	Walks to casepacker/uncaser/etc.	○ ● ▽ ☐												
15	Begins to help on the line.	● ○ ▽ ☐												
16		○ ○ ▽ ☐												
17		○ ○ ▽ ☐												
18		○ ○ ▽ ☐												
19		○ ○ ▽ ☐												
20		○ ○ ▽ ☐												
21		○ ○ ▽ ☐												
22		○ ○ ▽ ☐												
23		○ ○ ▽ ☐												
24		○ ○ ▽ ☐												
25		○ ○ ▽ ☐												
		○ ○ ▽ ☐												
27		○ ○ ▽ ☐												
28		○ ○ ▽ ☐												
29		○ ○ ▽ ☐												

APPENDIX G

RESULTS OF TIME STUDIES COMPLETED ON FORKLIFT OPERATION

APPENDIX G

RESULTS OF TIME STUDIES COMPLETED ON FORKLIFT OPERATION

Table 1. Results of time studies completed on Forklift Operation.

Date and time of timing	Timing	Time Minutes
January 12, 1982 10:00 - 11:30 A.M.	1	3.23
	2	2.87
	3	2.83
	4	3.08
	5	3.78
	6	3.08
	7	3.47
	8	3.58
	9	2.83
	10	4.48
January 20, 1982 9:30 - 11:00 A.M.	11	2.92
	12	2.87
	13	3.04
	14	3.03
	15	2.94
	16	3.18
	17	4.02
January 28, 1982 9:30 - 11:30 A.M.	18	3.58
	19	3.67
	20	4.08
	21	3.28
	22	3.67
	23	2.83
	24	3.77
	25	3.62
	26	2.98
	27	2.90
	28	2.75
	29	2.77
	30	2.78
	31	2.62
	32	2.85

Table 1 - Continued

Date and time of timing	Timing	Time Minutes
January 28, 1982 12:45 - 2:40 P.M.	33	2.85
	34	3.42
	35	4.60
	36	3.18
	37	3.17
	38	4.58
	39	4.40
	40	4.68
	41	4.68
	42	4.50
February 3, 1982 9:45 - 11:00 A.M.	43	3.87
	44	3.93
	45	3.47
	46	3.27
	47	3.18
	48	3.83
	49	3.83
	50	3.17
	51	3.62
	52	3.02
	53	3.35
	54	3.50
February 3, 1982 2:30 - 3:30 February 11, 1982 9:30 - 10:45 A.M.	55	2.85
	56	3.32
	57	3.28
	58	3.63
	59	4.53
	60	4.27
	61	4.95
	62	3.80
	63	3.98
	64	3.68
February 11, 1982 1:00 - 3:00 P.M.	65	3.77
	66	3.38
	67	4.48
	68	4.05
	69	3.78
	70	4.10
	71	4.40
	72	4.65
	73	4.85
	74	4.03

Table 1 - Continued

Date and time of timing	Timing	Time Minutes
February 11, 1982 1:00 - 3:00 P.M.	75	4.32
	76	4.05
	77	3.87
	78	4.32
	79	4.37
	80	3.88
	81	4.15
	82	4.27
	83	4.30
	84	4.15
February 12, 1982 9:00 - 11:30 A.M.	85	4.50
	86	4.47
	87	3.78
	88	4.60
	89	4.93
	90	3.98
	91	3.83
	92	3.87
	93	4.00
	94	3.50
	95	3.87
	96	3.65
	97	3.88
	98	3.90
	99	4.33
February 15, 1982 9:00 - 11:30 A.M.	100	3.83
	101	3.66
	102	3.77
	103	4.71
	104	4.93
	105	3.78
	106	4.08
	107	3.88
	108	3.68
	109	3.77
	110	3.65
	111	4.15
	112	4.67
	113	4.11
	114	4.75
	115	4.05
	116	4.45

Table 1 - Continued:

Date and time of timing	Timing	Time Minutes
February 15, 1982 9:00 - 11:30 A.M.	117	3.61
	118	4.73
	119	4.01
February 15, 1982 12:45 - 3:00 P.M.	120	3.83
	121	4.95
	122	4.18
	123	4.45
	124	4.65
	125	4.00
	126	4.55
	127	3.88
	128	4.17
	129	4.37
	130	4.10
	131	3.88
	132	3.85
	133	3.91
	134	4.57
	135	3.90
	136	3.81
	137	3.65
February 16, 1982 1:15 - 3:45 P.M.	138	3.80
	139	4.41
	140	3.75
	141	4.57
	142	4.25
	143	4.23
	144	4.20
	145	4.30
	146	4.41
	147	4.11
	148	5.30
	149	4.75
	150	4.21
	151	4.17
	152	4.98
	153	4.57
	154	4.68
	155	4.48
	156	3.75
	157	4.33
	158	4.37
	159	4.52

