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DISCRETE-EVENT SIMULATION APPLIED TO APPAREL MANUFACTURING

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SUMMARY

This report presents the results of a project directed toward discrete-event simulation of apparel (specifically, trousers) manufacturing. Thus, the first major topic covered is a description of the discrete-event simulation of a utility trouser manufacturing plant. The simulation model, written in the GPSS/PC language, was validated with operating data from a large plant with a nominal production capacity of 40,000 pairs of men's denim trousers per week. Specifically, the simulation results closely agreed with key plant operating figures, such as production rate, number of work stations, work-in-process inventory and residence time in production.

This first phase of the project was then followed by the construction of another discrete-event simulation model, again using the GPSS/PC system, to explore various production scenarios in a high-technology trouser plant, with a nominal production capacity of 8,000 pairs per day. Specifically, the effects of stochasticism, deriving from human factors and represented by the normal distribution, in the various cutting and sewing operations were investigated with this second model. Effects measured included production rate, work-in-process (WIP) inventory and manufacturing residence time. Production scenarios simulated were absent workers, new employee training and the introduction of more efficient equipment.

Introduction

Simulation has been a commonly accepted engineering tool and manufacturing aid in many industries for more than thirty years now. Specifically, discrete-event simulation [1] is commonly employed by industries engaged in discrete parts or items manufacturing, e.g., machine tools, vehicles, appliances, etc. Very few applications of simulation and, particularly, of discrete-event simulation in the textile and clothing industries have been reported in the literature, however.

The manufacture of apparel, of all sorts, can be described as a sequence of parallel and consecutive discrete events, each with its own characteristic inputs, outputs and time requirements. Thus, such a manufacturing system readily lends itself to discrete-event simulation. Traditionally, the clothing industry has not been particularly noted for the development of sophisticated new technology or new manufacturing systems [2]. However, in the recent past and with the pressures of quick-response manufacturing, this industry has shown renewed interest in applications of computer-based tools to manufacturing systems. Simulation, which has been a widely used tool in other industries, has received considerable attention for its possible applications in apparel manufacturing.

To date, however, little application of discrete-event simulation in the overall textile industry (knitting/weaving, finishing, apparel manufacture) has been reported in the open literature. In one of the few known studies in this area, the General Purpose Simulation System (GPSS) was used to model and perform a discrete-event simulation of a large textile finishing mill, producing a variety of woven and knit fabrics for sheeting and men's and women's apparel [3]. This model was validated with actual mill operating data. Simulations were made to determine the effects of market demands, maintenance practices, quality control policies, and total production on equipment and manpower utilization, work-in-process (WIP) inventory, and total processing time, such as measured in any just-in-time (JIT) program. There also recently appeared a simplified application of GPSS/H to the modelling of T-shirt manufacturing {4}.

Queuing Theory

Many manufacturing processes may be viewed as a series of service operations and waiting lines (queues). Many problems of interest to engineers have to do with the formation and length of queues. For example, a bundle of back pockets (denoted as a transaction) that has passed through a hemming operation and is waiting for the next work station (facility) to become available is considered to be in a queue. Intermediate staging areas may also be viewed as queues of limited capacity. Insofar as human factors are often an element of queuing theory problems, interarrival times (between successive transactions) and processing times are frequently characterized by probability distributions, introducing a stochastic aspect.

Only a small number of queuing problems, generally of minimal size and invoking standard probability distributions, may be solved analytically [5]. Such a simple example would be a single battery of identical, parallel work stations (denoted as a storage), at which transactions arrive in a fashion characterized by the exponential probability distribution, and where the service time at any one of the identical facilities is also assumed to be exponentially distributed. When there is no analytical solution, however, or when the standard probability distributions do not reflect the actual process, engineers usually turn to simulation techniques.

Discrete-Event Simulation

Thus, discrete-event simulators were originally developed as numerical aids to solve complex queuing theory problems, not amenable to analytical solution. In such systems, state variables change only at discrete sets of points in time (as opposed to a continuous system, wherein state variables change continuously over time). Queuing problems occur routinely in the field of industrial engineering; typical examples include machine shops, materials handling facilities, customer service stations, and transportation networks.

Discrete simulators have a time clock. The proper scheduling of events in time is a formidable task and is typically implemented by the internal logic of the processor. In order to support the modelling of human or random factors, most such simulators also have one or more built-in random-number generators. Output from these latter is used to sample event times (or durations between time events) from various probability distributions, of which the simplest is the uniform or rectangular distribution. That is, an interarrival or service time can take the form a ± b, where a represents the mean value and b is the half-width, in appropriate time units, of the distribution. Empirical, user-developed distribution functions, e.g., from a plant histogram, can also be supplied by an analyst. These time distributions are clearly key inputs to the simulation model.

GPSS Processor

The progenitor of discrete-event simulation systems is GPSS [6, 7], which dates back to 1959 and is still used extensively in many manufacturing sectors. Because of its easy use, availability, reliability, and efficient operation (integer arithmetic only in many versions), GPSS is a very effective tool if only discrete simulation capability is required. Other popular discrete-event simulation systems include SIMULA [8](more prevalent in Europe) and SIMSCRIPT [9].

There are 50-60 (depending upon the version) different precoded functional subroutines, called blocks and generally written in the FORTRAN or C language, in GPSS. The transactions which move from block to block in a GPSS model have associated with them various parameters (such as priority and lifetime in the model), which can be modified by passage of the transaction through certain blocks. The capabilities of the latter vary from simple to complex.

GPSS automatically prints (and displays in the case of running GPSS on a personal computer [10]) a variety of output statistics from a discrete-event simulation. These pertain primarily to the various facilities, queues and storages in the model.

Thus, from an inspection of the facility output statistics from a GPSS simulation, an analyst might find that the average holding time per transaction for a given facility is considerably greater than the user-supplied average service time for that facility. In an apparel manufacturing application, for example, this could indicate that a sewing machine, after finishing processing of a bundle of parts (transaction), often cannot discharge the bundle because of an unavailable needed facility.

The latter might correspond to a staging area which is full or another work station which is engaged, or a human operator. The regular occurrence of such a situation would normally be accompanied by an average utilization (fraction of total time busy) approaching unity for the original upstream facility, and would suggest the existence of some downstream bottleneck. The existence of similar bottleneck situations can also be deduced from the output statistics for GPSS storages.

The output statistics for queues also represent very valuable information. Thus, high average values for a given queue length and high average waiting times per transaction would again result from some downstream bottleneck in the process being modelled. The model could then be easily and appropriately modified, perhaps by additional or more efficient downstream facilities representing proposed process modifications, as in this present study of apparel manufacturing. The productivity (number of apparel items processed or produced) of the modelled process is, of course, related to the number of transactions passing through the GPSS model.

Prior Applications

The literature abounds with example applications of GPSS to materials handling systems and discrete-parts manufacturing facilities. A number of simple examples are given in the textbook by Schriber [6], including the movement of rough castings by an overhead crane in a foundry, accommodation of oil tankers at a port, and an inventory control system. More complex applications of discrete-event simulation with GPSS - generally the subject of individual journal articles - are modelling of materials handling in the processing of oil-bearing tar sands [11], accumulating and non-accumulating conveyor systems [12], and a fleet [13] of automatic guided vehicles (AGVs).

In recent years discrete-event simulation has become an accepted design tool in chemical and allied processing. There has recently occurred an intense revival of commercial interest in batch processes, such as those employed in the manufacture of specialty chemicals, foods, pharmaceuticals, and agricultural chemicals, in the developed countries of the world. Certainly, one of the primary driving forces for this industry change has been the recent commissioning of many world-scale commodity chemical plants in various developing countries. Thus, recently published batch process applications of GPSS have included polyvinyl chloride (PVC) production [14], penicillin synthesis [15], and manufacture of choline chloride [16] - used as a nutrient in the fortification of animal and poultry feeds, as well as a sequence of multicomponent batch distillation columns [17], as in a solvent recovery operation. A brief summary of these and other process applications of GPSS has recently been published [18], as well as a tutorial article [19] on the subject.

Thus, the objective of the first phase of this project was to develop a validated simulation of a typical size utility trouser manufacturing plant, to serve as a tool for evaluating new technologies and manufacturing methods. Such an application, with its plant input being the output of a textile finishing mill, is a natural extension of the prior work described above. This model, written in the GPSS/PC language, includes all of the major machine operations in an apparel plant, such as cutting, 2-dimensional subassembly and 3-dimensional joining, as well as representing the various labor pools. Such a model also permits ready extension of operating data from a demonstration phase, for example, to a full-scale plant.

Utility Trouser Plant Configuration

The facility chosen for simulation and model validation in this work is a large traditional plant manufacturing men's utility denim trousers. It has a nominal production capacity of 40,000 pairs of trousers per week, but has operated at times in excess of 43,000 pairs/week. There are 37 identifiable operations in this process, occurring at 250-300 work stations, all of which require manual attendance. The various joining and assembly operations are performed with either Juki or Singer sewing machines. The plant operates on a single (day) shift for a total of 40 hours/week. Plant input is 62,000 yards of fabric (either 100% cotton or 65-35 polycotton) per week, and at any time it is estimated that there are 1-2 weeks of production in the plant as WIP inventory.

The material flow configuration for this trouser plant is shown as Figure 1. Associated with this figure is Table I, which identifies the various operations and is organized into segments in the same fashion as the GPSS model (to be discussed later). In addition to identifying the various operations indicated in Figure 1, this table also shows the GPSS name, number of work stations (N), unit processing time (t, minutes/pair) and average processing time (t/N, minutes) for each operation.

This trouser manufacturing operation begins with the spreading of fabric rolls on large tables (25 yards long). Anywhere from 120 to 200 plies (depending upon the fabric) are spread, prior to cutting of the various parts according to the marker. The individual parts are then labelled and collected into bundles of 40, after which they are carried to their various respective work stations. These above operations comprise the first model segment.

Model segment 2 consists of back pockets fabrication, beginning with hemming and followed by clip-stitching, buttonhole making and creasing. This second segment is then merged into the third segment, representing back panel assembly. This latter segment commences with sewing of labels onto the cut and marked back panels. This is then followed by sewing of darts,

Figure 1
Material flow configuration
for trouser manufacturing
plant

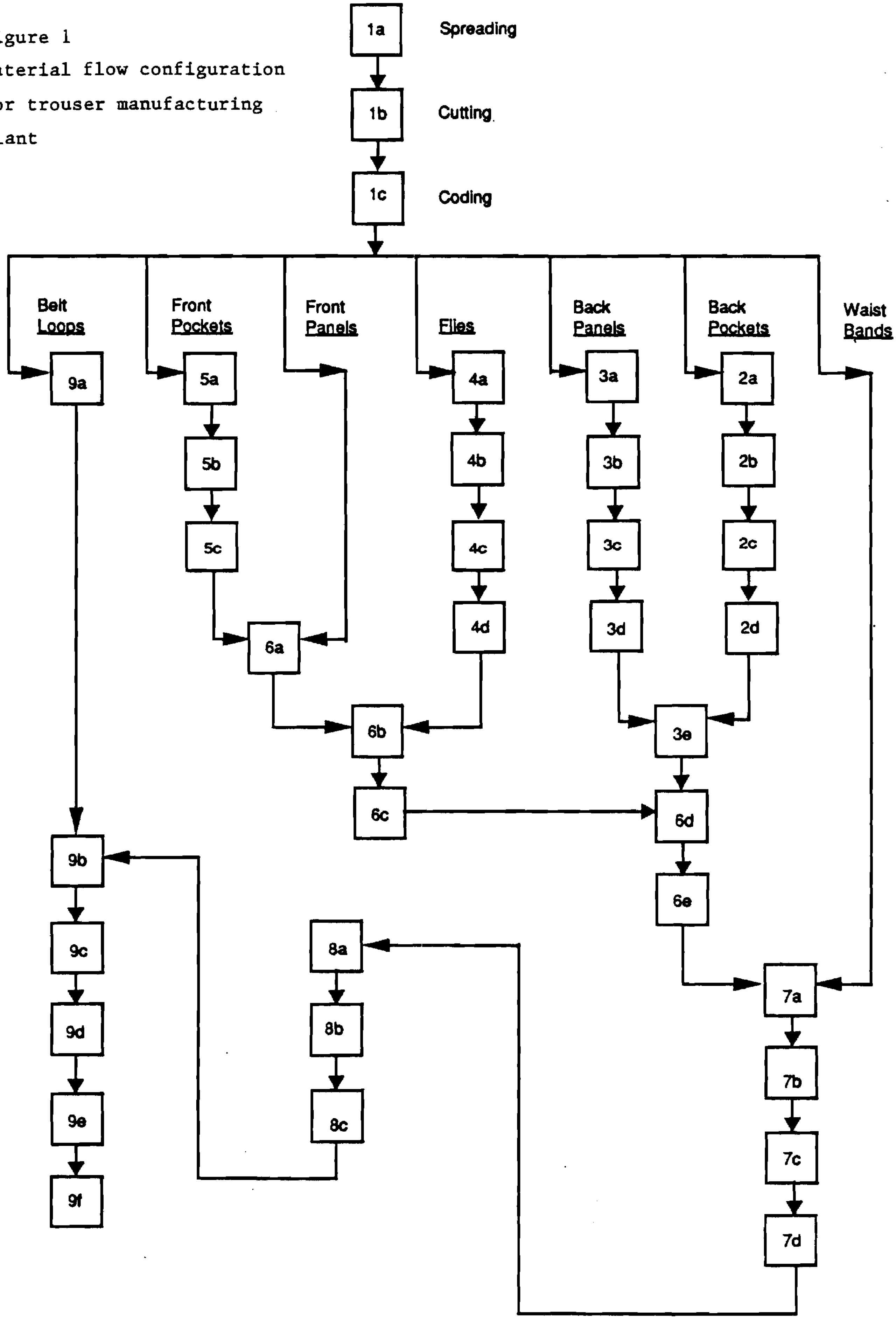


Table I

Work Stations in Utility Trouser Manufacturing Plant

Station No.	Operation	GPSS Name	No. of Work Stations (N)	Unit Proc. Time (t), min/pair	Avg. Proc. Time (t/N), min
	Model Segment 1 - - Spreading and Cutting				
1a	Spread fabric roll	SPRED	4	0.1875	0.0469
1b	Cut various pieces	CUTTR	11	0.625	0.0568
1c	Mark cut plies	CODER	14	0.8125	0.0580
	Model Segment 2 – Back Pockets				
2a	Hem back pockets	BHEM	3	0.167	0.0557
2b	Clip-stitch back pockets	CLIP	2	0.087	0.0435
2c	Buttonhole back pockets	BHOL	3	0.154	0.0513
2d	Crease back pockets	CRSE	4	0.240	0.0600
	(Joined with back panels in 3, FBACK)				
	Model Segment 3 – Back Panels				
3a	Sew back label	BLAB	3	0.167	0.0557
3b	Sew darts on back panels	DARTS	4	0.202	0.0505
3c	Topstitch darts	TOPS	4	0.197	0.0493
3d	Sew buttons on back panels	SBTN	3	0.147	0.0490
	(Joined with back pockets from 2, FBACK)				
3e	Attach back pockets	ABP	13	0.753	0.0579
	(Joined with finished fronts in 6, FBKS)				
	Model Segment 4 – Right and Left Flies				
4a	Make zipper	MFLY	1	0.043	0.0430
4b	Set zipper on left fly	LFLY	4	0.197	0.0493
4c	Topstitch fly	TOPF	5	0.274	0.0548
4d	Set zipper on right fly	RFLY	5	0.270	0.0540
	(Joined with finished front pockets and panels in 6, FRNT)				

Table I (continued)

Station No.	Operation	GPSS Name	No. of Work Stations (N)	Unit Proc. Time (t), min/pair	Avg. Proc. Time (t/N), min
	Model Segment 5 – Front Pockets				
5a	Hem front pockets	FHEM	3	0.167	0.0557
5b	Clip-stitch front pockets	STCH	2	0.087	0.0435
5c	Crease front pockets	CRPC	4	0.240	0.0600
	(Joined with front panels in 6, FPANL)				
	Model Segment 6 – Front Panels and Pockets				
	(Joined with front pockets from 5, FPANL)				
6a	Stitch front pockets on panels	FPOC	13	0.753	0.0579
	(Joined with finished flies from 4, FRNT)				
6b	Set left fly	SETL	7	0.404	0.0577
6c	Set right fly	SETR	7	0.376	0.0537
	(Joined with finished back pockets and panels from 3, FBKS)				
6d	Sew side seams	SEAM	11	0.635	0.0577
6e	Sew seat seam	SEAT	5	0.287	0.0574
	(Joined with waist bands in 7, BNDS)				
	Model Segment 7 – Waist Bands				
	(Joined with finished fronts and backs from 6, BNDS)				
7a	Attach waist bands	AWB	11	0.653	0.0594
7b	Attach button flys to bands	BFLY	3	0.177	0.0590
7c	Close band ends	BEND	13	0.780	0.0600
7d	Set slide stops on zipper	SLDE	7	0.392	0.0560
	(Moved to fronts and backs in 8, COMBN)				

Table I (continued)

Station No.	Operation	GPSS Name	No. of Work Stations (N)	Unit Proc. Time (t), min/pair	Avg. Proc. Time (t/N), min
	Model Segment 8 – Front and Backs				
8a	Join fronts	JOINT	6	0.349	0.0582
8b	Sew inseam	INS	12	0.674	0.0562
8c	Buttonhole waist band	BUTB	4	0.201	0.0503
	(Joined with belt loops in 9, FEVRY)				
	Model Segment 9 – Belt Loops				
9a	Make belt loops	LUPS	2	0.077	0.0385
	(Joined with finished fronts and backs from 8, FEVRY)				
9b	Attach belt loops	ALUP	22	1.293	0.0588
9c	Sew labels on	SLAB	5	0.295	0.0590
9d	Press and fold	FOLD	11	0.619	0.0563
9e	Top press trousers	PRES	5	0.274	0.0548
9f	Inspect and fold	INSP	19	1.097	0.0577
	Total no. of work stations		255		

topstitching of the darts and sewing of buttons onto the back panels, before merger with the finished back pockets from the second segment. Segment 3 continues on with attachment of the back pockets to the back panels, before being merged with finished front panels and pockets in model segment 6 (to be discussed later).

