SIMULATION OF A DISTRIBUTION CENTER (WAREHOUSE)
CENTRAL CONVEYOR SYSTEM

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ABSTRACT

A GPSS/360 Model has been used to simulate a large Distribution Center conveyor system. The large warehouse facility (1000 items) is served by one complex conveyor system. The system has been designed to combine man, machine and computer into a reliable and flexible shipping system. Five prebalanced assembly lines run through the warehouse, being manually loaded and converging into a single line for Quality Control and coding services. The system is capable of loading two trailer trucks at 4000 cases per hour. The model is used for facilities performance studies and long term expansion planning to meet anticipated shipping capacity growth.

CHAPTER 1

A DESCRIPTION OF PROBLEM

Description of Existing Facilities

The warehousing facility under study services about 1000 separate items which are on-loaded and conveyed to waiting trailer trucks at an average rate of 1800 cases per hour. A System called "Conveyoromatic" had been installed to combine men, machine and computer into an accurate, reliable and flexible shipping system. Product is manually loaded onto a conveyor from five assembly lines and transported through the system. Computer programs pre-establish the order processing routine, the five assembly lists, and coordinate the mechanical and manual functions. The present system handles approximately 15,000 cases per eight hour shift.

Description of Constraints:

Management anticipates rapid growth in demand for warehousing and shipping capacity and has commissioned this study to evaluate and recommend such modifications as are necessary to meet this expectation within the following managerial established constraints:

1. No new warehouse facility is to be contemplated.

2. Modifications, as far as practicable, are to be incrementally implemented to meet projected capacity requirements, thus minimizing capital expenditures for idle facilities.

3. While cost will ultimately govern decisions of Conveyoromatic, cost information was excluded from consideration in this phase of the study. Alternatives which were clearly impractical from a cost standpoint, however, were excluded from consideration.

4. Customer satisfaction is paramount, and system expansion must continue to provide for "next-day-delivery" on every order received prior to 4:00 PM on the previous day.

System requirements

Management has provided the following projection of capacity requirements through 1975.

<table>
<thead>
<tr>
<th>Year</th>
<th>CS/DAY</th>
<th>CS/HR.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>27,000</td>
<td>3440</td>
</tr>
<tr>
<td>1974</td>
<td>25,200</td>
<td>3150</td>
</tr>
<tr>
<td>1973</td>
<td>22,400</td>
<td>2800</td>
</tr>
<tr>
<td>1972</td>
<td>19,200</td>
<td>2400</td>
</tr>
<tr>
<td>1971</td>
<td>16,500</td>
<td>2060</td>
</tr>
<tr>
<td>1970 (end)</td>
<td>13,500</td>
<td>1650</td>
</tr>
</tbody>
</table>

The above projections have been recast into FIGURE 1.2 to reflect the inherent uncertainty involved in the projections; and the necessity to plan expansion to accommodate the probabilistic nature of the capacity requirements.

*Note: data in this report has been coded to preserve proprietary information.
FIGURE 1.2
DISTRIBUTION OF CAPACITY REQUIREMENTS
(G/CAS/DAY)

DISTRIBUTION OF CASES PER DAY BASED ON AVERAGES (CASES IN 000)

1975
1974
1973
1972
1971
1970
YEAR

303

The objectives have been clearly defined:
To match Conveyomatic capacity to demand within the established constraints. Thus,
to determine what combination of men and machinery best satisfies the expected ship-
ing demand over the next five years. The operational procedure is to identify the
pertinent variables and bottlenecks and to make such changes as to increase the
variable's contribution to capacity and to reduce or eliminate bottlenecks. To
accomplish this a computer simulation model of the conveyomatic system was de-
veloped mapping the real world. After correspondence was established the simul-
ation runs were used to study and optimize systems parameters and modified system
configuration. The results of these
changes on performance are embodied in the
next chapters.

CHAPTER II
CONVEYOMATIC SYSTEM

The present conveyomatic system as
modeled for reality studies, is repre-
seated in Figure 2.1 (the major facilities
have been marked). Orders are filled by
loading the cases of different items
from stacks surrounding the lines, where
they flow onto the main belt, to a checker,
stencil, metering belf, retractable con-
veyors, and finally to the loader and
truck.

Manning:
The conveyomatic crew requires ten em-
ployees within the four operations: assem-
by, checking, stenciling and loading. The
present shipping system performance of
1800 cs/hr (average) requires the follow-
ing allocations (Table 2.2).