Table 1 - Continued

Date and time of timing	Timing	Time Minutes
February 17, 1982 9:45 - 10:15 A.M.	160	3.97
	161	3.67
	162	4.77
	163	4.58
	164	4.00
	165	4.17
	166	3.90
	167	3.87
February 17, 1982 1:45 - 3:15 P.M.	168	3.38
	169	3.67
	170	2.98
	171	3.15
	172	2.70
	173	3.23
	174	4.01
	175	4.63
	176	4.68
	177	3.68
	178	3.95
	179	4.07
February 18, 1982 9:30 - 11:30 A.M.	180	3.67
	181	3.98
	182	4.10
	183	4.58
	184	4.97
	185	4.08
	186	4.42
	187	4.10
	188	3.72
	189	3.77
	190	4.48
	191	3.87
	192	4.27
	193	4.22
	194	4.35
	195	4.12
	196	4.40
	197	3.77
	198	3.60
	199	3.73
	200	4.38
Mean		3.924
Standard Deviation		.568

APPENDIX H

FREQUENCY AND DURATION OF DOWNTIME OF THE FILLER

APPENDIX H

DOWNTIME FREQUENCY SUMMARY

Table 2 - Frequency of Filler Downtime

Date and time of downtime	Number of downtimes	Frequency downtimes/minute
January 28, 1982 9:30 - 2:40	33	.12
February 3, 1982 9:45 - 11:00	14	.19
February 11, 1982 9:30 - 10:45	12	.16
February 11, 1982 1:00 - 3:00	29	.24
February 12, 1982 7:45 - 9:30	12	.11
February 15, 1982 9:00 - 11:30	22	.24
February 15, 1982 12:45 - 3:00	31	.23
February 16, 1982 9:30 - 11:30	21	.18
February 17, 1982 1:45 - 3:00	8	.11
TOTAL	182	MEAN .18 (10.8/hour)

APPENDIX H

DOWNTIME FREQUENCY AND DURATION OF THE FILLER INDIVIDUAL INCIDENTS

Table 3 - Duration of Filler downtime

Date and time of downtime	Time filler was down	Duration of Downtime Seconds
January 28, 1982	1	5
9:30 - 2:40	2	2
	3	5
	4	180
	5	155
	6	10
	7	10
	8	16
	9	27
	10	7
	11	22
	12	2
	13	44
	14	59
	15	9
	16	8
	17	20
	18	3
	19	9
	20	32
	21	23
	22	2
	23	27
	24	26
	25	97
	26	20
	27	3
	28	5
	29	90
	30	10
	31	67
	32	7
	33	15

Table 3 - Continued

Date and time of downtime	Time filler was down	Duration of downtime Seconds
February 3, 1982 9:45 - 11:00 A.M.	1	9
	2	61
	3	44
	4	10
	5	43
	6	2
	7	64
	8	5
	9	53
	10	9
	11	170
	12	34
	13	58
	14	2
February 11, 1982 9:30 - 10:45 A.M.	1	30
	2	83
	3	20
	4	10
	5	5
	6	11
	7	7
	8	13
	9	45
	10	3
	11	14
	12	124
February 11, 1982 1:00 - 3:00 P.M.	1	6
	2	95
	3	10
	4	23
	5	2
	6	13
	7	18
	8	56
	9	90
	10	22
	11	15
	12	2
	13	50
	14	45
	15	9
	16	10
	17	13
	18	7
	19	25

Table 3 - Continued

Date and time of downtime	Time filler was down	Duration of Downtime Seconds
February 11, 1982	20	14
1:00 - 3:00 P.M.	21	33
	22	2
	23	24
	24	7
	25	58
	26	67
	27	11
	28	15
	29	50
February 12, 1982	1	5
7:45 - 9:30 P.M.	2	15
	3	4
	4	2
	5	10
	6	70
	7	4
	8	9
	9	5
	10	9
	11	4
	12	95
February 15, 1982	1	15
9:00 - 11:30 A.M.	2	46
	3	5
	4	5
	5	3
	6	2
	7	36
	8	183
	9	25
	10	9
	11	3
	12	10
	13	13
	14	63
	15	2
	16	2
	17	120
	18	8
	19	2
	20	9
	21	6
	22	64

Table 3 - Continued

Date and time of downtime	Time filler was down	Duration of downtime Seconds
February 15, 1982 12:45 - 3:00 P.M.	1	64
	2	5
	3	75
	4	5
	5	10
	6	68
	7	19
	8	4
	9	52
	10	37
	11	6
	12	123
	13	55
	14	43
	15	11
	16	130
	17	9
	18	5
	19	20
	20	10
	21	68
	22	73
	23	23
	24	14
	25	2
	26	7
	27	56
	28	3
	29	4
	30	10
	31	17
February 16, 1982 9:30 - 11:30 A.M.	1	2
	2	2
	3	15
	4	37
	5	55
	6	5
	7	30
	8	32
	9	39
	10	51
	11	18
	12	28
	13	52
	14	7
	15	5

Table 3 - Continued

Date and time of downtime	Time filler was down	Duration of downtime Seconds
February 16, 1982 9:30 - 11:30 A.M.	16	5
	17	22
	18	39
	19	76
	20	2
	21	39
February 17, 1982 1:45 - 3:00 P.M.	1	34
	2	53
	3	8
	4	9
	5	95
	6	21
	7	14
	8	58
MEAN DURATION		29.7 seconds

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