Fly making occurs at the beginning of model segment 4. After the initial step of zipper making, the latter is set onto the left fly. After topstitching, the zipper is set onto the right fly, before joining with finished front pockets and panels from segment 6. Front pocket assembly occurs in model segment 5. Here, the cut and marked front pockets are, just as in the case of the back pockets, hemmed, clip-stitched and creased (obviously no buttonhole in this case). Segment 5 concludes with the assembly of the finished front pockets with the cut and marked front panels from segment 6.

The first step in model segment 6 consists of stitching the finished front pockets from segment 5 onto the front panels. After setting of left and right flies from segment 4, the completed front panels join up with completed back panels from segment 3. The sewing of side and seat seams then constitutes the last steps of model segment 6, before moving on to segment 7.

In model segment 7, the cut and marked waist bands are first joined with the finished and assembled back and front panels from the sixth segment. There follows attachment of the waist bands to the back panels, button fly attachment, closing of the waist band ends and installation of slide stops on the zipper. The finished backs then move on to model segment 8, which consists of joining of the fronts, sewing the inseam and buttonholing the waist band. The nearly finished trousers then move on to the last manufacturing segment (9).

Belt loops are first made in this last segment. The remainder of this latter segment consists of the various finishing operations in this plant. These begin with attachment of the belt loops and sewing on labels, followed by pressing and folding. The last two manufacturing steps are top pressing and then inspection and folding. The finished trouser products are then ready for shipment.

The division of this utility trouser manufacturing facility into the nine segments described above is clearly arbitrary. This particular division was selected so as to facilitate coding of the GPSS model of this plant, as described below. Certainly, other valid divisions of this plant could be conceived, so long as the materials flow configuration remains correct.

Preliminary Modeling Considerations

This model of a trouser plant was coded with the Industrial Version (as opposed to the Student Version) of GPSS/PC, supplied by Minuteman Software of Stow, Massachusetts. The various simulations were run on an IBM PS/2, Model 50 PC with 1000K of RAM (core memory). In principle, this Version of GPSS/PC can be run on any IBM-compatible PC with only 320K of core memory, but considerably longer run times result (most of the simulations reported in this work ran for less than 10 minutes). More significantly, however, a lower core memory availability would gravely exacerbate the transaction storage problems encountered in this work and discussed below.

One of the first decisions to be made in any GPSS simulation pertains to the size of the transactions passing through the model. A transaction size of one production unit, i.e., one pair of trousers, would be ludicrously small in modelling of a plant producing 40,000 pairs of trouser per week, and in which there are 1-2 weeks of WIP inventory. It was originally hoped to define a transaction size as 40 pairs or parts (the various incomplete parts must also be represented as separate transactions) in this model, corresponding to the bundle size employed in this particular plant. It was found, however, that with the slightest imbalance in the model, e.g., as a result of overfeeding from the spreading and cutting operations, computer core memory was rapidly exhausted as the simulation proceeded. Specifically, with the 1000K PC, core memory became depleted whenever the total number of transactions in the model exceeded approximately 1500. This problem is not inherent with GPSS/PC. The same difficulty was encountered in the earlier GPSS simulation of a textile finishing mill [3], which was run on a Control Data Corporation Cyber 855 mainframe computer. Hence, the transaction size in this present work was increased to 160, corresponding to four bundles, which was found to be satisfactory in all of the simulations. This value also corresponds to the average number of plies spread and cut in one such operation in this plant.

Having defined the transaction size, it remained to decide upon the elementary time unit for the simulations. This quantity must be an integer, representing the smallest value into which any processing time can be divided. Table I shows that the unit processing times for each operation are in minutes/pair, to three or four decimal places. It was thus decided to employ 0.01 minute as the elementary time step in these GPSS simulations. That is, 100 time units in the simulation corresponded to one minute of real plant operation. With this decision and the prior definition of one transaction as representing 160 identical parts or pairs, the various unit processing times in Table I were all multiplied by 100 x 160 = 16,000 for model coding purposes. Thus, for example, the unit processing time of 0.167 minute for hemming of back pockets became equal to 2672 GPSS time units in the model.

All GPSS simulations begin from a cold start; that is, initially (time = 0) there are no transactions at all (either in the various work stations or in the upstream queues) in the model. This situation may be appropriate in some cases, but certainly not in this present instance, where WIP inventory is typically left in place at the end of each working day or shift. Thus, it often becomes necessary in GPSS simulations to first run the model for a brief startup period, and then clear all of the output statistics and reset the clock back to zero, before running the model again. The objective here is to start the simulation from a representative steady-state initial condition (known as a hot start). This procedure is easily implemented in GPSS/PC; the startup period, needed to fill up the subject model with transactions at various locations, is typically much less than the duration of the simulation from a hot start. Based upon the prior estimate of 1-2 weeks of production in this plant as WIP inventory, the duration of the startup period in this work was selected as two weeks. Simulations were then run for four weeks or more of plant time after this startup period, in order to obtain representative statistical output.

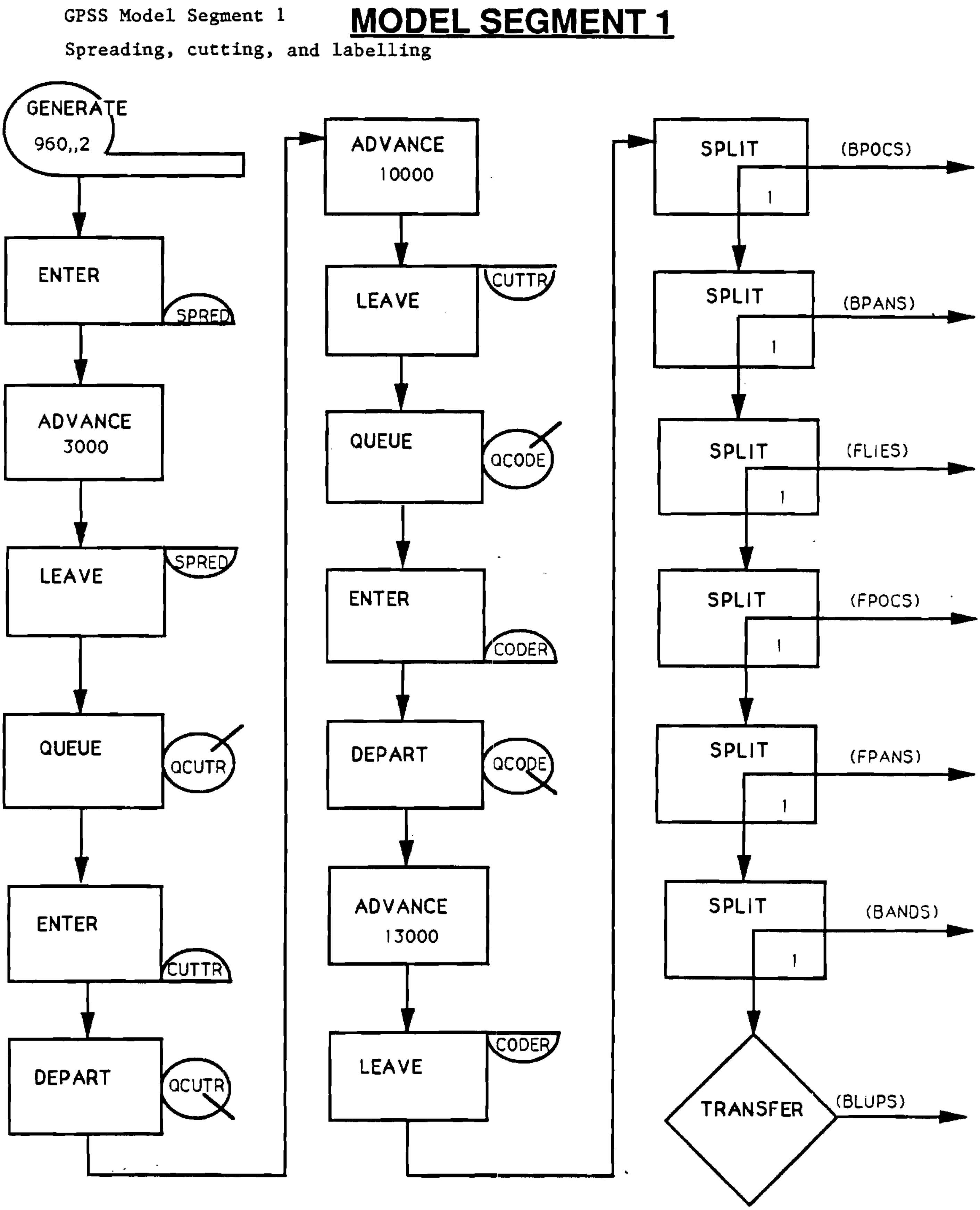
Utility Trouser Plant Model

This GPSS model of a utility trouser plant closely follows the configuration summarized in Figure 1 and Table I. Thus in model segment 1, depicted in Figure 2, the starting GENERATE block supplies enough rolled fabric for 160 pairs of trousers or one transaction. The first (and only) operand or argument of this block represents the interarrival time between successive batches of feed fabric to the initial spreading operation, and thus regulates the feed rate to this plant. For example, at a nominal

Figure 2

GPSS Model Segment 1

Spreading, cutting, and labelling



(balanced) production rate of 40,000 pairs/week or 16.7 pairs/min, this interarrival time between successive transactions (of 160 pairs each) would be 9.6 minutes or 960 GPSS time units. Values less than the latter value for this operand would correspond to overfeeding of this plant, and larger values to underfeeding.

Each new transaction from the GENERATE block then attempts to engage one of the four spreading work stations (ENTER SPRED), after successful completion of which it passes on to the cutting and ply marking operations. There then follows a series of six SPLIT blocks, each of which creates a daughter transaction representing cut parts (back pockets, front panels, waist bands, etc) to be sent off to their respective work stations in other model segments. After execution of these SPLIT blocks, the parent transaction is unconditionally transferred to the last manufacturing segment (9, belt loops) in this model.

In Figure 2, there is twice observed the occurrence of the following sequence of blocks:

QUEUE

ENTER

DEPART

ADVANCE

LEAVE

These two sequences in Figure 2 specifically pertain to the cutting and ply marking operations, respectively. The QUEUE block and its inverse (DEPART block) are needed here to collect queuing or waiting time statistics from the simulation. A similar sequence of these five blocks is also needed for each of the other 34 operations in this plant. Thus, for purposes of brevity in presentation, it became convenient to define a conceptual macro block, denoted by QEDAL (from the first letter of each of the above five blocks), representing this sequence. This definition is illustrated in Figure 3, showing the compression of this sequence into one QEDAL macro block, as it appears in succeeding model segments. The convention most often adopted here was to restrict the GPSS name of a given work station to four alphabetic characters, and to denote the associated upstream queue by the same four letters prefixed by the letter Q. Thus, in model segment 2, for example, one has BHEM and QBHEM, respectively.

Each of the succeeding seven manufacturing segments begins with an ADVANCE block, labelled in accordance with the segment function. An operand for these ADVANCE blocks could be used to simulate the transportation time lag to deliver one transaction (or 160 parts) to the first work station in each segment. Such time lags were not incorporated into this model, inasmuch as no plant data were available on this subject. Model segment 2 in Figure 4 thus commences with an ADVANCE block labelled BPOCS, which is then succeeded by four QEDAL sequences corresponding to the four work

Figure 3: Definition of conceptual QEDAL macro block representing the sequence: QUEUE - ENTER - DEPART - ADVANCE - LEAVE blocks