<table>
<thead>
<tr>
<th>Operation</th>
<th>Number of Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Assembler</td>
<td>5</td>
</tr>
<tr>
<td>Console Operator</td>
<td>1</td>
</tr>
<tr>
<td>Stenciler</td>
<td>1</td>
</tr>
<tr>
<td>Loader/Case Aligner</td>
<td>3</td>
</tr>
</tbody>
</table>

A brief description of the specific opera-
tions follows:

A. Loader/Case Aligner
Operation Description - The three employees
within this job group rotate between
loading cases in the trailer and aligning
cases on a platform adjacent to the meter-
ing belt. Each half hour, a trailer
loader will rotate to the aligners plat-
form. The aligner's major responsibilities
are:

1. To maintain an orderly flow of cases
to the trailer, breaking jams as re-
quired and re-sealing opened cases.

2. To insure that an empty trailer is
suitable for loading. He inspects the
trailer, and positions one of the two
retractable conveyors in the empty
trailer.

B. Line Assemblers
Operation Description - All flow of
materials through the system initiates
at the line assembler operation. On
five individual assembly lines, product
is loaded to a conveyor belt. Using a list created by a computerized order balancing program, the line assembler is instructed to walk to a specific product location and load a quantity of cases on the conveyor belt. Pallet flow racks are arranged to minimize walking distance. The cases are accumulated on a pressure sensitive roller conveyor.

C. Console Operator

Operation Description - Through a computer routine, the particular product codes and quantity required to satisfy an order have been assembled and accumulated over five lines. The first case of each order from each assembly line is identified by a strip of photo-electric tape applied by the line assembler.

The releasing sequence necessary to complete the order is printed at the bottom of each order sheet. The Console Operator sets this information into a console, releasing only the proper amount of product from each line. This is accomplished by means of the photo-electric tape and an electric eye, releasing a number of cases until a piece of tape is identified. A manual override at the Console adjusts any inaccuracies that may occur.

The console operator checks the product code and quantity specified on an order, stopping the line as required with a foot pedal.

D. Stenciler

Operation Description - A single stream of product is fed on accumulation roller conveyor past the stenciler's work area. Rotating the stencil color between orders, he stencils an identification on each case.

After stenciling, material is transferred to a powered roller conveyor and up incline belts to the metering belt, then to the respective truck belt.

System Description:

Within the Conveymatic system there are five physically independent assembly lines. Two of these lines are located on an upper level above the lower lines.

Each line is approximately 100 feet in length. On both sides of each line, running the length of the line, are full pallet positions, three unit loads deep.

Product is coded and stacked by rate of movement; fastest moving items are palletized to provide initial balance. Remaining products are assigned to case flow positions and slow moving items receive shelf storage.

Each product code is assigned enough space to maintain an average two day volume capacity. Product space and position had been allocated in case flow racks to provide efficient space utilization and to accommodate case dimension characteristics.

Additional Data:

Data, included: workload distribution, downtime, manning requirements, capacity, idle time, order processing routines, product location, and physical characteristics. Most of the data was not directly available as to the average and distribution for loading times, downtime, order sequences, stenciler times, picking time, cases per job, picking times, and checking times.

From the available data covering the
last four months activities for 1969
the following tables of performance
were compiled.

TABLE 2.4

<table>
<thead>
<tr>
<th></th>
<th>AVERAGE</th>
<th>VARIABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(per case)</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>pick from pallet floor</td>
<td>.085 ± .090</td>
</tr>
<tr>
<td>2.</td>
<td>miscellaneous P(.003)</td>
<td>.553</td>
</tr>
<tr>
<td></td>
<td>P(.007)</td>
<td>.307</td>
</tr>
<tr>
<td></td>
<td>P(.018)</td>
<td>.249</td>
</tr>
<tr>
<td>Apply tape</td>
<td></td>
<td>.152 ± .015</td>
</tr>
</tbody>
</table>

Walking speed = .004 ± .0004 min. per foot

TABLE 2-5

<table>
<thead>
<tr>
<th></th>
<th>Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg.</td>
<td></td>
</tr>
<tr>
<td>Per Case</td>
<td>Check cases</td>
</tr>
<tr>
<td>Per Job</td>
<td>Process Job</td>
</tr>
</tbody>
</table>

