SIMULATION OF A DISTRIBUTION CENTER (WAREHOUSE)
CENTRAL CONVEYOR SYSTEM

D. Grossman
Operations Research Department
Johnson & Johnson Corporation

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 "Conveyormatic" 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 managerially 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 Conveyormatic,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 1.1 CAPACITY REQUIREMENTS*

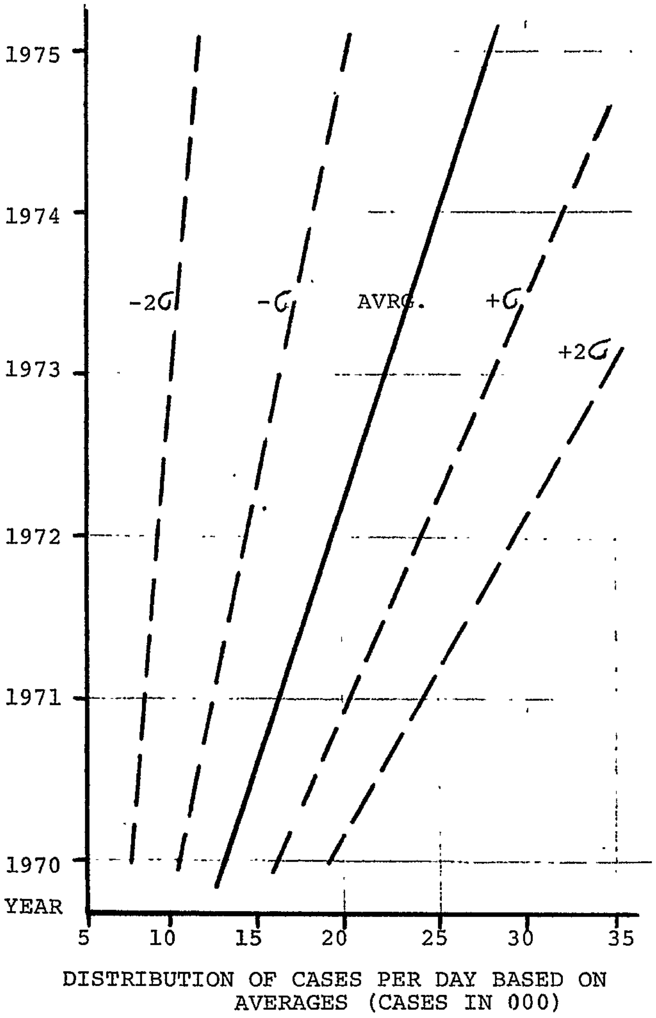
	CS/DAY	CS/HR.
1975	27,000	3440
1974	25,200	3150
1973	22,400	2800
1972	19,200	2400
1971	16,500	2060
1970 (end)	13,500	1650

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
(CS/DAY)
σ = .3x (CS/DAY)



Objectives:

The objectives have been clearly difined: To match Conveyormatic capacity to demand within the established constraints. Thus, to determine what combination of men and machinery best satisfies the expected shipping 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 conveyormatic system was developed mapping the real world. After correspondence was established the simulation 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

CONVEYORMATIC SYSTEM

The present conveyormatic system as modeled for reality studies, is represented 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, stencler, metering belf, retractable conveyors, and finally to the loader and truck.

Manning:

The conveyormatic crew requires ten employees within the four operations: assembly, checking, stenciling and loading. The present shipping system performance of 1800 cs/hr (average) requires the following allocations (table 2.2).

TABLE 2.2

Operation	Number of Employees
Line Assembler	5
Console Operator	1
Stenciler	1
Loader/Case Aligner	3

A brief description of the specific operations follows:

A. Loader/Case Aligner

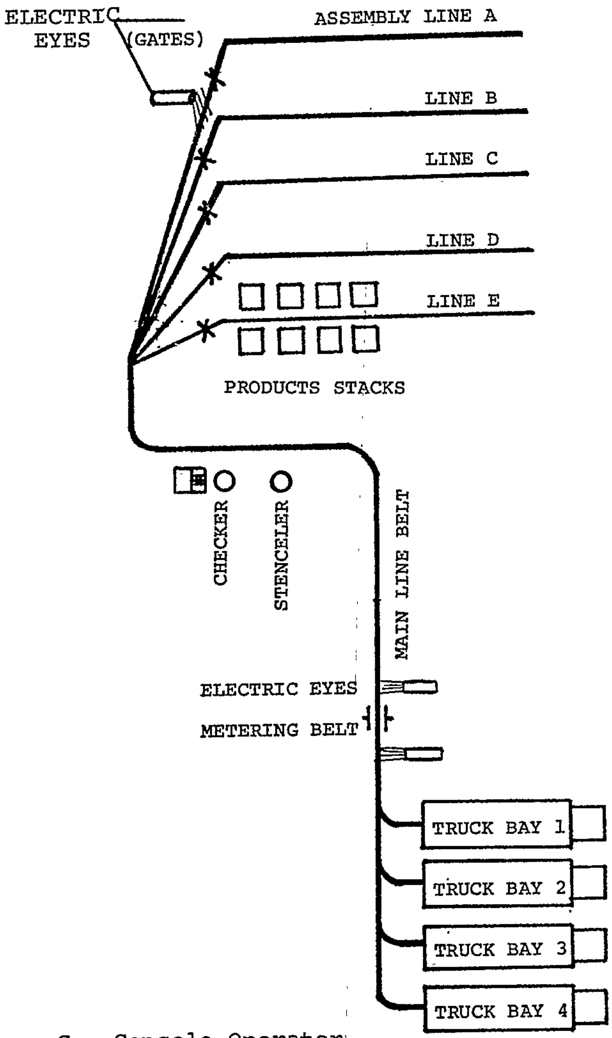
Operation Description - The three employees within this job group rotate between loading cases in the trailer and aligning cases on a platform adjacent to the metering belt. Each half hour, a trailer loader will rotate to the aligners platform. The aligner's major responsibilities are:

1. To maintain an orderly flow of cases to the trailer, breaking jams as required 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.

FIGURE 2-1 MANUMATIC SYSTEM



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 Conveyormatic 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 accomodate 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

PICKING TIMES - (Minutes)

	AVERAGE (per case)	VARIABILITY
1. pick from pallet floor	.085	± .090
2. miscellaneous P(.003)	.553	
P(.007)	.387	
P(.018)	.249	
Apply tape	.152	.015

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

TABLE 2-5

CHECKING TIMES - (Minutes)

		Avg.	Variability
Per Case	1. Check cases	.019	.003
Per Job	1. Process Job	.624	.06

STENCILER TIMES - (Minutes)

		Avg.	Variability
Per Case	Stencil Cases	.021	.003
Per Job	Process Job	.383	.038

TABLE 2-6

LOADER TIME - (Minutes)
(2 men loading)

		Avg.	Variability
Per Case	1. Load cases	.025	.008
	2. Align P(.024)	.111	.011
	3. Pick Fallen P(.005)	.260	.026
Per Job	Change job	.600	.100
	(1 man loading)		
Per Case	1. Load cases	.052	.013
	2. Align P(.024)	.120	.012
	3. Pick Fallen P(.005)	.260	.026
Per Job	Change job	.600	.100

TABLE 2-7

DOWNTIMES - (Minutes)

For crew of 5+ 1+ 1+ 3

	Probability	Value	Random #
Mechanical	.024	30 min.	.001 to .024
Paperwork	.009	15 min.	.025 to .033

TABLE 2-8

METERING SPEED

CASE LENGTH (inches)	SPEED (FPM)
0.- 4.7	25
...	..
...	..
...	..
...	..
...	..
...	..
...	..
...	..
42.4 - 47.0	70

The above tables and data reflect attributes and operations of the existing Conveyor-matic system. This data formed the basis for our model, and a measure against which correspondence could be judged. The present system configurations 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

RANDOM NUMBER GENERATOR - CASES PER JOB

(CS/JOB) Y VALUE	RANDOM # X VALUE	
51 to 100	.001 to .167	
101 to 150	...	
151 to 200	...	
201 to 250	...	continuous function to nearest whole number value
251 to 300	...	
301 to 350	...	
351 to 400	.945 to .999	

TABLE 2.10

RANDOM NUMBER GENERATOR - CASES PER ITEM

(CASES) Y VALUE	RANDOM # RANGE X VALUE	
1	.001 to .302	
2	.303 to .486	
3		
4	...	
5	...	
6	...	Step Function
7	...	
8	...	
9	...	
10	...	
11	...	
12	.931 to .950	
13 to 50	.950 to .955	Continuous Function - pick closest whole # value
150	.955 to .999	Step Function

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.