QEDAL SEQUENCE

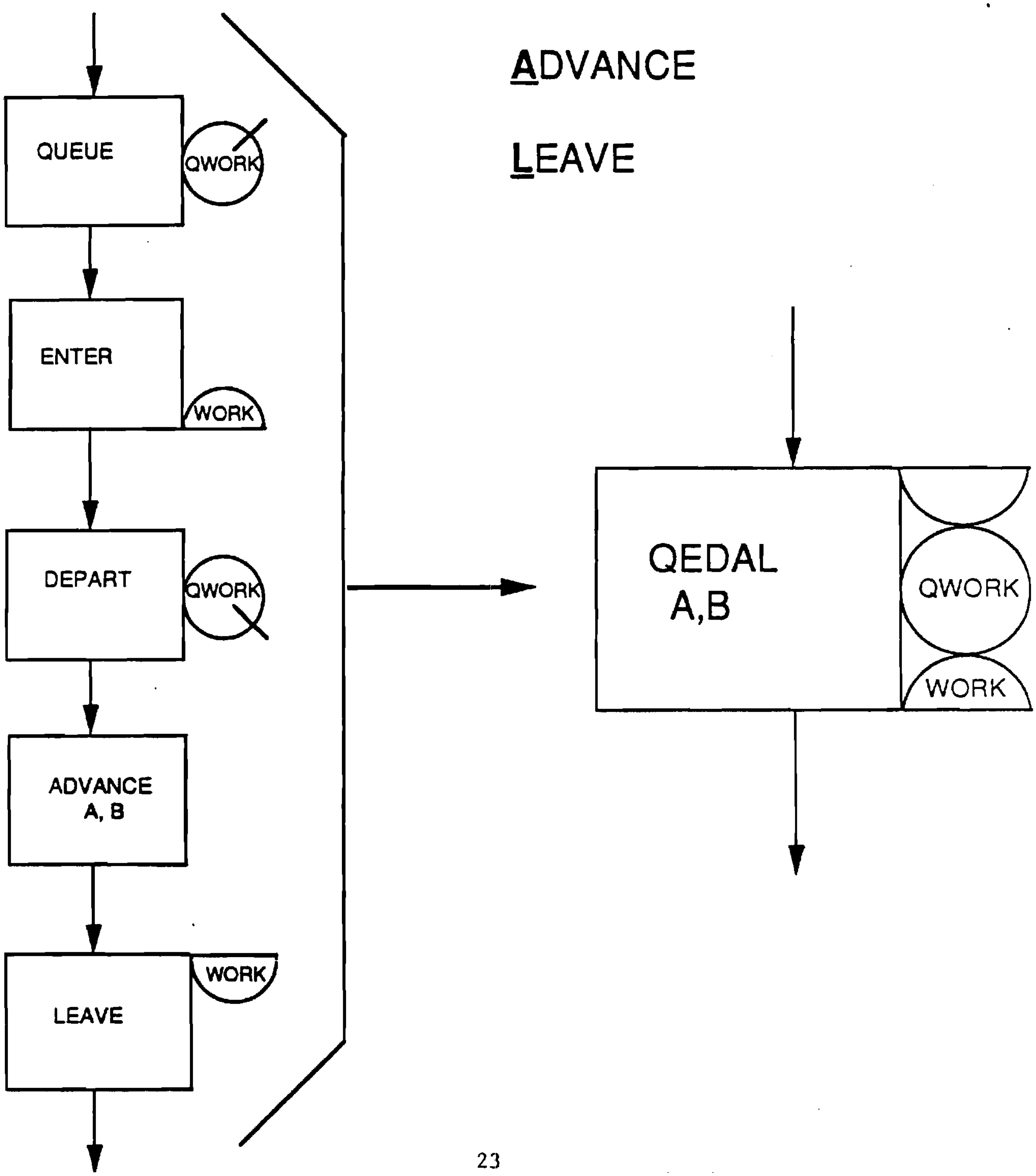
QUEUE

ENTER

DEPART

ADVANCE

LEAVE

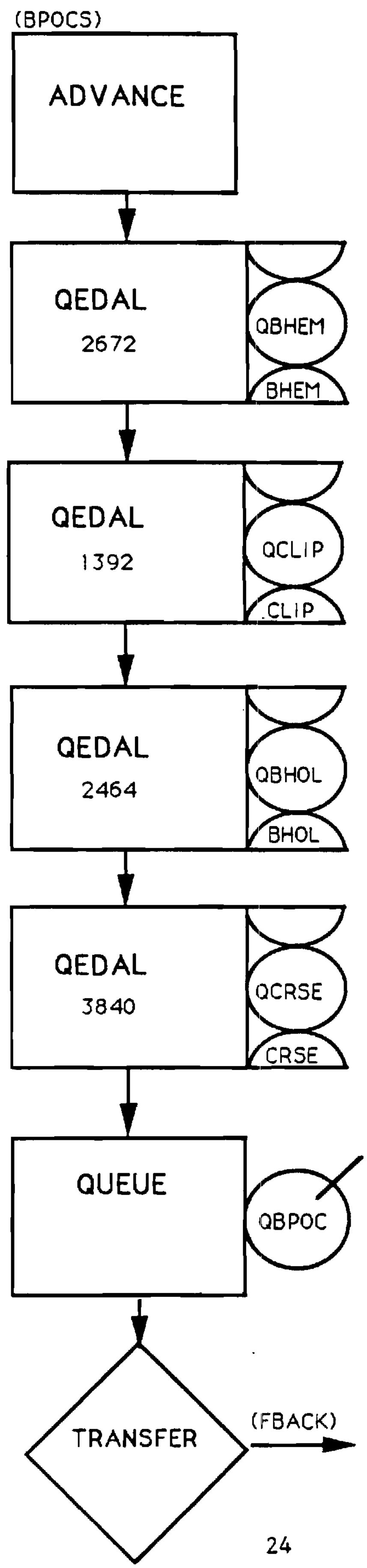


MODEL SEGMENT 2

Figure 4

GPSS Model Segment 2

Back pockets



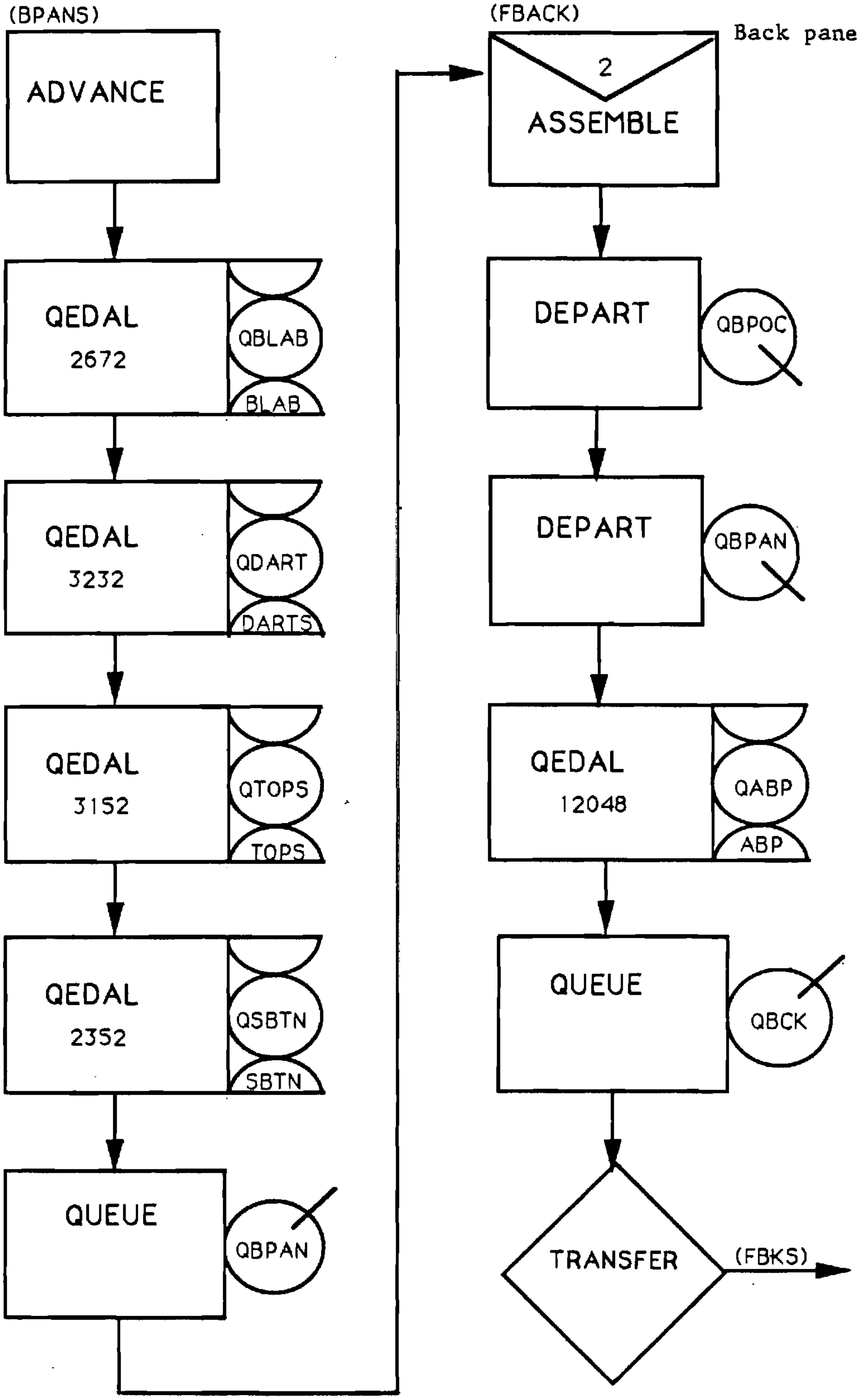
station operations in this segment (see Table I).

In addition to queuing statistics for each work station, it was also desired to collect such statistics from these simulations on any time that finished or partly finished parts spent waiting to be joined with other parts. Thus, before any such joining or matching operation, each transaction was routed through a QUEUE block for this purpose. The corresponding DEPART block, denoting exit from the waiting line, was executed only after all necessary parts had been collected before moving onto the next work station. Thus, in model segment 2, for example, a QUEUE block named QBPOC is placed immediately after the four work stations. The transaction is then transferred unconditionally to model segment 3 (FBACK) to be joined with a matching transaction therein.

Model segment 3 in Figure 5 begins with the ADVANCE block labelled FBACK, followed also by four QEDAL sequences representing the work stations in this segment. A leaving transaction (denoting 160 pairs of partially finished back panels in this case) then moves into the QUEUE block named QBPAN, whose function is to collect statistics on any time that these partially finished back panels spend waiting for finished back pockets (from model segment 2). The following ASSEMBLE block then joins a transaction of partially finished back panels with a transaction of finished back pockets. The latter transaction is destroyed in this joining process, and thus the total transaction count resident in the model

MODEL SEGMENT 3

Figure 5
GPSS Model Segment 3
Back panels



is reduced. Model segment 3 then concludes with attachment of back pockets (again denoted by a QEDAL sequence), before unconditional transfer to model segment 6 (front panels and pockets).

The four work station operations comprising fly making constitute model segment 4 in Figure 6. The finished flies then join with finished front panels from model segment 6. Similarly, model segment 5 consists of the three work stations employed to form front pockets, before being merged into model segment 6.

This latter segment (see Figure 7) really begins with the merger (FPANL) of cut front panels and finished front pockets. After stitching of the latter onto the former, the merger with finished flies (FRNT) occurs. Model segment 6 then continues with the two fly setting operations, before merging again -- this time with finished back panels and pockets from segment 3. The surviving transactions of model segment 6 continue on through the last two sewing operations of this segment, before being merged into the waist band segment (BNDS).

In model segment 7, shown in Figure 8, waist bands directly from the ply marking step collect finished front and back panels from segment 6, before proceeding through the four work stations associated with waist band attachment. These transactions then move on directly to model segment 8 and its joining operations, before transferring unconditionally to the last manufacturing segment.

Figure 6: GPSS Model Segment 4 (Right and left flies)

GPSS Model Segment 5 (Front pockets)

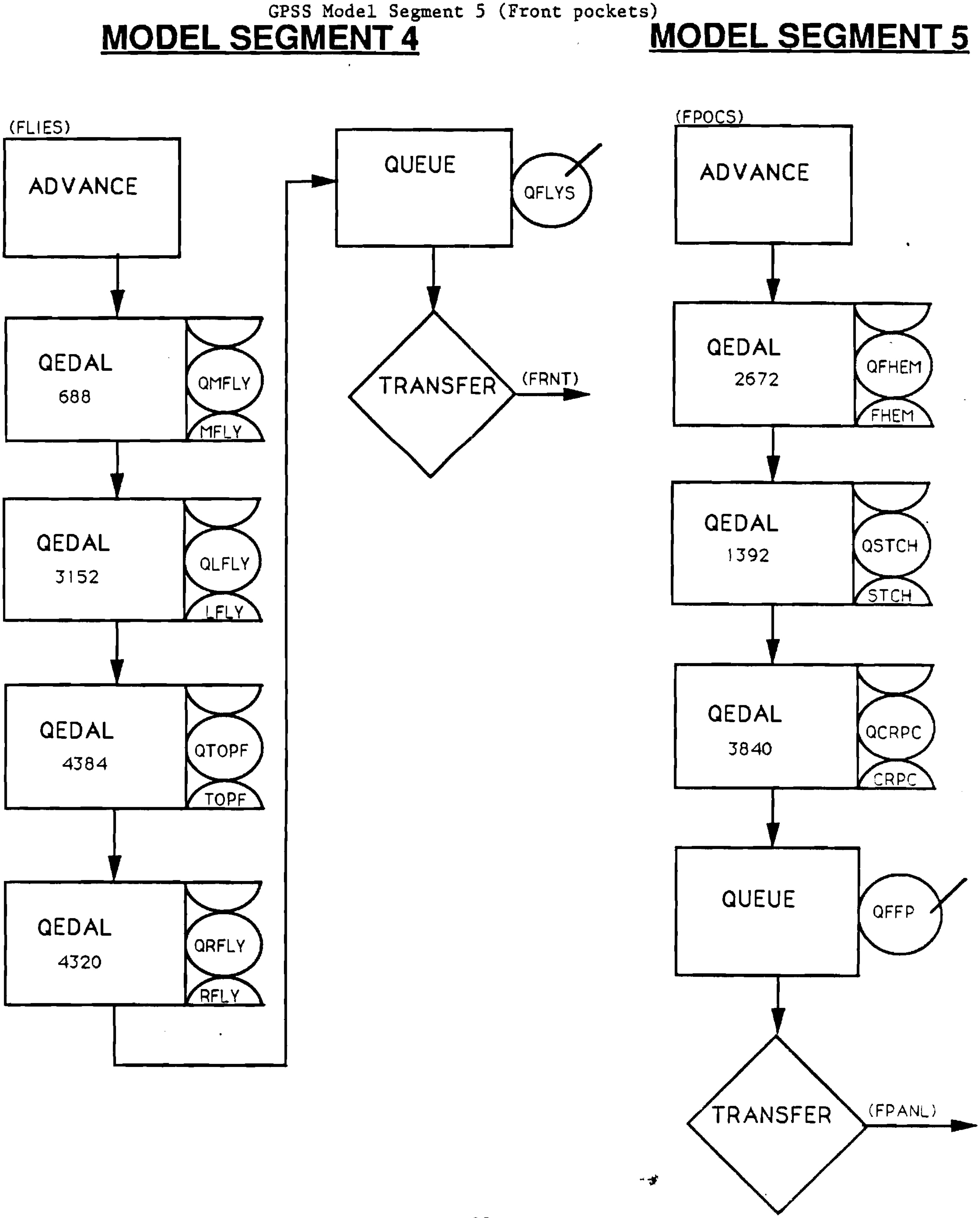


Figure 6

GPSS Model Segment 6

Front panels and pockets

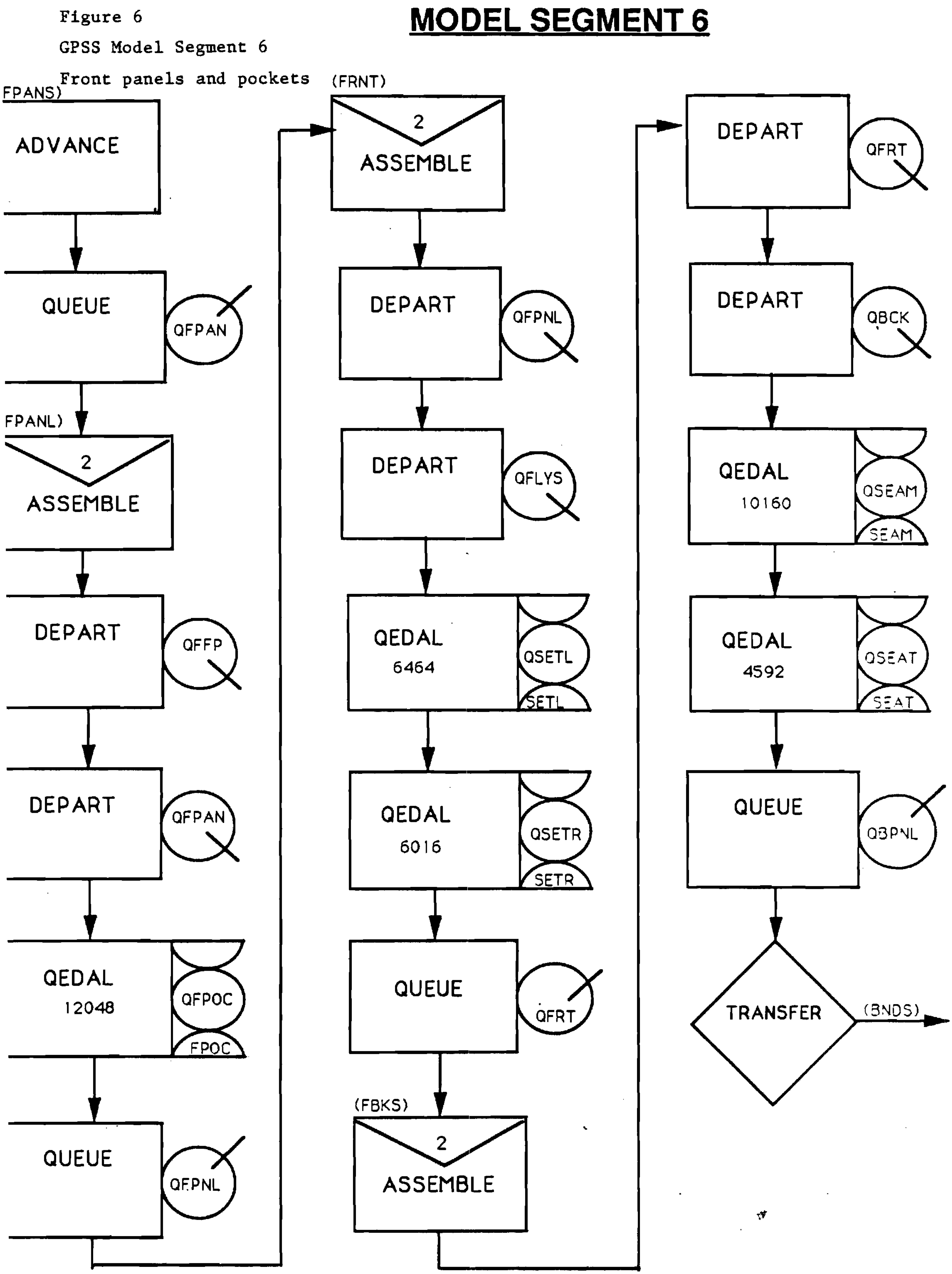
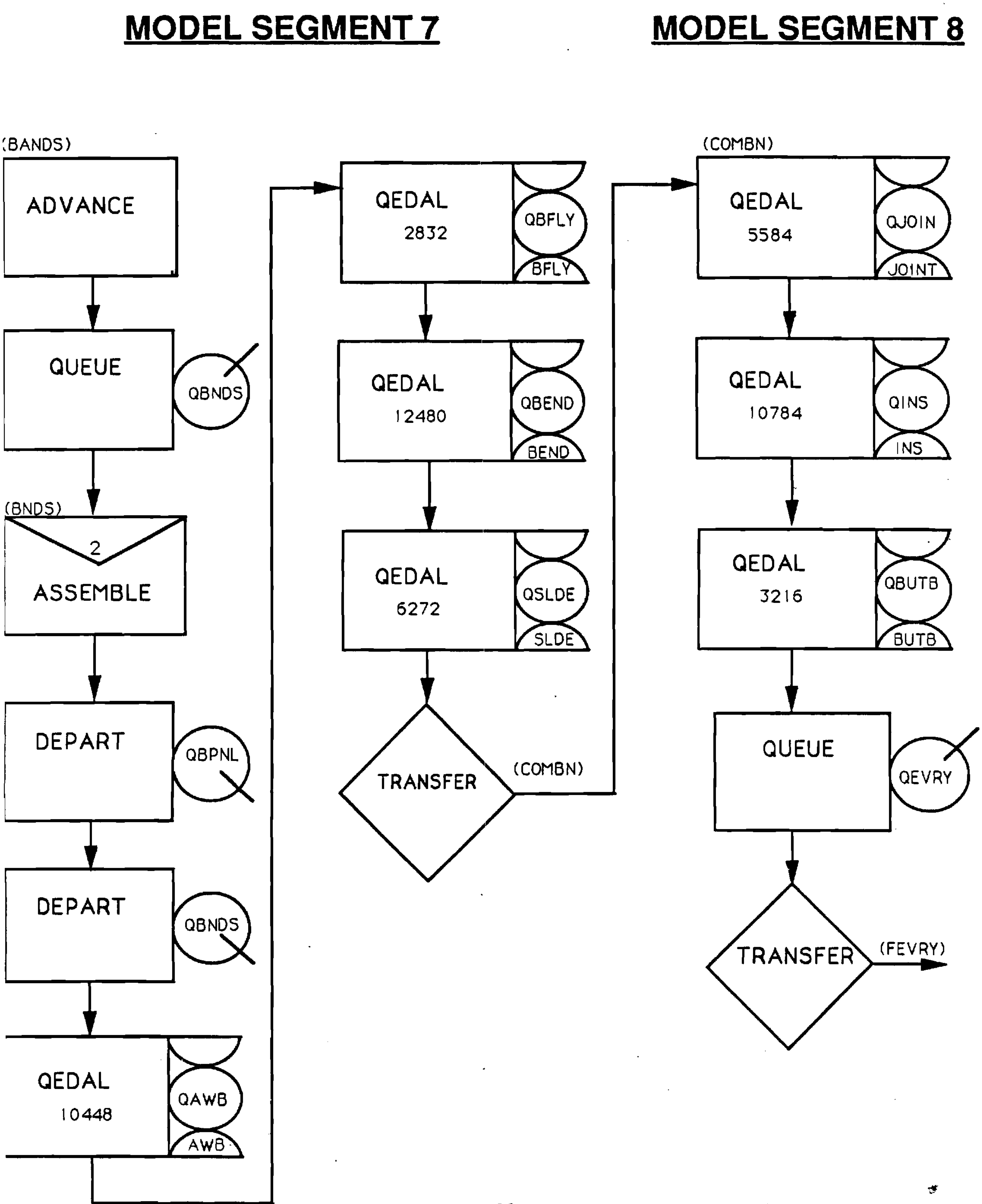


Figure 8: GPSS Model Segment 7 (Waist bands)
GPSS Model Segment 8 (Fronts and backs)



Belt loops are first made in model segment 9, shown in Figure 9. These then merge with the joined fronts and backs from segment 8. The various finishing operations (e.g., pressing, inspection, folding) then conclude model segment 9. After leaving the last inspection station, transactions (here representing finished pairs of trousers) first pass through a TABULATE block named JIT, wherein the total manufacturing time for each transaction is tallied. A transaction then exits the model through the TERMINATE block ending model segment 9. A count of the total number of transactions passing through this last block gives the total production over the duration of a simulation.