TABLE 2-6

<table>
<thead>
<tr>
<th></th>
<th>Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg.</td>
<td></td>
</tr>
<tr>
<td>Per Case</td>
<td>Stencil Cases</td>
</tr>
<tr>
<td>Per Job</td>
<td>Process Job</td>
</tr>
</tbody>
</table>

TABLE 2-7

DOWNTIMES - (Minutes)

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Random #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>.024</td>
<td>30 min.</td>
</tr>
<tr>
<td>Paperwork</td>
<td>.009</td>
<td>15 min.</td>
</tr>
</tbody>
</table>

The above tables and data reflect attributes and operations of the existing Conveyomatic system. This data formed the basis for our model, and a measure against which correspondence could be judged. The present system configuration formed the basis for identifying bottlenecks and for assigning priorities to the sequence of evaluation and modification.

Functions generated:
The following tables were constructed from the Conveyomatic data accumulated over a four month operating period and represent the dependent variables as functions of their probability distributions. The random number generators in the GPSS simulation (discussed in CHAPTER 3: SIMULATION) was programmed to produce the dependent Y variable i.e. cases/job, cases/item, sequence/order and items/sequence.
### Table 2.9

<table>
<thead>
<tr>
<th>RANDOM NUMBER GENERATOR - CASES PER JOB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y VALUE</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>51 to 100</td>
</tr>
<tr>
<td>101 to 150</td>
</tr>
<tr>
<td>151 to 200</td>
</tr>
<tr>
<td>201 to 250</td>
</tr>
<tr>
<td>251 to 300</td>
</tr>
<tr>
<td>301 to 350</td>
</tr>
<tr>
<td>351 to 400</td>
</tr>
</tbody>
</table>

### Table 2.10

<table>
<thead>
<tr>
<th>RANDOM # RANGE</th>
<th>RANDOM #</th>
<th>X VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.001 to .322</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.383 to .784</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Step Function</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>.931 to .950</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>.950</td>
<td></td>
</tr>
<tr>
<td>to 50</td>
<td>Function - pick</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.955</td>
<td></td>
</tr>
<tr>
<td></td>
<td>closest whole</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>.955 to .999</td>
<td></td>
</tr>
</tbody>
</table>

### Conclusion:

The above discussion and tables highlight some of the areas where study was directed as a methodological approach to optimizing our efforts; e.g., line balancing, loader bottleneck, multiple belts, duplicate metering facilities, additional pickers, etc.

A description of these investigations is contained in the following chapters.

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### Figure 3.1 - Simulation Flow Diagram

The purpose of simulation is to build a computerized model of the real world, to determine the significant parameters and to reproduce the real world behavior. After a satisfactory model has been built with a significant correspondence with accumulated real world data, then the model parameters can be modified and manipulated to represent changes in the real system. Changes can be readily induced and their effects on the output capacity studied.

Figure 3.1 is a schematic representation of the simulation model. It reveals the basic flow concept of the model, although in a very abbreviated and condensed form. The actual GPSS/360 model consists of 240 basic blocks, 18 "facilities", 12 "storages", 10 "queues", 14 "user chains", 10 "tables", 12 "functions", 36 "savevalues", and 30 "variables". The size and the complexity of the model forced us to revise the model several times in order to shorten the total running time and increase the efficiency of GPSS blocks in the model. To save running time,
a tape containing the items list for one shift of operation was generated using the "WRITE" block and read in via "JOBTAPE" on subsequent runs. This procedure also facilitated comparison of various runs.

**Simulation Sequence:**

In order to effectively isolate the impact of each variable on the total performance, successive runs were made holding all but one variable as constant. Each run showed the impact on performance of the system for the independent variable selected. Successive runs were then compared for output at a given conveyor speed and the most satisfactory input-output relationship was selected within the given constraints.

The following lists the variables that were modified in the simulation runs:

<table>
<thead>
<tr>
<th>Run Group</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Conveyor speed</td>
</tr>
<tr>
<td>B</td>
<td>One loader per truck, two trucks simultaneously</td>
</tr>
<tr>
<td>C</td>
<td>Alternate (5) assembly line balancing program</td>
</tr>
<tr>
<td>D</td>
<td>One checking station, two main lines, two metering belts, two loaders per truck, two trucks simultaneously</td>
</tr>
<tr>
<td>E</td>
<td>Two checking stations, System as D</td>
</tr>
<tr>
<td>F</td>
<td>6-10 pickers on five (5) assembly lines System E</td>
</tr>
<tr>
<td>G</td>
<td>Change conveyor speed and length, System as F</td>
</tr>
<tr>
<td>H</td>
<td>Six (6) picking lines, System as G</td>
</tr>
<tr>
<td>I</td>
<td>System as H, but replace metering belts by retractable accumulating conveyors</td>
</tr>
</tbody>
</table>

In addition, several runs were made to study the effect of conveyor speed, conveyor length, automatic card reader and improved picking time on the different models.