CHAPTER III

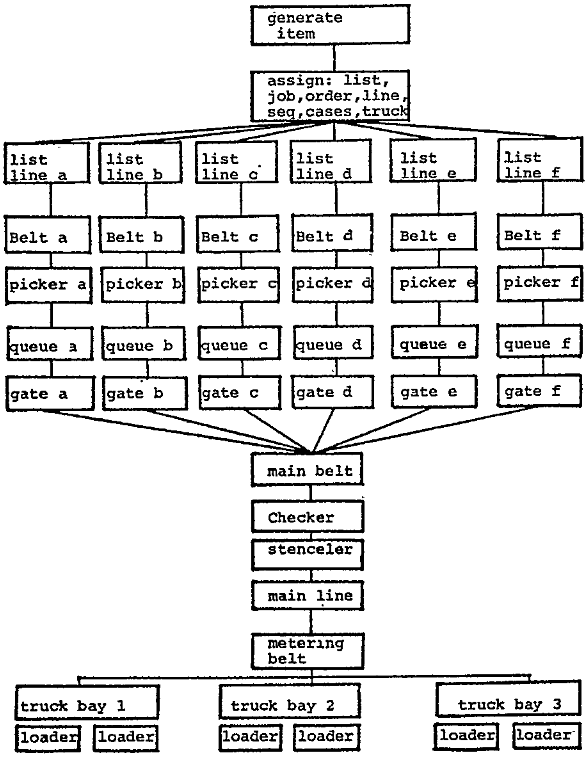
SIMULATION

Introduction:

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 ,

FIGURE 3.1 - SIMULATION FLOW DIAGRAM



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:

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

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 Conveyormatic. 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, sequence, 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 results has been dealt with in many models, and it has been shown that a GPSS model will yield exact steady state queueing 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 simulation tools available.

The validity of this particular simulation 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 feed back factors that can vary with conveyor speed, length, and the line balancing method being used.

The complexity of the system, the numerous alternatives available, and the chain of interactions within its components have given us sufficient knowledge to develop a mathematical representation of the system. (See APPENDIX 1) This approach gave us a better understanding 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 throughput of the Conveyormatic 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 sensitivity of the system to the balancing program implies that new balancing routines must be created and operational before maximum benefits of hardware changes can be realized.

One option presently available to compensate for line balancing inefficiency by increasing the accumulation length and conveyor speed to the picking lines. (See simulation results, Table 3.5) Another 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 simulation. Adding a sixth picking line will not increase the system output until several other system modifications are introduced. (See Table 3.5 and APPENDIX 1)

FIGURE 3.2 LOADER (LOADER A) UTILIZATION GRAPH

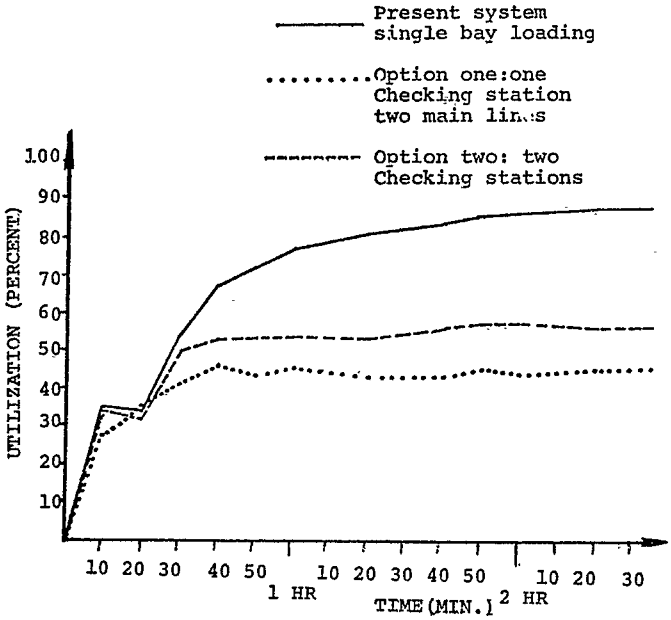
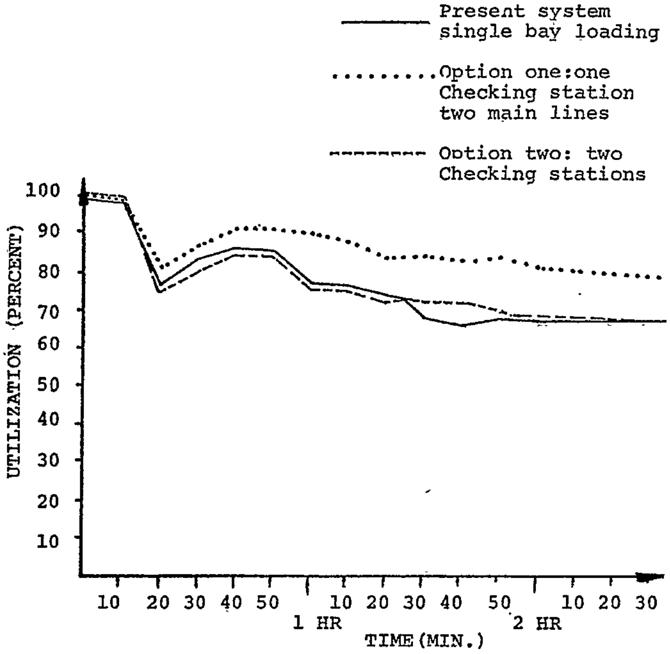