Also shown in Figure 9 is the timer for regulating the duration of a simulation -- model segment 10. It consists simply of a GENERATE block followed by a TERMINATE block. The value of the (first and only) operand for this GENERATE block is set equal to 48,000, which is the number of GPSS time units (0.01 minute) in one 8-hr day of operation. The duration of a startup period or of a succeeding simulation was then regulated by the integer value of the A operand in the START control statement for each run. Thus, a value of 10 for this START operand would set the duration of a startup period or production simulation to be 10 days.

The complete GPSS coding for this discrete-event simulation model of an operating utility trouser manufacturing plant is provided in Appendix A.

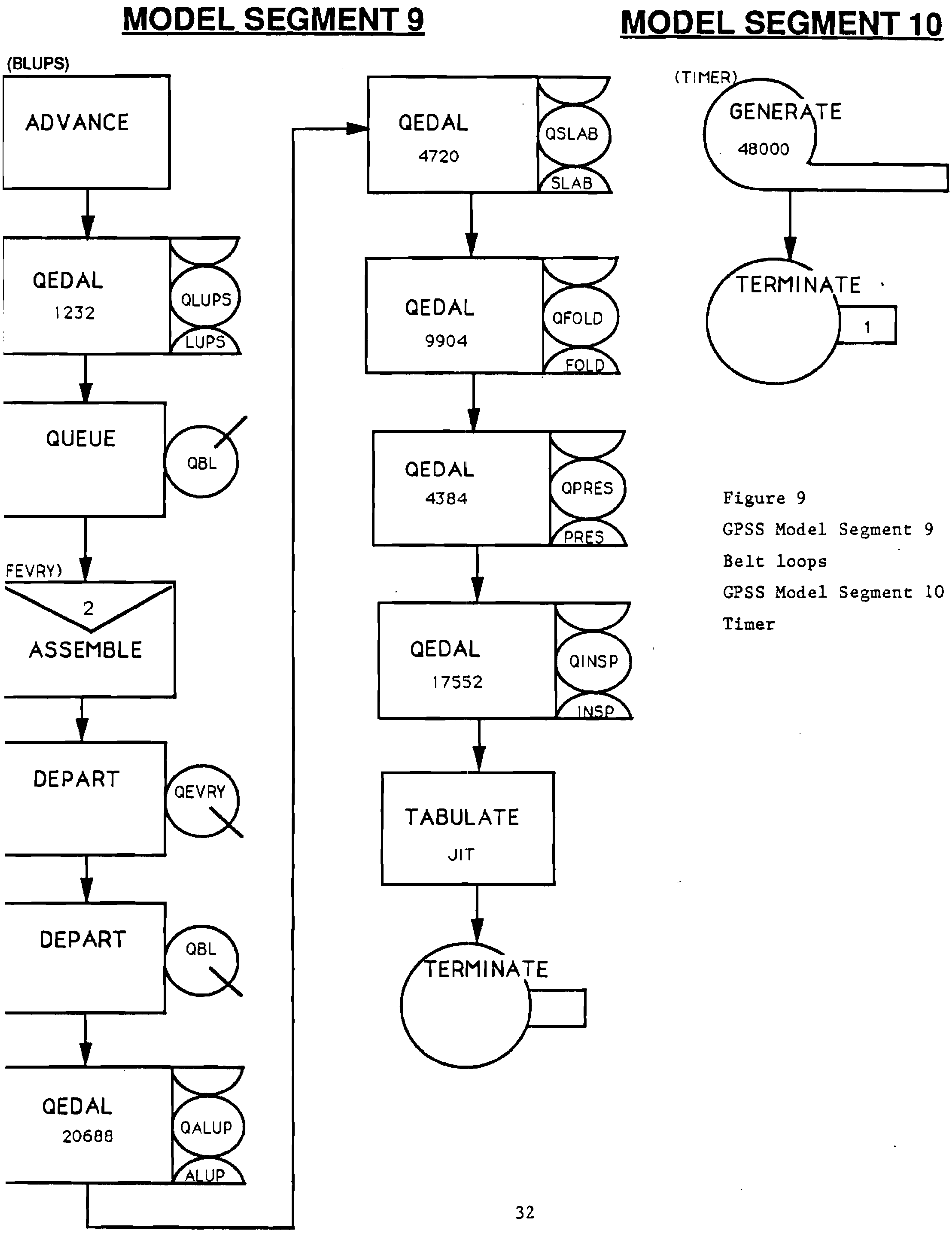


Figure 9

GPSS Model Segment 9

Belt loops

GPSS Model Segment 10

Timer

Simulation Results from Utility Trouser Plant Model

As noted earlier, the nominal production capacity of the subject plant is 40,000 pairs of trousers per week. Hence, on the basis of 40 operating hours per week, the maximum average time that can be allotted to the manufacture of any one part for a pair of trousers is 0.06 minute. This plant model was thus configured (e.g., number of individual work stations) so that the average processing time for each operation was no greater than this value. This average processing time was obtained by dividing the actual processing time, as obtained from typical trouser assembly operations, by the number of work stations assigned to the given operation. Table I shows that the average processing time for several of these operations (creasing back pockets, creasing front pockets, closing waist band ends) is exactly equal to 0.06 minute, with the number of such work stations selected. These particular operations then become the limiting steps or bottlenecks to increased production. That is, if this plant were to be overfed (as in some of our simulations), production would remain limited to 40,000 pairs per week and unsteady-state conditions would develop. Specifically, WIP inventory (of all sorts) would increase monotonically with production time and the plant would become saturated. In the context of this GPSS model, transactions would continue to accumulate therein until core memory was exhausted. The only way to alleviate this overfeeding problem would be through reallocation and/or addition of resources (work stations), if unit processing times could not be reduced.

Figure 10 shows simulation results corresponding to both underfeeding and overfeeding cases. The feed rate of fabric, plotted as the abscissa therein, was adjusted by varying the value of the operand for the GENERATE block in model segment 1, as discussed earlier. These results show the production rate increasing linearly and exactly (45° line) with the plant feed rate, up to its nominal limiting capacity of 40,000 pairs per week. Beyond this point, production remains flat at this value for the case of overfeeding. As mentioned earlier, the production rate in these simulations is determined from the number of transactions leaving the TERMINATE block in model segment 9. The total number of work stations (255, from Table I) required to achieve this nominal production level is within the range of 250-300, as provided by plant management.

The inventory (both of pairs and total parts) curves of Figure 10 are of considerable interest. Thus, both inventory figures increase slowly with feed rate until the limiting capacity of 40,000 pairs/week is reached. Thereafter, both of these figures begin to increase more dramatically, the sum of the individual parts more so than the pairs. This behavior clearly indicates the onset of plant saturation. Indeed, it must be emphasized that all of these simulation results in Figure 10 are for a 4-week production period, after a 2-week startup period. Clearly both inventory figures, at a given plant feed rate, would increase

Production and WIP inventories as functions of plant feed rate

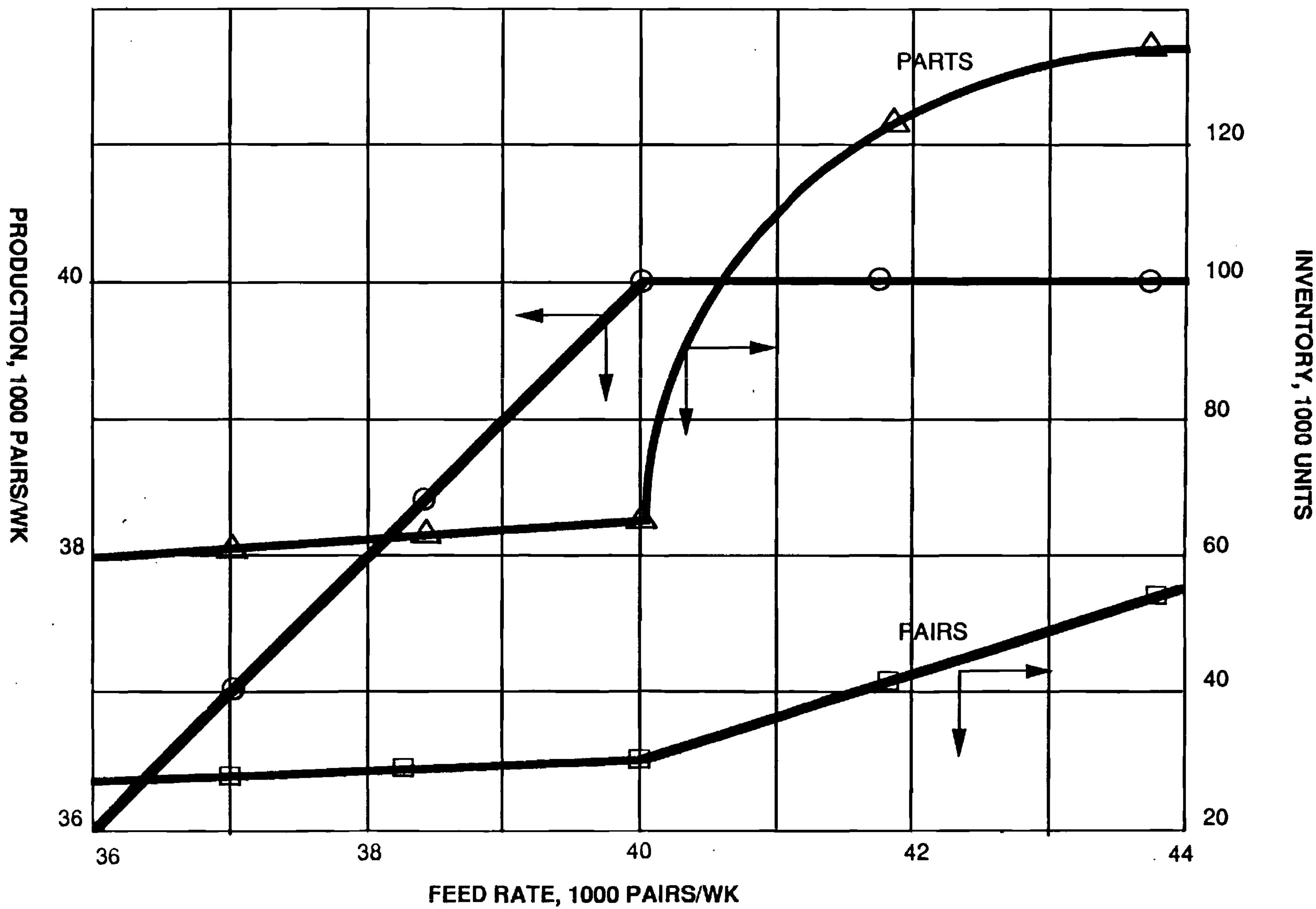


Figure 10

(decrease) if a longer (shorter) production simulation period were chosen (because of the unsteady-state conditions at overfeeding).

The total WIP inventory of parts (both at work stations and in queues) in Figure 10 is easily determined from the total transaction count in the model -- part of the standard GPSS/PC output -- at the conclusion of a simulation. The total number of unfinished pairs of trousers in this plant must be determined in a different fashion, however. This quantity is determined by summing up all of the transactions along one of the various manufacturing routes (including both work stations and queues) in the plant. Table II shows the four longest such routes in this particular plant.

Specifically, Figure 10 shows that the total number of unfinished trousers in inventory at the end of four weeks of overfeeding as exceeding 50,000, and the total number of parts as approaching 140,000. These results clearly bracket the plant management estimate of 77,000 for its WIP inventory.

Table II also gives the total unit processing times (Σt, minutes/pair) along each of the manufacturing routes therein. In this case, the largest such total, of 11.378 minutes/pair, is seen to occur along Route No. 1. The physical significance of this value corresponds to the minimum possible time it would take to manufacture one pair of trousers in this specific plant (sometimes referred to as residence time). Realistically, however, this number would have to be multiplied by an integer representing the

Table II
Production Routes in the Manufacture of Utility Trousers

Operations	Unit Proc. Times ($\sum$ t), min/pair
Route No. 1	
1a - 1c	1.625
5a - 5c	0.494
6a - 6e	2.455
7a - 7d	2.002
8a - 8c	1.224
9b - 9f	3.578
Total	11.378
Route No. 2	
1a - 1c	1.625
4a - 4d	0.784
6b - 6e	1.702
7a - 7d	2.002
8a - 8c	1.224
9b - 9f	3.578
Total	10.915
Route No. 3	
1a - 1c	1.625
3a - 3e	1.466
6d - 6e	0.922
7a - 7d	2.002
8a - 8c	1.224
9b - 9f	3.578
Total	10.817
Route No. 4	
1a - 1c	1.625
2a -2d	0.648
3e	0.753
6d - 6e	0.922
7a - 7d	2.002
4g - 4i	1.224
8b - 8f	3.578
Total	10.752

number of pairs cut in the initial operation or, downstream thereof, the bundle size. Thus, a bundle size of 40 pairs would incur a residence time in excess of 450 minutes or almost one day of operation. Similarly, the residence time for a transaction size of 160 pairs would be 1800+ minutes, or almost four days. It is also clear from a comparison of Figure 1 and Table II that not all of the possible manufacturing paths have been included in the latter. Thus, several routes, for example, through waist bands or belt loops, have been excluded. Mere inspection of the materials flow configuration in Figure 1 and of the processing times in Table I clearly shows that neither of these routes could contribute to the unit residence time.

As described earlier, the function of the TABULATE block in model segment 9 of Figure 9 is to collect statistics on the total time transactions spend in the model. These output statistics are summarized in Table III -- showing both the mean values and standard deviations for these residence times. In the cases of underfeeding and balanced operation, these results show the residence time per pair of trousers to be exactly equal, as expected, to the value of 11.378 minutes computed in Table II. That is, even when the plant is underfed, there is no way in which the minimum time required to produce one pair of trousers in this plant can be less than this value (without any reallocation of resources). Similarly, in the absence of overfeeding, the standard deviation in this residence time is equal to zero. As the plant

Table III

Manufacturing Residence Times as Functions of the Plant Feed Rate

Plant Feed Rate, $\frac{pairs}{week}$	Residence Time, $\frac{min}{pair}$	Standard Deviation, $\frac{min}{pair}$
	Underfeeding	
36,920	11.378	0.0
38,400	11.378	0.0
	Balanced Operation	
40,000	11.378	0.0
	Overfeeding	
41,740	13.404	0.722
43,640	15.431	1.444

is overfed, however, both the manufacturing residence time and the standard deviation begin to increase (the latter from its previous value of zero). These figures thus indicate the onset of inventory backup in the plant. Again, because of the unsteady-state conditions prevalent at overfeeding, both of these figures would increase monotonically if longer production times (greater than four weeks) were simulated.

Appendix B supplies the actual output from this GPSS model of the utility trouser plant operating in balanced fashion at its nominal production capacity of 40,000 pairs/week.

It was indicated earlier in the discussion of the GPSS processor that a variety of output statistics are automatically printed out at the conclusion of a simulation. Thus, Table IV shows the simulation results for the most utilized work stations (fraction of total time busy) in this plant at balanced production conditions. There are 15 such work stations shown therein, all with a fractional utilization greater than 95%. Also shown in Table IV are the average processing times (t/N, from Table I) for each of these 15 stations, all of which are either equal or close to the limiting value of 0.06 minute/pair. Indeed, for this rather simple application with no randomness or stochasticism incorporated, these fractional utilizations are all equal to the respective unit processing times divided by the limiting value of 0.06, as expected from queuing theory.

Table IV

Most Utilized Work Stations at a Balanced Production Level
(40,000 pairs/week or 0.06 min/pair)

Station No.	Operation	Avg. Proc. Time (t/N), min	Fractional Utilization
2d	Crease back pockets	0.0600	1.000
5c	Crease front pockets	0.0600	1.000
7c	Close band ends	0.0600	1.000
7a	Attach waist bands	0.0594	0.989
7b	Attach button flies to bands	0.0590	0.983
9c	Sew labels on	0.0590	0.983
9b	Attach belt loops	0.0588	0.980
8a	Join fronts	0.0582	0.969
1c	Mark cut plies	0.0580	0.967
3e	Attach back pockets	0.0579	0.965
6a	Stitch front pockets on panels	0.0579	0.965
9f	Inspect and fold	0.0577	0.962
6d	Sew side seams	0.0577	0.962
6b	Set left fly	0.0577	0.962
6e	Sew seat seam	0.0574	0.957

Lastly, in Table V are presented selected simulation results on the most crowded manufacturing queues in this plant, again at a balanced production level of 40,000 pairs per week. These results agree closely with expectations from Table II. That is, the most crowded queues and, correspondingly, the longest waiting times occur along routes which do not contribute to the total residence time in this plant. Specifically, these queues all develop at points immediately upstream of assembly operations. Thus, Table V shows that the largest queue (QBL) consists of belt loops waiting to be merged with finished backs and fronts, then waist bands (QBNDS) to be merged with finished backs and fronts, and so on. With the onset of overfeeding, all of these queues in Table V grow both in length and waiting time, and there also appears the development of new additional queues at various points in the plant.