**Level of Model Detail:**

The simulation program incorporates data on activities and process measured to seconds, with appropriate probabilistic distributions around mean times. The following real-world features were incorporated and represented in the model: Distances between physical locations, product lists, locations, sequence of assembly, pickers, belts, gates, checker, stenciler, program of belt, loaders, metering, delays, job changeovers, breakdowns, and product size. These factors make the model extremely detailed and yield good correspondence with reality.

**Language Selected:** GPSS

The simulation language selected was GPSS. It is a discrete simulation language which is suitable to the discrete system of the Conveyomatic. Originally, the program was designed to follow the flow of cases through the system, but, because of core limitations of the computer, cases were combined into groups of similar product and the discrete entity was renamed ITEMS. The number of cases for each item was assigned as a parameter. The statistics generated by GPSS are well suited to following an entity through the system.

The GPSS outputs yield data of belt storages, facilities and mean utilization, queues of product in different locations, and waiting time for services e.g. list, picker, main line gates, checkers, main belt, meterbelt, loader. These statistics detail the average performance and delay times against which the criteria of time effectiveness of each facility and change can be gauged. This permits location of bottlenecks and areas amenable to change. It seems that the use of SIMSCRIPT as an alternative simulation language could have provided us flexibility in various stages of the study. However, the availability of the GPSS compiler dictated our choice.

**Pertinent Data:**

Data on orders, jobs, sequences, etc. existed; however, there was no data on the distributions of these parameters from which to build the random number based functions required for simulation. Consequently, data was obtained for four months performance, and the distribution statistics for each parameter was prepared. These data are represented in Tables 2.10 through 2.13 in Chapter II and were incorporated as functions in the number generators of the computer program. The data was obtained from the assembly sheets from which each picker worked.

Data on costs have not been introduced as a further constraint in the present study, however, preliminary study showed that cost constraints could be incorporated into the present model with minor modifications.

**Simulation Results:**

For a large enough sample size (about 2.5 hours in our case) the simulation results of the present system were remarkably accurate. Twelve hours of the simulated system generation were considered sufficient for its performance study. The
question of whether or not the GPSS
simulation model will yield valid re-
sults has been dealt with in many models,
and it has been shown that a GPSS model
will yield exact steady state queuing
results, as well as correct utilization
of services numbers if the model is
properly constructed.

In our experience, inaccuracy in the
simulation model was not a fault of
the simulation itself, but was generally
attributable to errors in the programmers
logic or misinterpretation of the simu-
lation tools available.

The validity of this particular simu-
lation model was tested by comparing
the simulated results with actual data
previously obtained through time studies
and production records. EXHIBITS 3.2
- 3.3, present typical utilization graphs
for some of the facilities in the system.
Note that facilities utilization are
time delay back factors that can vary
with conveyor speed, length, and
the line balancing method being used.

The complexity of the system, the nu-
merous alternatives available, and the
chain of interactions within its compo-
nents have given us sufficient knowledge
to develop a mathematical representation
of the system. (See APPENDIX 1) This
approach gave us a better understand-
ing of the parameters, and permitted
us to identify critical points at which
bottlenecks shifted from one system
element to another.

Conclusions:

A limiting factor on the overall through-
put of the Conveyomatic system is
customer order size. Any plan which
does not involve changes to the balancing
routine or order size will not appreciably
increase system throughput. The sen-
sitivity of the system to the balancing
program implies that new balancing rou-
tines must be created and operational
before maximum benefits of hardware
changes can be realized.