FIGURE 3.3 PICKER (PICKER A) UTILIZATION GRAPH



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)

	SYSTEM CONFIGURATION	SIMULATION MODEL	MATHEMATICAL* STUDY	MATHEMATICAL* STUDY
		Using present average Order size 70 cases Per order		Based on order Size - 180 cases Per order
1.	Present "Conveyormatic"	2120	2230	2550
	a. Increased pickers accumulation conveyors (+36 ft.) and speed (+30%) one loading bay	2220	----	----
	b. Add checker card reader regular speed	2290	2480	2860
	c. Add second simultaneous loading bay and three more pickers	2520	2720	3280
II.	Two main lines, two checkers, two stencilers, two loading bays (no card readers)	2440	2720	3000
	a. Increased speed	2560	----	----
	b. Add 3 more pickers (increased speed, longer picking accumulation lines)	3020	3440	3660
	c. Add sixth picking line other conditions same as b.			4750

* 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.

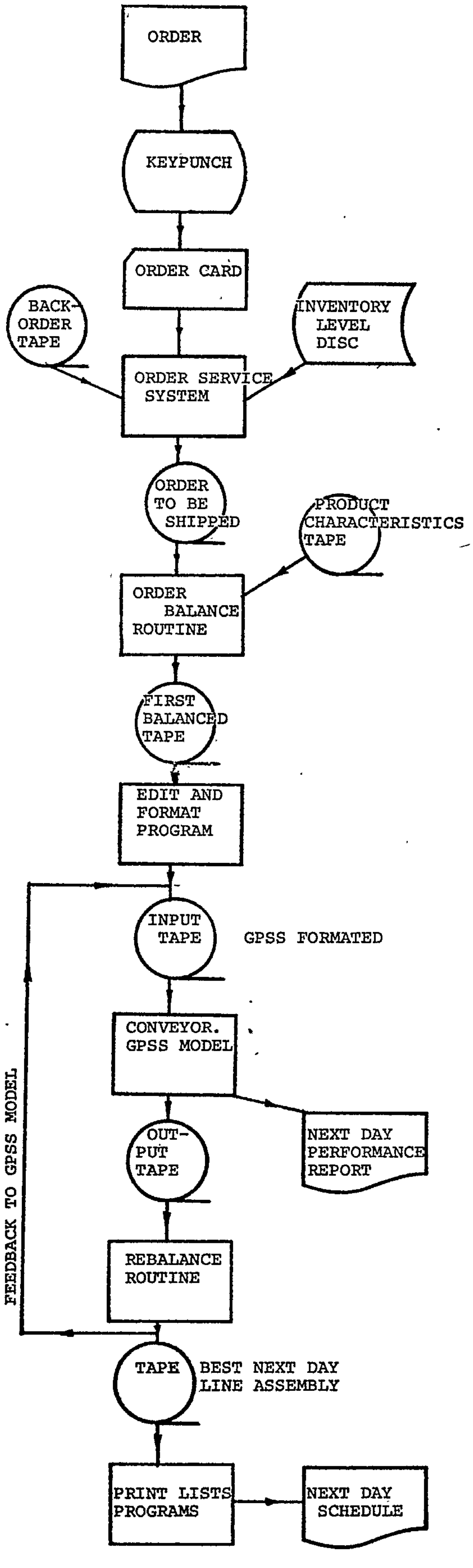
Real Time: Aid to Optimization and Flexibility.

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 changed enviornment.

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 retrivel 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.