Hi-Tech Trouser Plant Configuration

The hypothetical, high-technology facility chosen for investigation in this work corresponds, in its material flow configuration, to that at the Advanced Apparel Manufacturing Technology Demonstration (AAMTD) Center, located on the campus of the Southern College of Technology (SCOT) in Marietta, Georgia. This configuration was then scaled up to a nominal production level of 8,000 pairs of trousers per (8-hr) day. There are 33 identifiable operations (including cutting, sewing and matching) in this hypothetical facility, occurring at a total of 182 work

Table V

Most Crowded Queues at a Balanced Production Level (40,000 pairs/week)

Queue Name	Downstream Operation	Maximum Contents, pieces	Ave. Wait. Time, min/piece
QBL	Assemble belt loops and finished backs/fronts	16,320	5.534
QBNDS	Assemble waist bands and finished backs/fronts	8,000	2.811
QBCK	Assemble finished fronts and backs	1,600	0.556
QFPAN	Assemble front panels and pockets	1,440	0.490
QFLYS	Assemble flies and front panels	1,280	0.460
QBPOC	Assemble back pockets and back panels	320	0.065

stations. By way of comparison, the total number of such stations required for the same production rate, but with older technology, in the operating utility trouser plant simulated earlier amounted to 255.

The material flow configuration for this hypothetical trouser plant is shown in Figure 11. Associated with this figure is Table VI, which identifies the various operations and is organized into segments in the same fashion as the GPSS model (to be discussed later). In addition to identifying the various operations indicated in Figure 11, this table also shows the GPSS name, number of work stations (N), unit processing time (t, minutes/pair) and average processing time (t/N, minutes) for each operation. The unit processing time (t) actually served as the mean value ($\bar{t}$) in a normal distribution representing stochastic behavior of a given operation. The standard deviation (σ) in this distribution was then generally taken as some percentage (e.g., 15%) of this mean value.

The trouser manufacturing operation begins with the spreading of fabric rolls on a cutting table. Typically, 30 to 40 plies are spread in the operation at the AAMTD Center. An automated cutting machine (e.g., Gerber) then cuts the various parts, after which they are bundled (typically 60 to a bundle) and sent to various work stations. These operations comprise the first model segment (A).

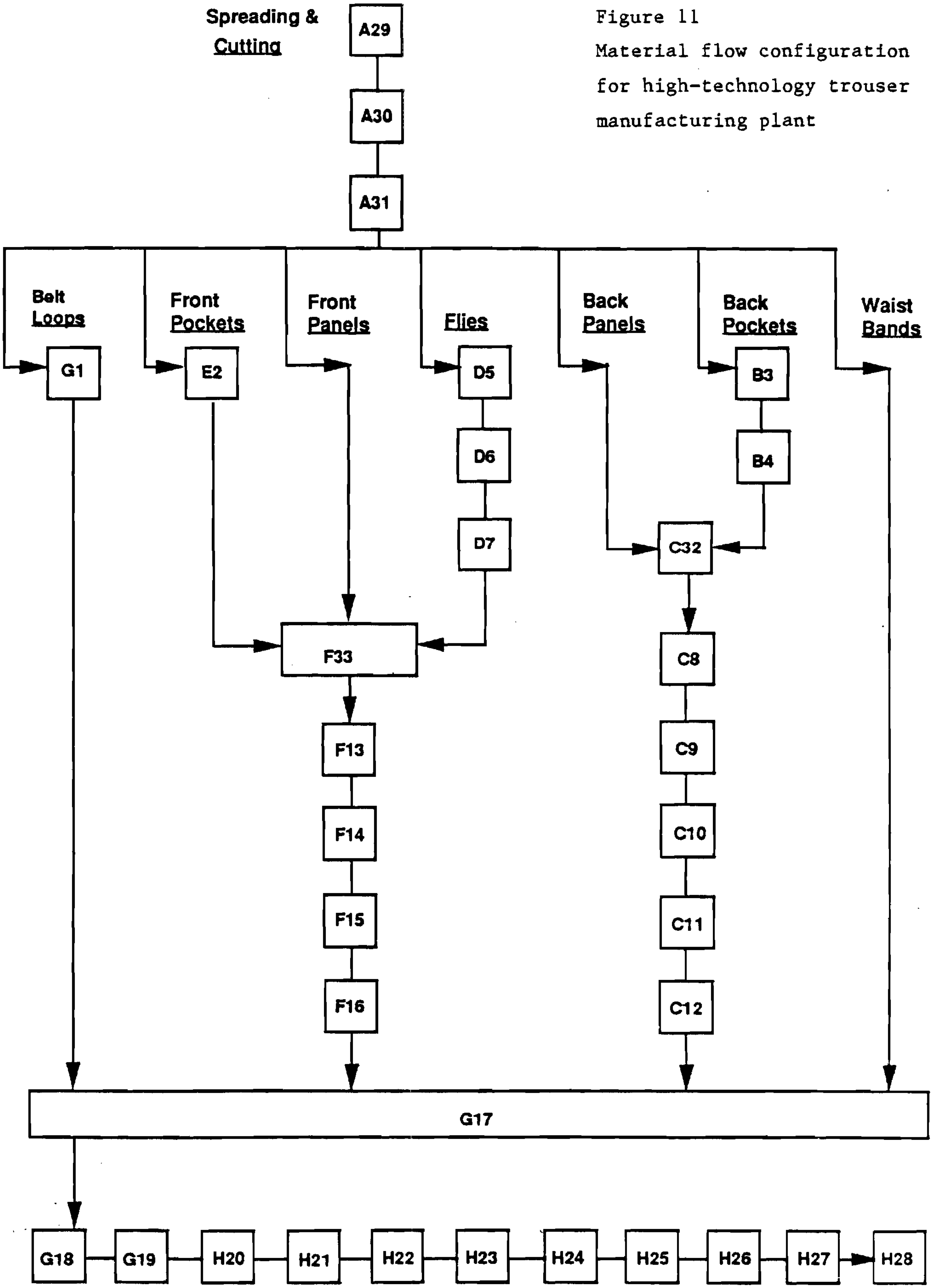


Figure 11

Material flow configuration for high-technology trouser manufacturing plant

Table VI

Work Stations in Hi-Tech Trouser Manufacturing Plant

Station ID	Operation	GPSS Name	No. of Work Stations (N)	Standard Unit Proc. Time (t), min/pair	Avg. Proc. Time (t/N), min
	Model Segment A -- Spreading and Cutting				
A29	Spread fabric roll	SPRED	3	0.1285	0.0429
A30	Cut various pieces	CUTTR	4	0.1714	0.0429
A31	Bundle cut pieces	CODER	5	0.2143	0.0429
	Model Segment B -- Back Pockets				
B3	Hem back pockets	BHEM	4	0.206	0.0515
B4	Buttonhole back pockets	BHOL	2	0.100	0.0500
	(Joined with back panels in C, FBACK)				
	Model Segment C -- Back Panels				
	(Joined with back pockets from B, FBACK)				
C32	Match back parts	MBKS	1	0.040	0.0400
C8	Make back darts	DARTS	4	0.208	0.0520
C9	Topstitch back darts	TOPS	4	0.197	0.04925
C10	Attach back label	BLAB	3	0.167	0.0556
C11	Attach back pockets	ABP	8	0.480	0.0600
C12	Sew seat seam	SEAM	5	0.282	0.0564
	(Joined with all other parts in G, FEVRY)				

Table VI (continued)

Model Segment D -- Right and Left Flies

D5	Make left fly	LFLY	1	0.055	0.0550
D6	Make right fly	RFLY	5	0.300	0.0600
D7	Join flies	JOINT	5	0.300	0.0600
	(Joined with front panels and pockets in F, FPANL)				

Model Segment E -- Front Pockets

E2	Hem front pockets	FHEM	4	0.204	0.0510
	(Joined with front panels and flies in F, FPANL)				

Model Segment F -- Front Panels

F33	Match front parts	MFTS	1	0.040	0.0400
F13	Attach front pockets	AFP	8	0.480	0.0600
F14	Attach left fly	AFLY	7	0.404	0.0577
F15	Topstitch left fly	TFLY	5	0.274	0.0548
F16	Join fronts	FINF	6	0.349	0.0582
	(Joined with all other parts in G, FEVRY)				

Model Segment G -- Belt Loops

G1	Make belt loops	LUPS	2	0.077	0.0385
	(Joined with all other parts from A, C and F, FEVRY)				
G17	Match all parts	MFBS	1	0.040	0.0400
G18	Load UPS	UPS	2	0.100	0.0500
G19	Sew side seam	SIDE	11	0.635	0.0577

Table VI (continued)

Model Segment H -- Finished Trousers

H20	Sew inseam	INS	12	0.674	0.0562
H21	Attach waistband	AWB	8	0.437	0.0546
H22	Finish band ends	BEND	8	0.434	0.05425
H23	Buttonhole band	BUTN	3	0.131	0.0437
H24	Attach belt loops	ABL	10	0.596	0.0596
H25	Tack fly, sew label	TACK	5	0.295	0.0590
H26	Press and fold	FOLD	11	0.619	0.0563
H27	Top press	PRES	5	0.274	0.0548
H28	Inspect	SPEC	19	1.097	0.0577
	Total no. of work stations		182		

Back pockets fabrication, consisting of the operations of hemming and buttonholing, occurs in model segment B. These finished parts are then matched with back panels in model segment C. This is followed by the various sewing operations associated with back panels fabrication: sewing and topstitching back darts, attaching the back label and back pockets, and seat seaming.

Model segment D consists of fly assembly. Left flies are first made, then right flies, following by joining of these two. The finished flies then move on to match with front panels and front pockets in model segment F. The front panels move directly from spreading and cutting to this matching operation, while the front pockets arrive via the short model segment E, consisting of the sole operation of hemming front pockets.

Thus, the sixth model segment (F) begins with matching of finished flies, front pockets and panels. The front pockets are then attached to the front panels, followed by attachment and topstitching of the left fly. This model segment concludes with joining of the front panels.

Model segment G begins with the making of belt loops, followed by matching of the various partially finished parts (fronts, backs and waist bands, in addition to belt loops). As described above, the backs come from segment B and the fronts from segment F. The waist bands arrive directly from the spreading and cutting operations. After this matching operation, the UPS is loaded and sideseams are stitched.

The above model segment G then flows naturally into the last manufacturing segment (H) in this hypothetical plant. Here, the various finishing operations associated with trouser manufacture are performed. In order, these are inseam stitching, attachment of waist bands, finishing the band ends, buttonholing and buttonsewing, attachment of the belt loops, tacking the fly and label sewing, and inspection and unloading of the UPS. Any repairs, if necessary, are performed at this point.

The above described division of this hypothetical trouser plant into the eight indicated segments is clearly somewhat arbitrary. It seems to be a reasonably natural division, and was implemented in order to facilitate coding of the GPSS model of this plant, as described below.

Hi-Tech Trouser Plant Model

As with the utility trouser model presented earlier, this present model was coded with the Industrial Version of GPSS/PC [10], supplied by Minuteman Software of Stow, Massachusetts. Similarly, all of the present simulations were run on an IBM PS/2, Model 50 PC with 1000K of RAM (core memory).

The final size of a GPSS transaction selected in this hi-tech plant model corresponded to 120 pairs of trousers (or parts thereof), which nominally represents two bundles in the subject hi-tech plant. Memory depletion rapidly occurred with smaller transaction sizes (e.g., 60), when simulating unbalanced conditions. Similar problems relating to the minimum size of a transaction in textile [3] and apparel applications have been addressed and discussed earlier. The elementary time step selected in these present GPSS simulations was 0.01 minute; that is, one minute of real plant operation corresponds to 100 time units in a simulation. Given the transaction size selected above, all of the various unit processing times in Table VI were then multiplied by 120 x 100 = 12,000 for representation in the model.

Since all GPSS simulations begin from a cold start (no transactions anywhere present in the model), a startup period is necessary to place transactions in the model, representing normal steady-state operating conditions. A 2-week startup period was typically employed in this present work.

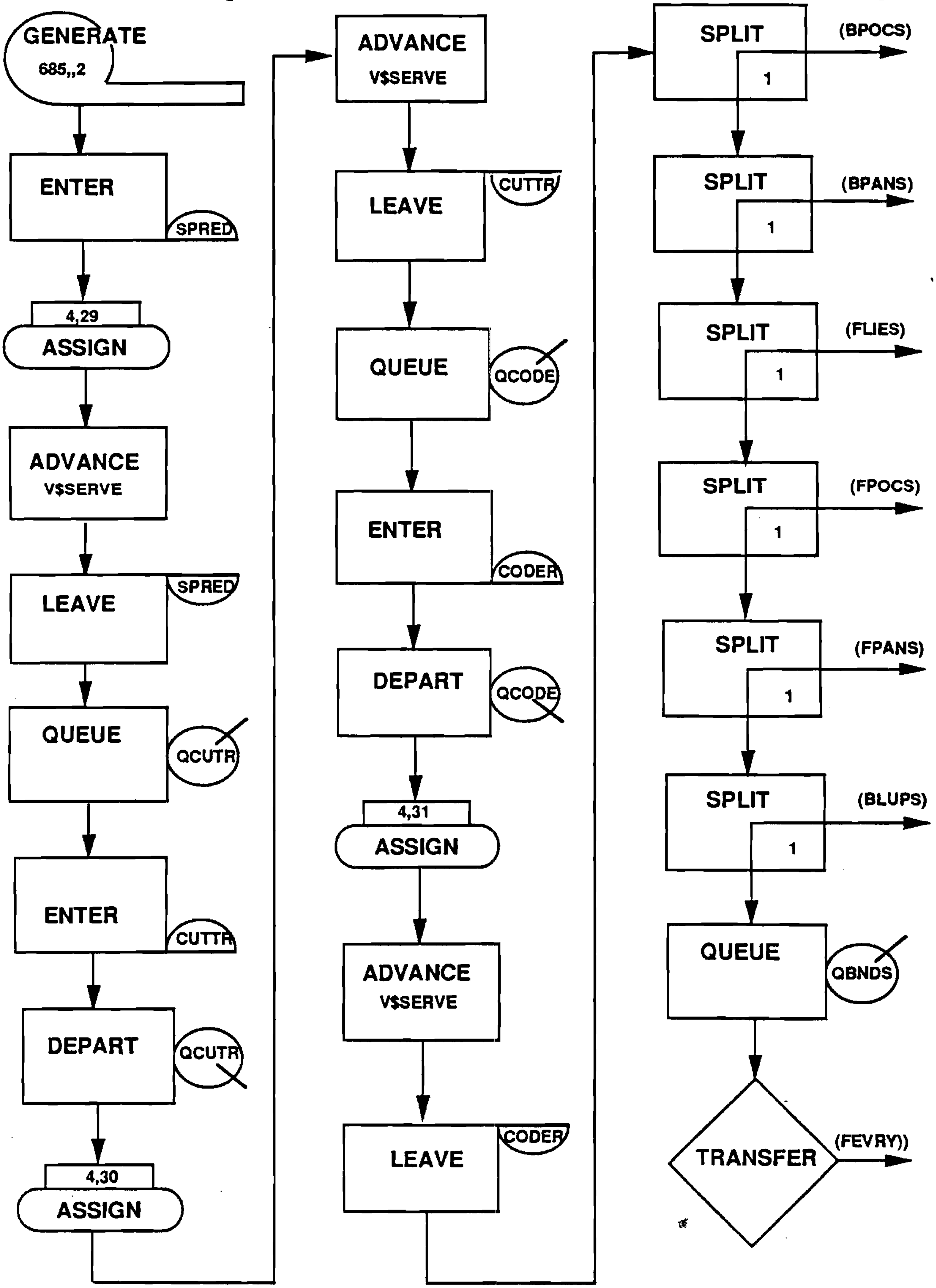
This GPSS model naturally follows the material flow configuration given in Figure 11 (and Table VI). Thus, the spreading, cutting and bundling operations of model segment A are coded as shown in Figure 12. The various cut parts generated by the SPLIT blocks following these operations are sent off to their respective work stations or matching locations.

Figure 12

GPSS Model Segment A

MODEL SEGMENT A

Spreading, Cutting Bundling



The A (or first) operand of the GENERATE block commencing model segment A regulates the input rate of transactions to the GPSS model. Specifically, this operand specifies the interarrival time (in GPSS time units) between successive transactions to the model. Thus, for the subject plant producing 8,000 pairs of trousers (or 66 2/3 transactions) per 8-hr day, the average interarrival time between transactions should amount to 7.2 minutes or 720 GPSS time units. Such would be the case for a perfectly balanced plant, with no stochasticism, producing 8,000 pairs/day. In some of the production scenarios explored later (e.g., more efficient equipment), however, there is the possibility of a larger production rate. Thus, as shown in Figure 12, this A operand was reduced to a value of 685, which represents a small amount of fabric overfeeding, to accommodate this possibility. This operand value would specifically correspond to a production rate of 8,409 pairs/day.