One option presently available to com-
penstate for line balancing inefficiency
by increasing the accumulation length
and conveyor speed to the picking lines.
(See simulation results, Table 3.5) An-
other possibility is to assign more
pickers to one line in order to increase
picking productivity. The physical
problem associated with multiple pickers
per line was not considered in this simu-
lation. Adding a sixth picking line will
not increase the system output until the
several other system modifications are
introduced. (See Table 3.5 and APPENDIX
1)
One of the Conveyormatic configurations which was studied (Option II, TABLE 3.5), considered of splitting into two independent main lines prior to the checking station. Each of these lines would lead to a different trailer with a two man loading crew. Only this configuration, of those studied, when combined with increased picking productivity and changes in conveyors length and speed, can yield the output capacity demand as forecasted for 1975 (4800 cs/hr or more).

Simultaneous loading of two trucks (one loader per trailer) would allow more efficient utilization of trailer space and loaders with no significant decrease in total present system output; however, this could be justified only as one stage toward total system redesign.

Other findings of the simulation model are:

a. Providing the stenciler with 50 feet of working area up-line from the checker will reduce some time delay factors within the system.

b. A 60 foot accumulation conveyor before the checker (in the split main lines system) will reduce the queueing time and therefore increase output.

c. The metering belt, though important for psychological reasons (controls loading rates), acts as a restriction on the system flow.

d. The low utilization of the main line (about 50%) indicates that up to 50% of the conveyor length, and the space it occupies, could be used for other purposes in a new system configuration (i.e., extending picking lines, prechecker accumulation conveyors, etc.)

e. Higher conveyor speed will increase system output when applied to the picking conveyors, but not to other conveyors in the system.

TABLE 3.5 - SYSTEM OUTPUT (CASES PER HOUR)

<table>
<thead>
<tr>
<th>SYSTEM CONFIGURATION</th>
<th>SIMULATION MODEL</th>
<th>MATHEMATICAL* STUDY</th>
<th>MATHEMATICAL* STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Using present average</td>
<td>Size - 180 cases</td>
<td>Per order</td>
</tr>
<tr>
<td>I. Present &quot;Conveyormatic&quot;</td>
<td>2120 2220</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>a. Increased pickers accumulation conveyors (+36 ft.) and speed (+30%) one loading bay</td>
<td>2290</td>
<td>2480</td>
<td>2860</td>
</tr>
<tr>
<td>b. Add checker card reader regular speed</td>
<td>2520</td>
<td>2720</td>
<td>3280</td>
</tr>
<tr>
<td>c. Add second simultaneous loading bay and three more pickers</td>
<td>2440</td>
<td>2720</td>
<td>3000</td>
</tr>
<tr>
<td>II. Two main lines, two checkers, two stencilers, two loading bays (no card readers)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Increased speed</td>
<td>2560</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>b. Add 3 more pickers (increased speed, longer picking accumulation lines)</td>
<td>3020</td>
<td>3440</td>
<td>3660</td>
</tr>
<tr>
<td>c. Add sixth picking line other conditions same as b.</td>
<td></td>
<td></td>
<td>4750</td>
</tr>
</tbody>
</table>

* Unlike simulation, the calculated capacities in the mathematical analyses do not consider the utilization problem resulting from queueing in the system.
CHAPTER IV

CONVEYORMATIC MODEL IN REAL TIME SYSTEM

Real Time System: Control Tool

A real time system can be defined as one in which the results of the system are available in sufficient time to effect the decision-making process. This is accomplished tying the system to "live" operations. In some such systems, the decision maker is supplied with data that truly reflects the conditions as they are developing; in others, information is not presented instantaneously but is still timely enough to be useful for decision making. The latter is the type of real time system in which our model is utilized.

With computerized real time systems, it is possible to apply and utilize simulation models to ascertain the impact of various alternatives decisions before actually committing oneself (sometimes irrevocably) to a specific course of action. Several alternatives or combinations can be simulated when management is provided with a continuous flow of real time information.

Real Time: Aid to Optimization and Flexibility.

At present, the warehouse supervisor makes the manpower and resource allocation based on the programmed shipping list, has experience, subjective evaluation, and minimal manual calculations. While adequate for past operations, the changing nature of the system, the introduction of extensive modifications, and the generation of numerous alternative actions makes his experience less valuable and subject to considerable error. Without system discussed below, management will be unable to cope with the variety of situations which arise in the changing environment.