FIGURE 4.1 - CONVEYORMATIC REAL TIME SYSTEM



The GPSS output tape is the input of the next day operation schedule. This schedule and the comperative 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, (eg. 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 1

THE MATHEMATICAL ANALYSIS OF THE CONVEYORMATIC OUTPUT

The limiting factors on the conveyormatic 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:

(1) 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.n.s+b (1)

$$F(c) = a.n.s+b \quad (1)$$

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.s+B (2)

$$F(p) = A.s+B \quad (2)$$

Where:
A = picking rate (minutes per case)
B = sequence processing time (a system constant)

The system output (cases per minute) based on assumption (1) will be:

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

When $\frac{b}{n.s} \longrightarrow 0$, $N_{(c)}$ max; i.e., the output of this system approaches its maximum.

$$N_{(c)\max.} = \frac{1}{a} \quad (4)$$

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

$$N_{(p)} = \frac{1.n.s}{F(p)} = \frac{1.n.s}{A.s+B} = \frac{1}{\frac{A}{n} + \frac{B}{n.s}} \quad (5)$$

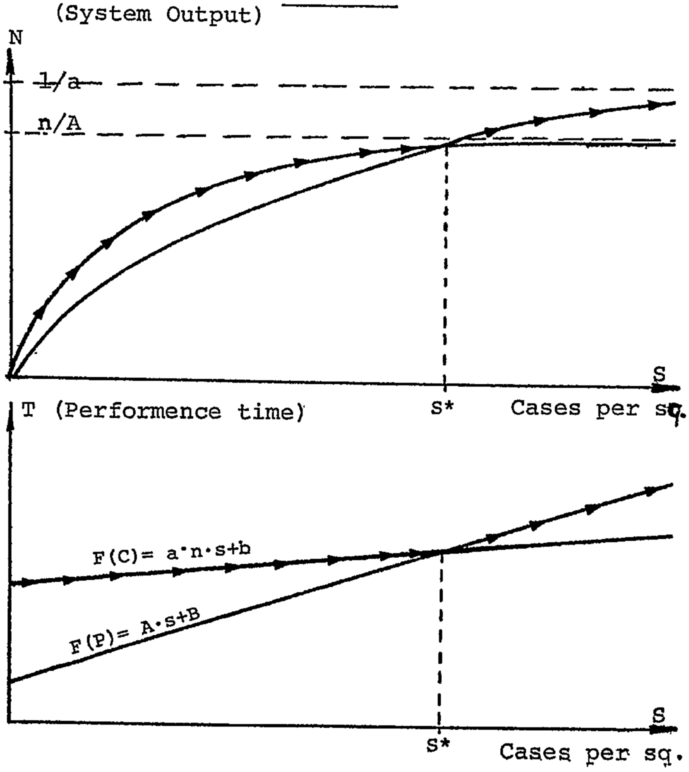
When $\frac{B}{n.s} \longrightarrow 0$, $N(p) \longrightarrow N(p)$ Max.

$$N_{(p)\max.} = \frac{n}{A} \quad (6)$$

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.n ≠ A), for a fixed set of system variables a,A, b,B, n.

FIGURE 1



At the point of intersection N(p) = N(c)

$$\therefore\ s^{*} = \frac{B - b}{a.n - A} \quad (7)$$

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.

a_2 One Checker System $\geqslant$ a (Checking rate in minutes/case) $\geqslant$ Two Checking Stations System a_1

A_2 Five Pickers On Five Lines $\geqslant$ A (Picking rate in minutes/case) $\geqslant$ Eight Pickers on Five Lines, Revised Balance Routine A_1

*Sixth Line Optional

*5 $\geqslant$ n= number of lines in checker cycle $\geqslant$ 1

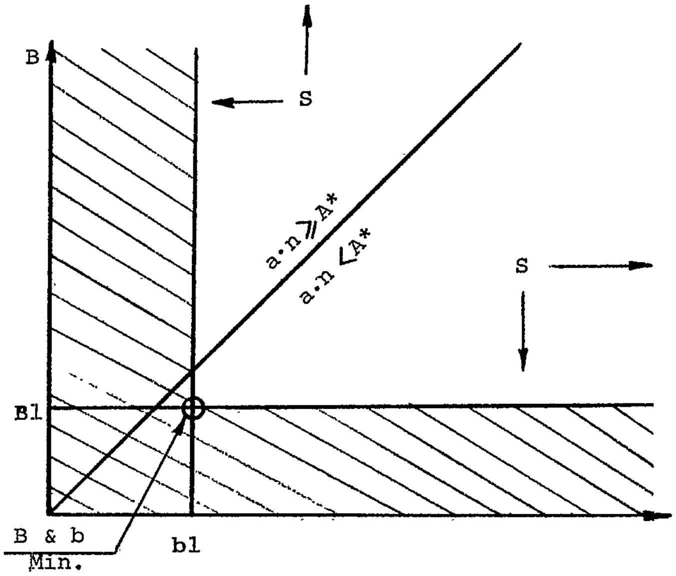
b = card reading device added checker cycle processing time $\geqslant b_1$

B = picker sequence processing time $\geqslant B_1$

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 2



*B and a·n will change signs simultaneously for positive s.

FIGURE 3

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