As mentioned earlier, stochasticism in this study was implemented with the normal distribution, represented by a mean and standard deviation for each operation. For this purpose, a generic normal distribution function, with a mean of zero and a standard deviation of unity, was defined. For a given operation then, a value of this function, as sampled with the aid of a random number generator, was multiplied by the actual standard deviation and added to the actual mean to yield a processing time. This latter arithmetic was performed with the aid of a global arithmetic variable named SERVE. The appropriate values of the mean and standard deviation for each operation (numbered from 1 to 33, as in Table VI) were then supplied from two generic functions (actually table lookups), named MEAN and SDEV, respectively.

Thus, the purpose of the ASSIGN blocks appearing in Figure 12 is to supply the transaction parameter number (4 in these simulations) and operation number, in order to look up the appropriate values of the mean and standard deviation for a given operation. In the latter two operations (cutting and bundling) in this figure, the ASSIGN block occurs within the following sequence of GPSS blocks: QUEUE-ENTER-DEPART-ASSIGN-ADVANCE-LEAVE. Since this 6-block sequence will occur again for each of the remaining 30 operations in this trouser plant, it becomes convenient to define a conceptual macro block, denoted by QEDAAL, to represent this sequence. Figure 13 illustrates this definition pictorially.

The GPSS block diagram then moves on to model segment B (back pockets), beginning with the ADVANCE block labelled BPOCS, as shown in Figure 14. After proceeding through the two work stations (denoted by the QEDAAL macros) in this segment, transactions (here representing 120 sets of finished back pockets) move into model segment C (back panels, also shown in Figure 14) at the ASSEMBLE block labelled FBACK. After this assembly operation and departure from the respective queues (QBPOC and QBPAN), the five operations

QEDAAL SEQUENCE

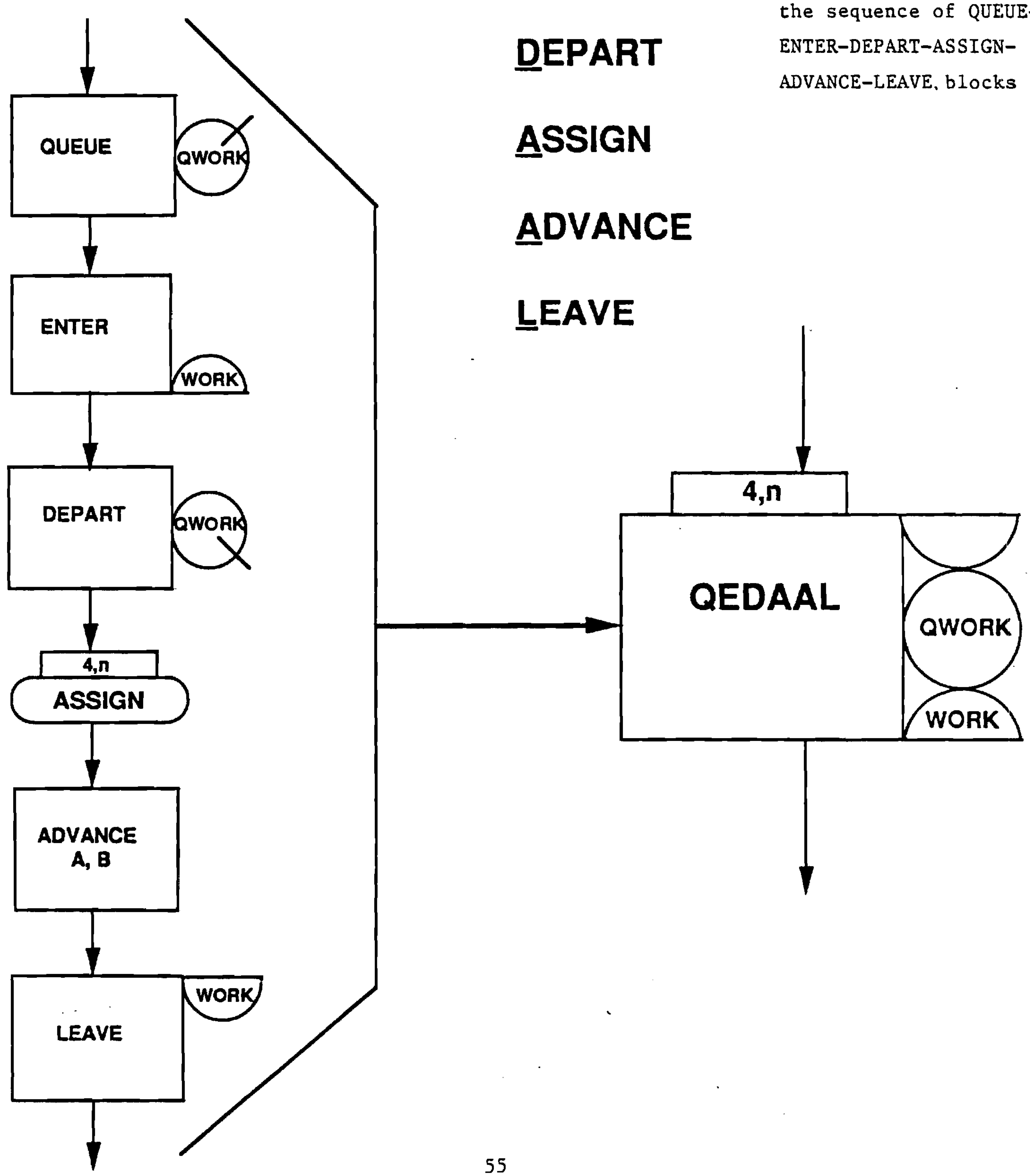


Figure 13
Definition of conceptual QEDAAL macro block for operation n, representin the sequence of QUEUE-ENTER-DEPART-ASSIGN-ADVANCE-LEAVE. blocks

MODEL SEGMENT B

MODEL SEGMENT C

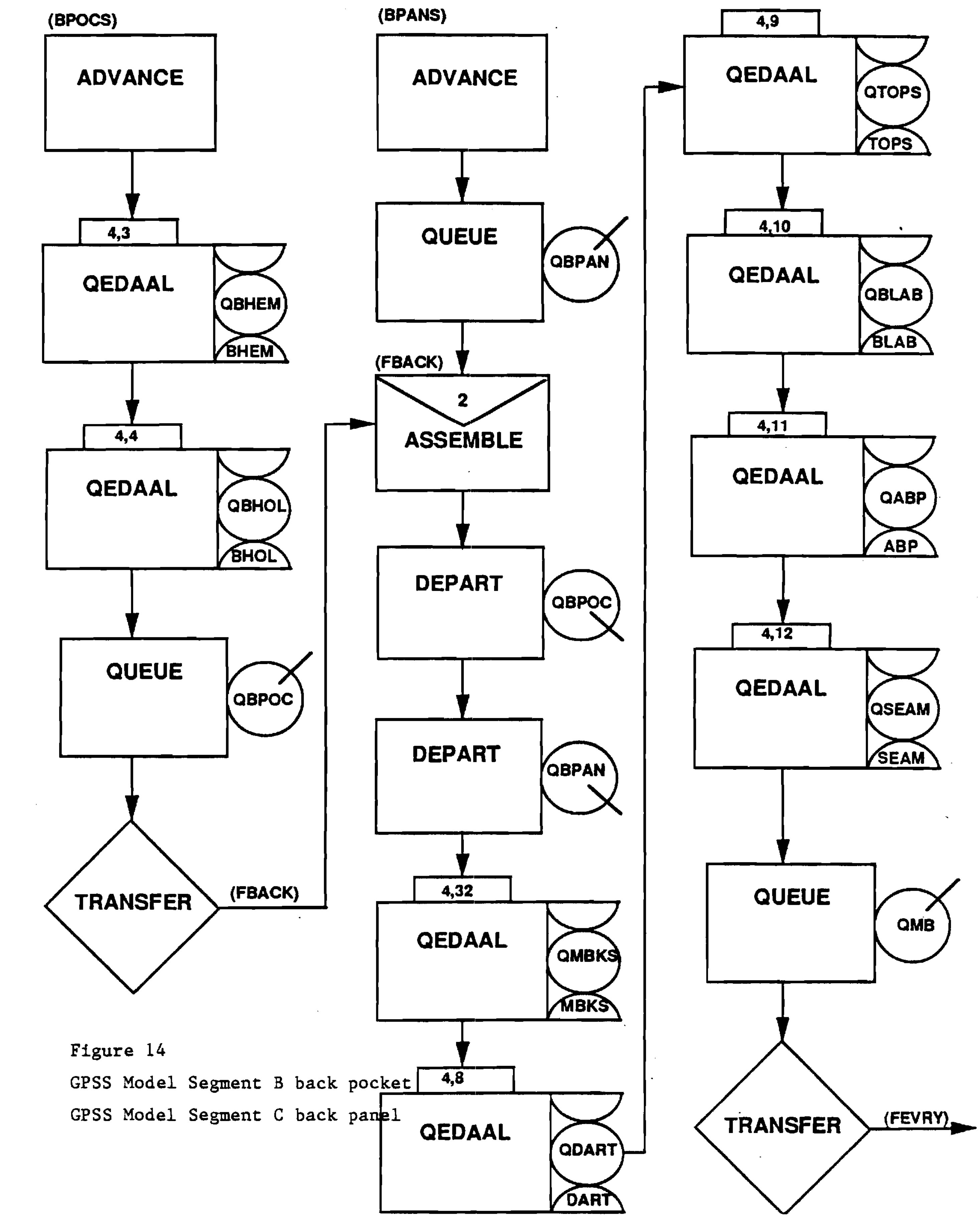


Figure 14

GPSS Model Segment B back pocket

GPSS Model Segment C back panel

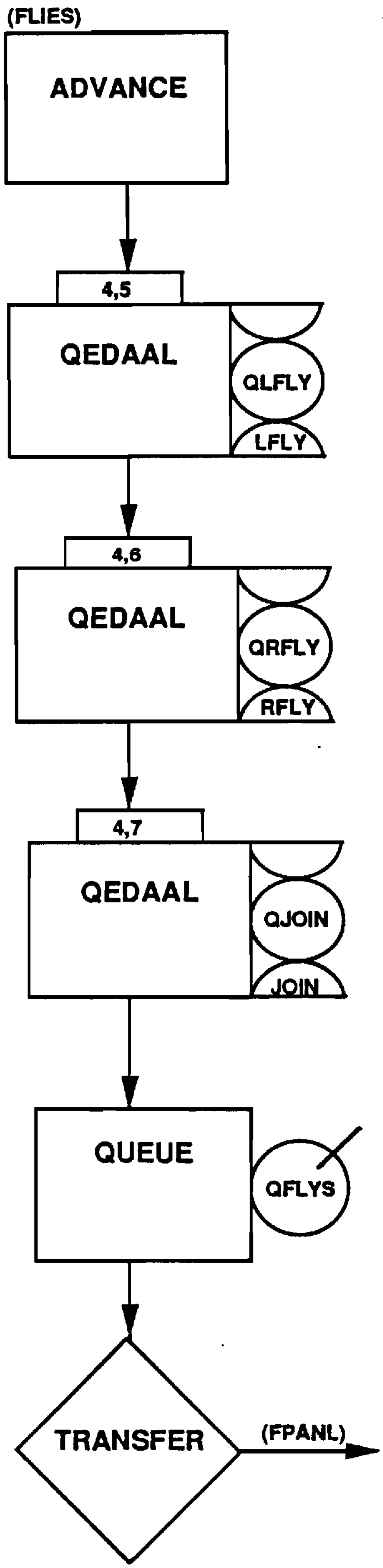
(C8 through C12) of the back panels segment are performed. The finished and assembled back panels with pockets are then transferred unconditionally to the ASSEMBLE point (FEVRY) upstream of the UPS loading station in segment G. Model segment C also begins with an ADVANCE block, labelled BPANS, to which the cut back panels are sent (from segment A).

The block diagrams for the short model segments D and E are both shown in Figure 15. The three operations (D5-D7) comprising fly making constitute the first of these segments while the sole operation (E2) of hemming front pockets makes up the second. Both of these model segments conclude with an unconditional transfer to the assemble point (FPANL) for front parts in segment F, as described below.

The cut front panels are sent directly (from segment A) to model segment F, shown in Figure 16. Having collected the finished front pockets and flies at the assemble point FPANL, the transactions (here representing 120 sets of finished front parts) after matching move on through the four work stations (F13-F16) in this segment. The transactions from this segment are then also transferred to the major assembly point FEVRY.

Model segment G commences with the ADVANCE block labelled BLUPS, as shown in Figure 17. After fabrication of belt loops (step G1), the transactions then pick up all of the other parts,