System Description:

Figure 4.1 presents schematically the real time system for order processing with the GPSS simulation model built into it. All orders received prior to order closing time will be processed through the computerized order service system and the order balance routine, to allocate jobs evenly among the existing lines. At this stage, a general retrieval package is used to edit and produce a new tape for the GPSS model in the proper "WRITE" format. This newly produced tape contains the actual job requirement for the next day showing lines, items, and quantities. This "real data" in the GPSS language is run through the system simulation program to yield the anticipated "real" performance for the next day. Actual requirement are substituted for the stochastic distributions used by the model as input in the simulation runs.
The GPSS output tape is the input of the next day operation schedule. This schedule and the comparative statistics of the "real" operations anticipated for the next day can be presented to the warehouse supervisor early enough to permit reallocation of manpower before the beginning of the working day.

The real time simulation will permit flexibility in assigning manpower (e.g., 2 pickers/line, or 1 or 2 loaders per truck) as the scheduled load requires. Based on demand the computer will be able to detail the number and allocation of crews, belt speeds, overtime, working hours, trucks required, timing of next events and overall performance before the shift begins. This will provide management with an automatic resource scheduling program of high accuracy, and increase total system flexibility in the face of demand uncertainty.

APPENDIX I

THE MATHEMATICAL ANALYSIS OF THE CONVEYOROMATIC OUTPUT

The limiting factors on the conveyoromatic System output at present is loader; however, any increase in the number of loading bays will make the system more sensitive to its input, in terms of balancing routine and order size. The system output equations represent the total output per hour based on one of the following assumptions:

(I) System output depends on Checker while pickers are not completely utilized.

(II) System output depends on picker sequence time $F(p)$ while checkers are not completely utilized.

Checker Cycle Time $= F(c) = a \cdot n \cdot s + b$  \hspace{1cm} (1)

Where: $a =$ checking rate (min/cs)

$n =$ number of lines "fired" in the cycle

$s =$ number of cases per line sequence

$b =$ cycle processing time (constant)

Picker Sequence Time $= F(p) = A \cdot s + B$  \hspace{1cm} (2)

Where: $A =$ picking rate (minutes per case)

$B =$ sequence processing time (a system constant)

The system output (cases per minute) based on assumption (I) will be:

$$N = \frac{1}{F(c)} = \frac{1}{a \cdot n \cdot s + b} \quad (3)$$

When $b \rightarrow 0$, $N_{\text{max}}$ (c) of this system approaches its maximum.

$$N = \frac{1}{a} \quad (c)_{\text{max}}. \quad (4)$$

Based on assumption (II), the system output will be:

$$N = \frac{1}{F(p)} = \frac{1}{A \cdot s + B} \quad (5)$$

When $B \rightarrow 0$, $N(p) \rightarrow N(p)_{\text{Max}}$.

$$N = \frac{n}{A} \quad (p)_{\text{max}}. \quad (6)$$

OUTPUT FUNCTIONS ANALYSIS:

FIGURE 1 presents checker and picker functions as related to their output functions. The optimal output will be defined at the intersection point, $S^*$ (if $a \cdot n \neq A$), for a fixed set of system variables $a, A, b, B, n$. At the point of intersection $N(p) = N(c)$.

$$S^* = \frac{b - B}{a \cdot n - A} \quad (7)$$
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Under the present system constraints, it is feasible to limit the system variables to the confined zone of the admissible solutions such that optimization methods can be used in order to find the best operating combination.

The following list presents the boundaries of the system variable within the range of alternatives for system improvement.

Two

One Checker \( \Rightarrow a \) (Checking rate \( \Rightarrow a_1 \) in minutes/case) System

A2

Five Pickers On Five Lines \( \Rightarrow A \) (Picking rate \( \Rightarrow A_1 \) in minutes/case)

Eight Pickers on Five Lines, Revised Balance Routine

Sixth Line Optional

5 \( \rightarrow \) n = number of lines in checker cycle \( \rightarrow 1 \)

Card reading device added

b = checker cycle processing time

B = picker sequence processing time

FIGURE 2 presents the admissible solutions for \( b, B \) and the trends of various variables within that space limit.

A separate study has been conducted to identify and analyze the various combinations of system variables and feasible system configurations. A computer program has been used to calculate the checker and picker output functions as a result of changing system variables such as order size, number of picking lines, pickers per lines, and number of checking stations. This approach, which represented basically the linear programming analysis method, has not been restricted by any cost considerations and therefore could not lead to an economical optimal solution.

FIGURE 3 presents the admissible solution areas for \( a \cdot n \) (n=5) and A. The trend of N is marked for a given set of \( b \) and \( B \).