MODEL SEGMENT D



MODEL SEGMENT E

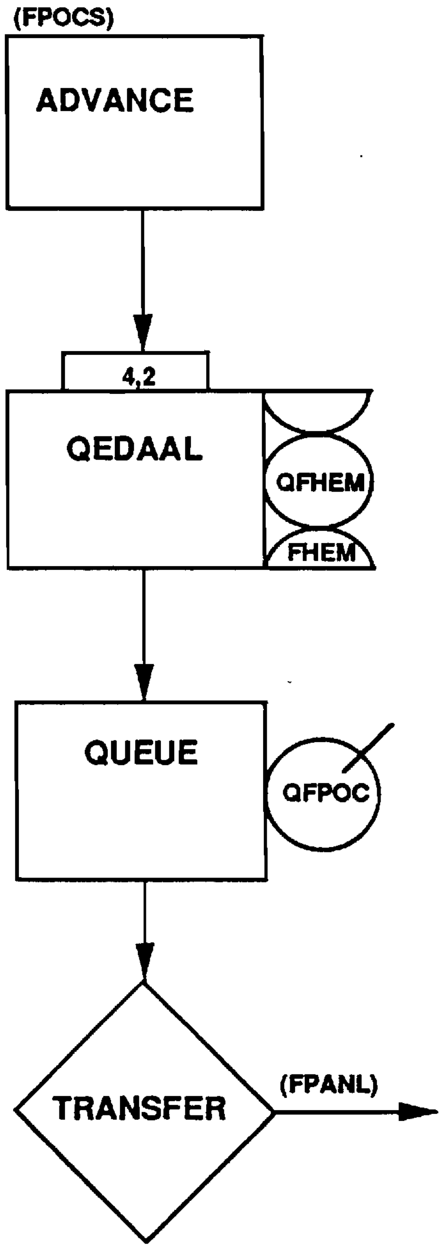


Figure 15

GPSS Model Segment D right & left flie

GPSS Model Segment E front pockets

Figure 16

GPSS Model Segment F
Front panels

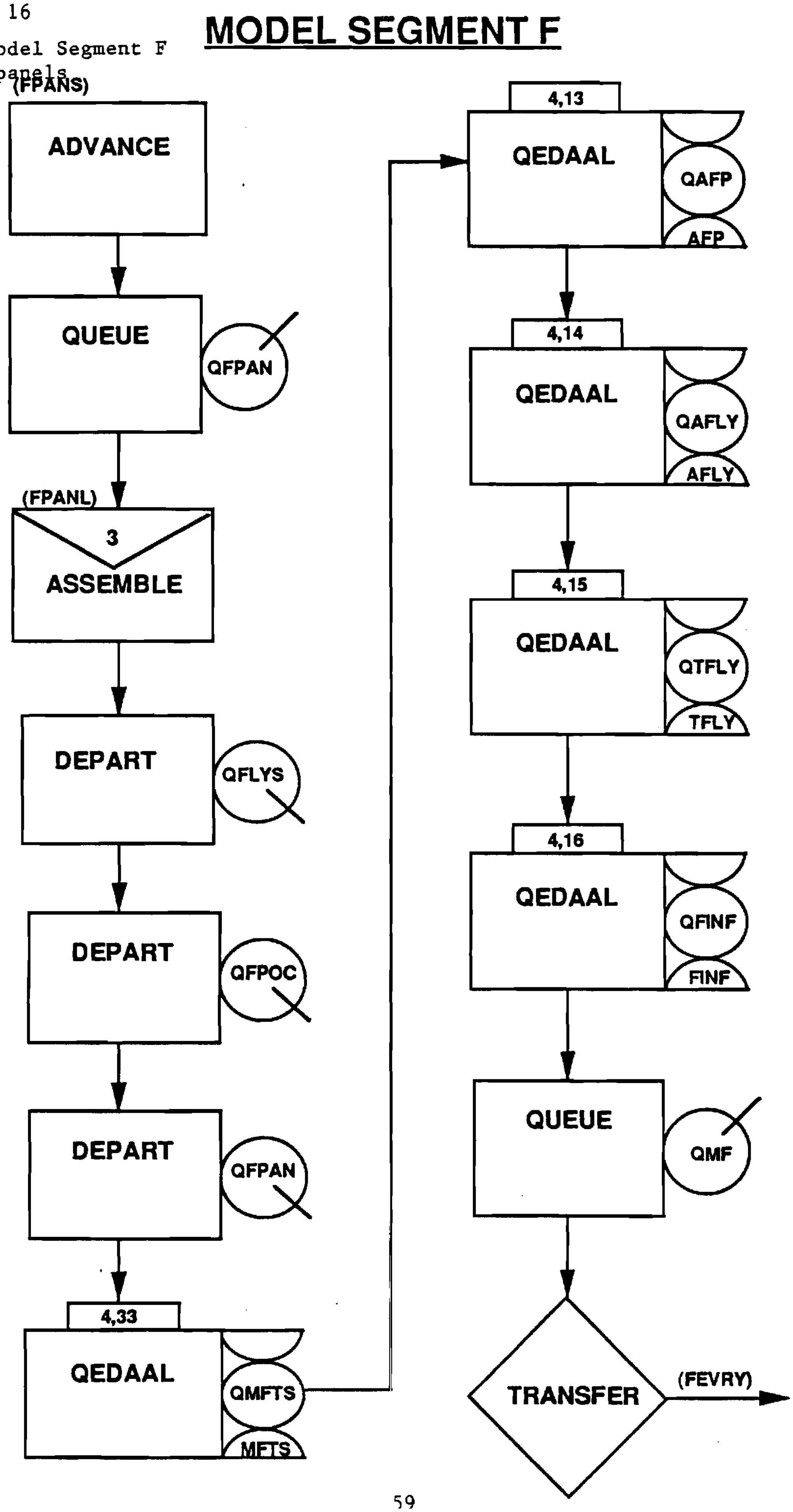
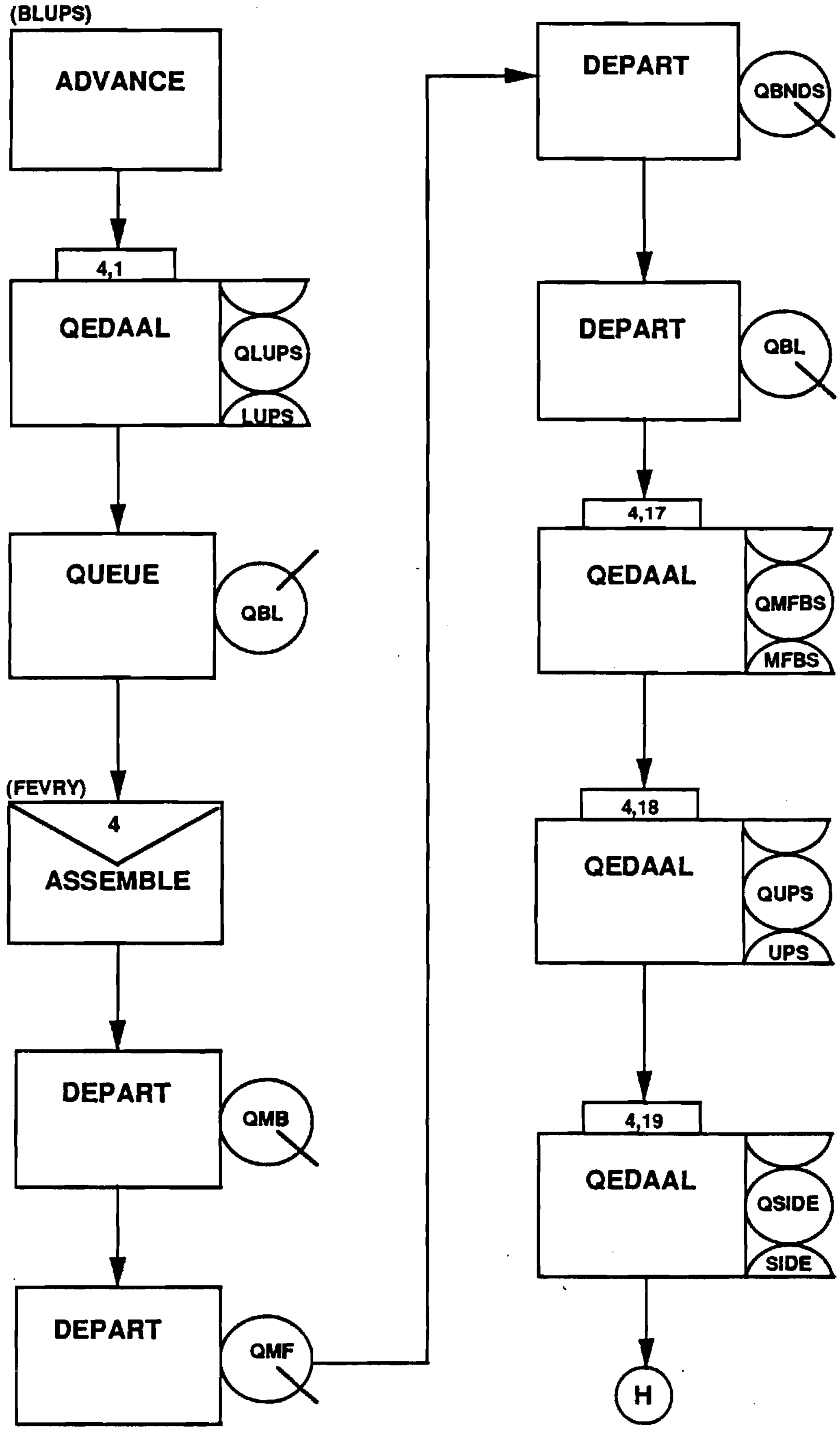


Figure 17

GPSS Model Segment G

Belt loops

MODEL SEGMENT G

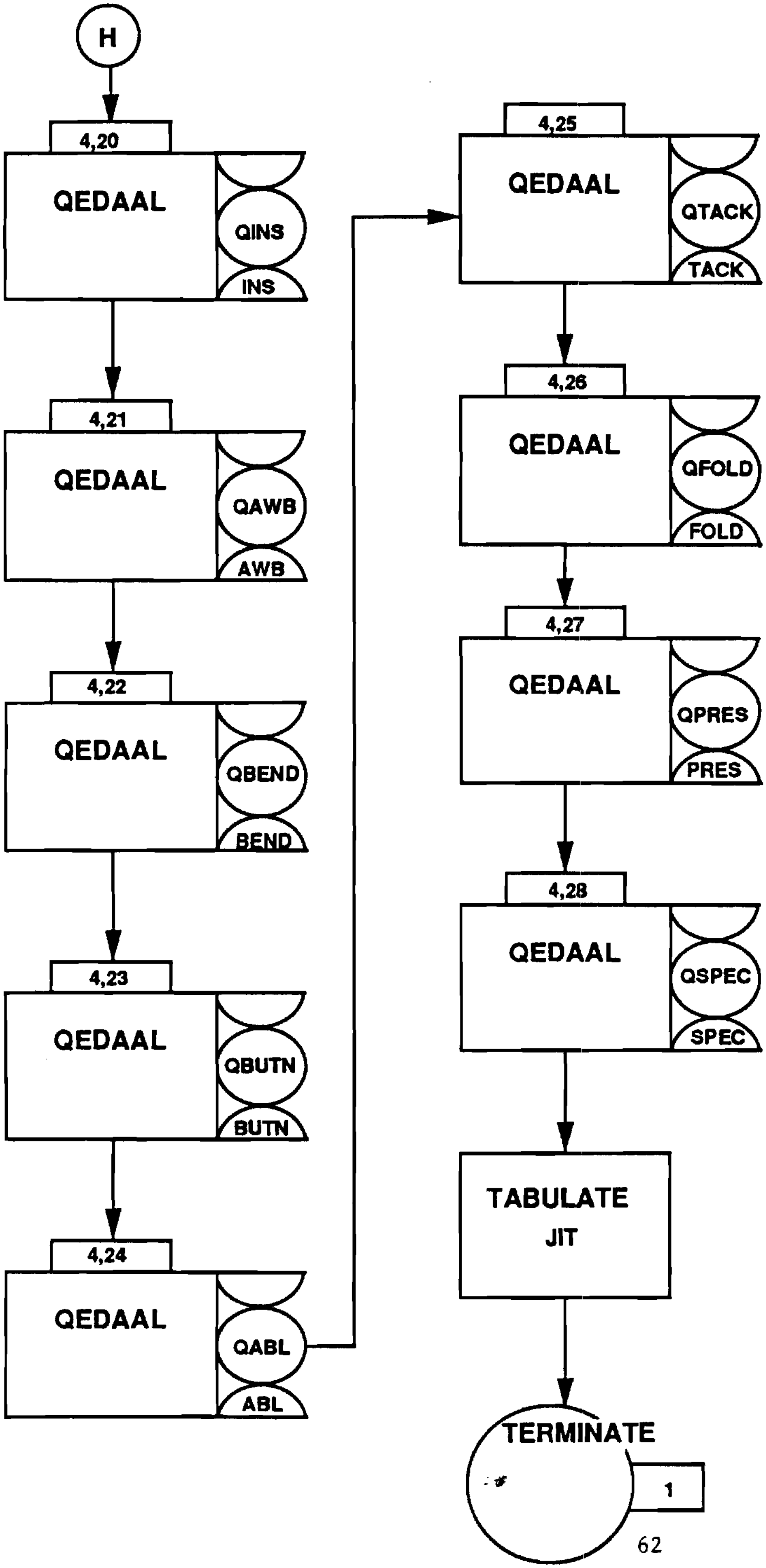


including cut waist bands directly from segment A, at the FEVRY ASSEMBLE block. After matching and loading the UPS, segment G concludes with the side seam sewing operation (G19) before flowing naturally into model segment H, the block diagram for which is shown in Figure 18. This latter segment is quite straightforward, consisting of the nine operations (H20-H28)concluding this trouser manufacturing operation. The TABULATE block following the last QEDAAL work station (inspection) in this segment tallies the total manufacturing residence time for each transaction and stores this information in a table labelled JIT. Similarly, a count of the total number of transactions executing the TERMINATE block ending model segment H gives the total production over the duration of a simulation.

Also shown in Figure 18 is the timer for regulating the duration of a simulation -- model segment I. It consists simply of a GENERATE block followed by a TERMINATE block. The value of the (first and only) operand for this GENERATE block is set equal to 48,000, which is the number of GPSS time units (0.01 minute) in one 8-hr day of operation. The duration of a startup period or of a succeeding simulation was then regulated by the integer value of the A operand in the START control statement for each run. Thus, a value of 10 for this START operand would set the duration of a startup period or production simulation to be 10 days.

Before moving on to the simulation results, it should be mentioned that the sole function of the queues constructed upstream of each set of identical work stations is to collect waiting line

MODEL SEGMENT H



MODEL SEGMENT I

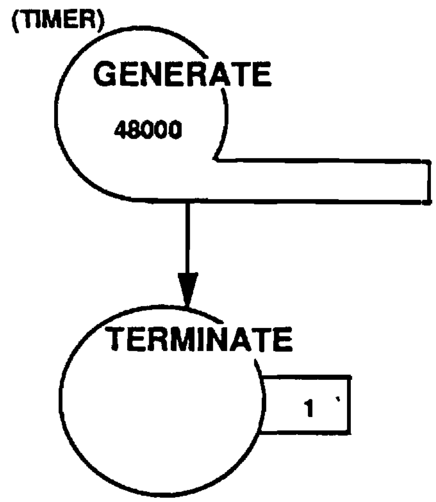


Figure 18
GPSS Model Segment H
Finished trousers
GPSS Model Segment I
Timer

statistics, such as average queue length and waiting time per transaction. These queues are represented by the QUEUE and DEPART pairs of blocks in the QEDAAL macros appearing in the various manufacturing segments. These pairs of blocks (performing inverse functions) are not essential to the model, and could be discarded wherever the accumulation of waiting line statistics was not of interest.

The complete GPSS coding for this discrete-event simulation model of a hi-tech trouser manufacturing facility is given in Appendix C.

Simulation Results from Hi-Tech Trouser Plant Model

Before simulation of the various production scenarios could begin in earnest, it was necessary to establish the startup procedure for this trouser plant and model thereof. This fixing of a consistent startup procedure is particularly important, insofar as stochasticism is incorporated into this model. Thus, it was first established that one week (five 8-hr days or 240,000 GPSS time units) was a sufficiently long startup period in the absence of stochasticism. That is, by this time the plant had become filled up to its normal steady-state inventory and its nominal production capacity of 8,000 pairs per day had been achieved. This latter figure corresponds to a maximum average processing time (t/N) of 0.060 minute/pair for any given operation, such as exhibited by several work stations (attach back pockets, make right fly, join flies, attach front pockets) in Table VI.

A longer startup period was invoked when stochasticism was introduced, in order to produce simulation results under comparable conditions. Specifically, in the exploration of all of the various production scenarios in this work, the GPSS model was first run for a 2-week startup period. All of the output statistics at this point were then cleared, the clock reset back to zero, and the model then run for a certain period of time in order to obtain representative and comparable output statistics.

A number of production scenarios were investigated in this work. In general, these corresponded to worker absenteeism, new employee training and the introduction of more efficient equipment. Effects measured then included production rate, work-in-process inventory and manufacturing residence time. The average value of the latter (in minutes/pair) for a given scenario is obtained from the output for the JIT table, fed by the TABULATE block in model segment H. The minimum value of this residence time is easily determined from consideration of the material flow configuration of Figure 11 and unit processing times in Table VI. This analysis, summarized in Table VII, shows that the longest manufacturing route in this hypothetical plant begins, naturally, with spreading and cutting, and then proceeds through fly fabrication and fronts assembly, before carrying on through such finishing operations as pressing and inspection. Specifically, the sojourn along this route amounts to 8.0482 minutes, as computed in Table VII, and physically represents the minimum possible time it would take to

Table VII

Critical Manufacturing Route in the Production of Trousers

Operations (from Fig. 1)	Unit Proc. Times (Σt), min/pair
A29-A31	0.5142
D5-D7	0.655
F33, F13-16	1.547
G17-G19	0.775
H20-H28	4.557
Total	8.0482

manufacture one pair of trousers in this specific plant.

The actual impact of stochasticism on production rate from this trouser plant is illustrated in Figure 19. In these simulations, the total production, after the 2-week startup period, over a following 2-week period was averaged over these latter ten days to get a daily production rate. The standard deviation for each of the 33 operations in this plant was varied from 0 (no stochasticism) to 20% of the mean value. Firstly, one sees from Figure 19 that the presence of stochasticism has, as one would expect, a deleterious effect on the production rate. Probably because of the large size (33 operations) of this facility, however, this production decrease is quite small, amounting to only 1.5% or about 120 pairs/day when the standard deviation rises to 20%. There is somewhat of a greater effect, however, on the average manufacturing residence time, plotted as the right ordinate in Figure 19. This time is seen to increase from 10.57 minutes per pair (significance of this discussed below) for a nonrandom system ($\sigma = 0$) to 12.27 minutes/pair with 20% stochasticism. Appendix D provides sample output from this GPSS model of a hi-tech plant for the (base) case of 15% stochasticism.

The above results are also shown in Table VIII, wherein the work-in-process (WIP) inventory figures are included. Both numbers of pairs and of parts (or pieces for each pair) are given in this table. As with the manufacturing residence time, both of these

Effect of stochasticism in the individual unit operations on trouser production rate

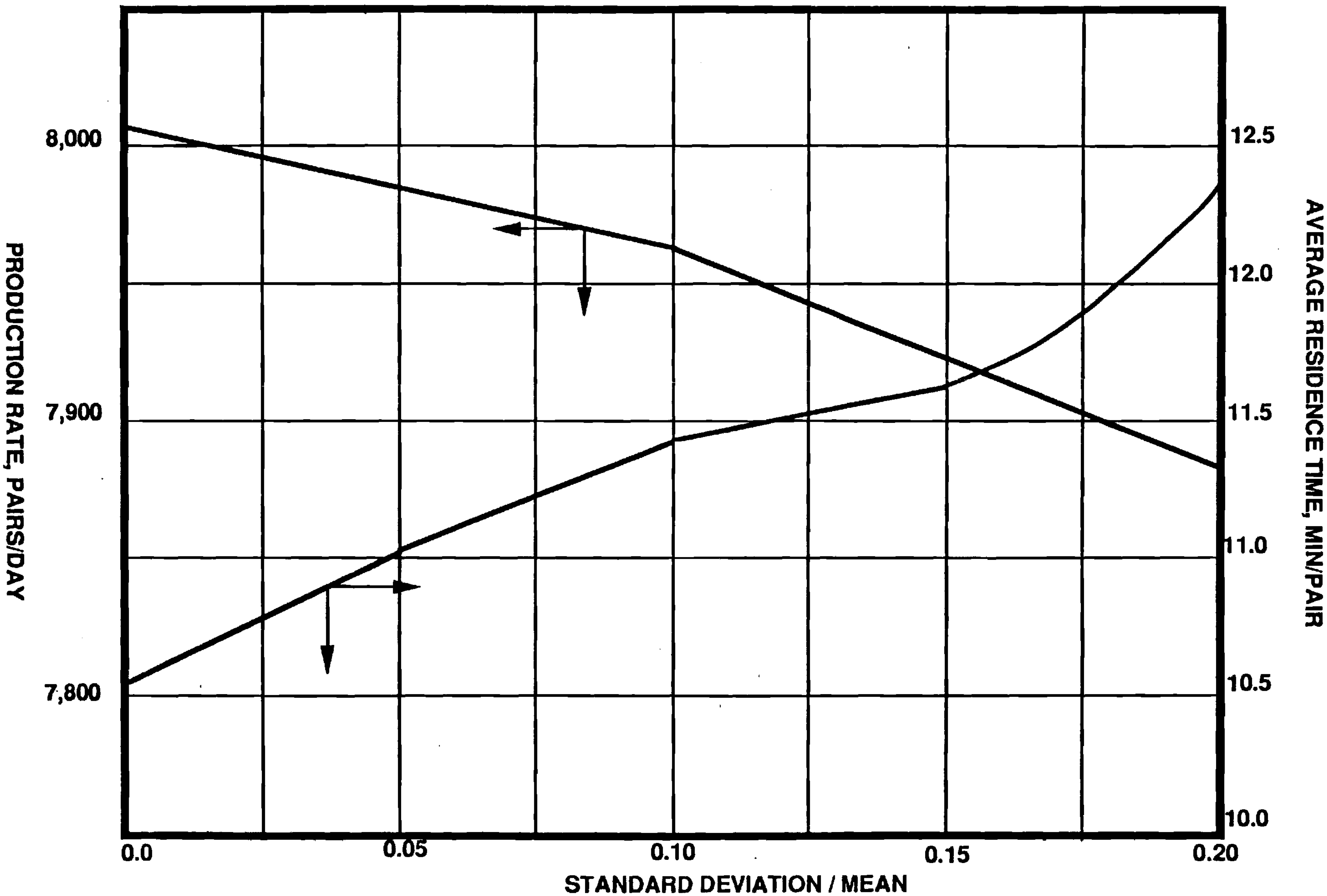


Figure 19

Table VIII

Summary of Effects of Stochasticism on Trouser Production and Inventory

Amount of Stochasticism (std. devn./mean)	Average Production Rate, pairs/day	Average Residence Time, min/pair	Work-in-Process Inventory: pairs	parts
0.00*	7,998	8.05	16,080	26,280
0.00	8,004	10.57	24,420	58,800
0.05	7,992	11.05	25,320	62,160
0.10	7,968	11.47	26,280	61,800
0.15	7,944	11.61	26,640	63,360
0.20	7,872	12.27	27,960	66,720

*This run corresponds to a perfectly balanced plant with no stochasticism; the remainder of the runs are with a small amount of overfeeding.

inventory figures generally rise monotonically as more randomness is introduced into the plant's operations. These two quantities are readily determined from appropriate counts of transactions resident in the model at the conclusion of a simulation. Also shown in Table VIII are the results of simulation of a perfectly balanced plant -- no overfeeding and no stochasticism (first row entry in this table); the actual GPSS output for this idealized case is presented as Appendix E. The average residence time in this case tallies exactly with the theoretical minimum computed in Table VII. The WIP figures for this idealized case, amounting to about two days of production, would represent the minimum attainable inventory in this hypothetical plant.

Key results from exploration of the various production scenarios are then summarized in Table IX. All of the results reported in this table are for the same amount of stochasticism (15%) in each of the plant operations. The base case for these scenarios has already appeared in Figure 19 and Table VIII (standard deviation/mean = 0.15).

Thus, the first set of scenarios presented in Table IX pertains to absent workers. In each of the scenarios explored, two variations were investigated, with three work stations impacted in all cases. In the first variation, none of these work stations were on the critical manufacturing route (from Table VII); thus, in this particular scenario variation, there was one less operating

Table IX

Key Results from Simulation of Various Production Scenarios (all with 15% Stochasticism)

Scenario Description	Average Production Rate, pairs/day	Average Residence Time, min/pair	Work-in-Process Inventory: pairs	parts
Base Case	7,944	11.61	26,640	63,360
Absent Workers (or Machines Down)				
Not on critical route: 1 each from B3, C9 and C11	7,332	12.42	32,760	96,960
On critical route: 1 each from D6, F13 and C9	6,900	13.30	37,080	105,480
New Employee Trainees (60% efficient)				
Not on critical route: 1 each from B3, C9 and C11	7,752	11.87	28,560	74,880
On critical route: 1 each from D6, F13 and C9	7,416	12.43	31,920	84,600
New Equipment (25% more efficient)				
Not on critical route: 1 each from B3, C9 and C11	7,884	11.59	26,880	64,920

Table IX (continued)

On critical route: 1 each from D6, F13 and C9	8,016	11.01	25,200	52,800

work station for hemming back pockets (B3), topstitching back darts (C9) and attaching back pockets (C11). In the second variation (of each scenario), two of the three impacted work stations are on the critical manufacturing route. Specifically, these are making right flies (D6), attaching front pockets (F13) and topstitching back darts (C9), the first two of which are on the critical route and have an average processing time (t/N) of 0.060 minute, corresponding to the nominal production rate of 8,000 pairs/day.

These absent workers scenarios were simulated by reducing each of the three appropriate GPSS storage (e.g., BHEM, TOPS and ABP) sizes by one unit, after completion of the standard 2-week startup period. The scenario simulation was then also run for a period of two weeks, which admittedly might be somewhat long for this scenario of absent workers. This 2-week production period was necessary in order to obtain realistic average daily production figures, in view of the stochasticism present in the model. Alternately, as Table IX indicates, one could view these scenarios as representing down machines at the affected work stations.

In any event, the results of Table IX show a dramatic decrease in production in this case of absent workers. As expected, the production drop is more serious for workers absent along the critical manufacturing route. Indeed, one would expect, in the latter case, the average production rate to decrease even further with time (longer than two weeks), specifically down to 6,400 pairs/day. This latter figure corresponds to an average processing time of 0.075 minute/pair, which results if the number of work stations dedicated to making right flies (on the critical route, unit processing time of 0.300 minute/pair) is permanently reduced from 5 to 4. The other indicators of manufacturing performance, average residence time and work-in-process inventory, are also impacted negatively in both of these scenario variations. That is, they both increase, more so for workers absent on the critical route, relative to the base case.

The second scenario presented in Table IX pertains to the training of new employees, again on and off of the critical manufacturing route. One each of three different work stations was again impacted in both cases. Representation of this scenario was achieved by assuming that any worker trainee performed at 60% of the production level of a trained employee. Thus, for example, in the case of making right flies (D6, five work stations total), both the mean value and standard deviation for this unit processing time were increased by:

$$\frac{(4)(1) + (1)(1/0.6)}{5} = 1.133$$

of their normal values (see Table VI). Specifically, the mean value and standard deviation (15% of mean) for this operation were increased from 3600 and 540 to 4080 and 612 GPSS time units, respectively, per transaction (120 pairs). Similar arithmetic was performed for the other impacted operations in this scenario.

An alternate interpretation of this second scenario, related to the first scenario, is also possible. That is, this second one could be construed as representing absent workers but temporarily replaced with utility or cross-trained workers, functioning at lower efficiency levels. These second scenario variations were also run for a 2-week production period, after the standard 2-week startup period under normal operating conditions.

As expected, the results from Table IX show a deleterious effect on all of the manufacturing parameters -- average daily production rate (decrease), average residence time (increase) and work-in-process inventory (increase), when new or cross-trained employees are used to replace normal production workers. And again, these results are more dramatic when work stations along the critical manufacturing route are impacted.

The third and last scenario explored corresponded to the introduction of new and more efficient equipment at selected work stations (same ones as in the preceding scenarios). Specifically, it was assumed that each new type of equipment was 25% more efficient (productive) than the machines being replaced. Thus, again using the operation of right fly making as the example, the original values (Table VI) of the mean and standard deviation for this operation were both multiplied by 1/1.25 = 0.8, to yield shorter processing times. These simulations were also run for a 2-week production period, following a 2-week startup period. For this latter period, however, it was assumed that the new equipment was already in place, so that more realistic statistical output results would be obtained for the production period.

The results for this third scenario, from Table IX, are certainly not as dramatic as in the preceding scenarios. Thus, only about a 1% daily production rate increase is observed when new equipment is introduced at the two work stations along the critical manufacturing route, and a small production rate decrease is actually seen in the non-critical route variation. Both of these results are most probably within the noise level generated by the assumed stochasticism in the model. A similar comment applies to the other manufacturing performance indicators except for, perhaps, the WIP inventory of trouser parts, where a significant reduction is seen in the critical case. In any event, the essential point here is that not enough has been done (i.e., not enough money has been spent) to improve the production rate in this third scenario. In effect, all that the introduction of this limited amount of new equipment has served to do is to create some additional imbalance in the plant. Clearly, if increased production is the objective, then additional investment in new or more equipment, certainly on and perhaps off the critical manufacturing route, would be necessary.

Conclusions

The first phase of this work clearly demonstrated the applicability of discrete-event simulation to a large commercial utility trouser manufacturing facility. The simulation results from the GPSS model are in good agreement with the limited production data, theoretical analyses and intuitional considerations. Despite the large size of the plant modelled here, however, this work by no means demonstrates the complete power and capabilities of discrete - event simulation, as applied to apparel manufacturing.

As discussed earlier, discrete-event simulation systems generally have the capability of representing stochastic or random events, resulting from human factors. Assuming that such data are available or can be estimated, standard probability distribution functions (e.g., uniform, normal, triangular, etc) can be employed for this purpose, as well as empirical, user-supplied distributions, as from a plant histogram. Thus, various levels of operator skill, training and availability at any given work station can be handled by representing the unit processing time in some such statistical fashion. Similarly, defects in product quality, requiring partial rework, can be simulated in statistical fashion. Numbers of work stations and processing times thereat can be easily varied to simulate different production scenarios (e.g., reduced workforce, increased demand, different maintenance practices, etc). Also, by proper selection of the operand value(s) for the initial GENERATE block, the expected production rate for a given configuration could then be determined as simulation output.

Thus, the second phase of this work extended the applicability of a discrete-event simulation language, specifically GPSS/PC [10], to the modelling and analysis of a high-technology trouser manufacturing facility. This capability should be useful in either an engineering or production environment. That is, engineers could use this tool for the design of new facilities, expansion of existing facilities, line balancing, economic analysis, and a number of other useful applications. Similarly, production personnel could employ such a model on a day-to-day basis for planning and scheduling purposes. Strictly speaking, the model described in this work is not an on-line simulation tool. Each of the scenarios presented herein, however, required ten or less minutes of PC execution time, including that required for the startup or warmup period. This is certainly a rapid enough turnaround time for supplying answers to many production-related questions. Finally, it should be clear that discrete-event simulation can be readily applied to the manufacture of apparel items other than trousers.

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Appendix A

Coding for GPSS Model of a Utility Trouser Manufacturing Plant

```
 ;  GPSS/PC Program File LPT1:.  (V 2, # 38796)  05-24-1990 12:17:42
10 **********************************************************************
20 *                              TROUSER MANUFACTURING PLANT
30 **********************************************************************
40 ABP        STORAGE       13
50 ALUP       STORAGE       22
60 AWB        STORAGE       11
70 BEND       STORAGE       13
80 BHEM       STORAGE       3
90 BHOL       STORAGE       3
100 BLAB      STORAGE       3
110 BUTB      STORAGE       4
120 BFLY      STORAGE       3
130 CLIP      STORAGE       2
140 CODER     STORAGE       14
150 CRSE      STORAGE       4
160 CRPC      STORAGE       4
170 CUTTR     STORAGE       11
180 DARTS     STORAGE       4
190 FHEM      STORAGE       3
200 FOLD      STORAGE       11
210 FPOC      STORAGE       13
220 INS       STORAGE       12
230 INSP      STORAGE       19
240 JOINT     STORAGE       6
250 LFLY      STORAGE       4
260 LUPS      STORAGE       2
270 MFLY      STORAGE       1
280 PRES      STORAGE       5
290 RFLY      STORAGE       5
300 SBTN      STORAGE       3
310 SEAM      STORAGE       11
320 SEAT      STORAGE       5
330 SETL      STORAGE       7
340 SETR      STORAGE       7
350 SLAB      STORAGE       5
360 SLDE      STORAGE       7
370 SPRED     STORAGE       4
380 STCH      STORAGE       2
390 TOPF      STORAGE       5
400 TOPS      STORAGE       4
410 JIT       TABLE         M1,800,40,9
420 *****Model segment 1 ******
430           GENERATE      960,,2
440           ENTER         SPRED
450           ADVANCE       3000
460           LEAVE         SPRED
470           QUEUE         QCUTR
480           ENTER         CUTTR
490           DEPART        QCUTR
500           ADVANCE       10000
510           LEAVE         CUTTR
520           QUEUE         QCODE
```

```
530           ENTER        CODER
540           DEPART       QCODE
550           ADVANCE      13000
560           LEAVE        CODER
570           SPLIT        1,BPOCS
580           SPLIT        1,BPANS
590           SPLIT        1,FLIES
600           SPLIT        1,FPOCS
610           SPLIT        1,FPANS
620           SPLIT        1,BANDS
630           TRANSFER     ,BLUPS
640 *****Model segment 2 *****
650 BPOCS     ADVANCE                          ;Back pocket matl dist
660           QUEUE        QBHEM               ;waiting for machine
670           ENTER        BHEM
680           DEPART       QBHEM               ;depart machine waiting line
690           ADVANCE      2672
700           LEAVE        BHEM                ;machine finished
710           QUEUE        QCLIP
720           ENTER        CLIP                ;clip/stitch back pocket
730           DEPART       QCLIP
740           ADVANCE      1392
750           LEAVE        CLIP
760           QUEUE        QBHOL               ;line for button hole machin
770           ENTER        BHOL
780           DEPART       QBHOL
790           ADVANCE      2464
800           LEAVE        BHOL
810           QUEUE        QCRSE               ;crease back pocket
820           ENTER        CRSE
830           DEPART       QCRSE
840           ADVANCE      3840
850           LEAVE        CRSE
860           QUEUE        QBPOC
870           TRANSFER     ,FBACK
880 *****Model segment 3 ******
890 BPANS     ADVANCE                          ;Back panel matl dist & code
900           QUEUE        QBLAB
910           ENTER        BLAB                ;sew back label
920           DEPART       QBLAB
930           ADVANCE      2672
940           LEAVE        BLAB
950           QUEUE        QDART
960           ENTER        DARTS               ;sew darts on back panel
970           DEPART       QDART
980           ADVANCE      3232
990           LEAVE        DARTS
1000          QUEUE        QTOPS
1010          ENTER        TOPS                ;topstitch parts
1020          DEPART       QTOPS
1030          ADVANCE      3152
1040          LEAVE        TOPS
1050          QUEUE        QSBTN
1060          ENTER        SBTN                ;sew buttons on back panel
```

```
1070         DEPART       QSBTN
1080         ADVANCE      2352
1090         LEAVE        SBTN
1100         QUEUE        QBPAN
1110 FBACK   ASSEMBLE     2                  ;combine back panel & pocke
1120         DEPART       QBPOC
1130         DEPART       QBPAN
1140         QUEUE        QABP
1150         ENTER        ABP
1160         DEPART       QABP
1170         ADVANCE      12048              ;attach/set back pocket
1180         LEAVE        ABP
1190         QUEUE        QBCK
1200         TRANSFER     ,FBKS
1210 *****Model segment 4 *****
1220 FLIES   ADVANCE                         ;fly material dist & coded
1230         QUEUE        QMFLY
1240         ENTER        MFLY               ;make fly
1250         DEPART       QMFLY
1260         ADVANCE      688
1270         LEAVE        MFLY
1280         QUEUE        QLFLY
1290         ENTER        LFLY
1300         DEPART       QLFLY
1310         ADVANCE      3152
1320         LEAVE        LFLY
1330         QUEUE        QTOPF
1340         ENTER        TOPF               ;topstitch fly
1350         DEPART       QTOPF
1360         ADVANCE      4384
1370         LEAVE        TOPF
1380         QUEUE        QRFLY
1390         ENTER        RFLY               ;set zipper in right fly
1400         DEPART       QRFLY
1410         ADVANCE      4320
1420         LEAVE        RFLY
1430         QUEUE        QFLYS
1440         TRANSFER     ,FRNT
1450 *****Model segment 5 *****
1460 FPOCS   ADVANCE
1470         QUEUE        QFHEM
1480         ENTER        FHEM               ;hem front pockets
1490         DEPART       QFHEM
1500         ADVANCE      2672
1510         LEAVE        FHEM
1520         QUEUE        QSTCH
1530         ENTER        STCH               ;crease front pockets
1540         DEPART       QSTCH
1550         ADVANCE      1392
1560         LEAVE        STCH
1570         QUEUE        QCRPC
1580         ENTER        CRPC               ;crease front pocket
1590         DEPART       QCRPC
1600         ADVANCE      3840
```

```
1610         LEAVE       CRPC
1620         QUEUE       QFFP
1630         TRANSFER    ,FPANL              ;match front pockets
1640 *****Model segment 6 *****
1650 FPANS   ADVANCE
1660         QUEUE       QFPAN
1670 FPANL   ASSEMBLE    2
1680         DEPART      QFFP
1690         DEPART      QFPAN
1700         QUEUE       QFPOC
1710         ENTER       FPOC                ;stitch frt pocket on panel
1720         DEPART      QFPOC
1730         ADVANCE     12048
1740         LEAVE       FPOC
1750         QUEUE       QFPNL
1760 FRNT    ASSEMBLE    2                   ;assemble lt&rt flies
1770         DEPART      QFPNL
1780         DEPART      QFLYS
1790         QUEUE       QSETL
1800         ENTER       SETL                ;set left fly
1810         DEPART      QSETL
1820         ADVANCE     6464
1830         LEAVE       SETL
1840         QUEUE       QSETR
1850         ENTER       SETR                ;set right fly
1860         DEPART      QSETR
1870         ADVANCE     6016
1880         LEAVE       SETR
1890         QUEUE       QFRT
1900 FBKS    ASSEMBLE    2
1910         DEPART      QFRT
1920         DEPART      QBCK
1930         QUEUE       QSEAM
1940         ENTER       SEAM
1950         DEPART      QSEAM
1960         ADVANCE     10160
1970         LEAVE       SEAM
1980         QUEUE       QSEAT
1990         ENTER       SEAT                ;sew seat seam
2000         DEPART      QSEAT
2010         ADVANCE     4592
2020         LEAVE       SEAT
2030         QUEUE       QBPNL
2040         TRANSFER    ,BNDS               ;assembly at waist band
2050 ******Model segment 7 *****
2060 BANDS   ADVANCE
2070         QUEUE       QBNDS
2080 BNDS    ASSEMBLE    2
2090         DEPART      QBPNL
2100         DEPART      QBNDS
2110         QUEUE       QAWB
2120         ENTER       AWB                 ;attach waist band
2130         DEPART      QAWB
2140         ADVANCE     10448
```

```
2150         LEAVE       AWB
2160         QUEUE       QBFLY
2170         ENTER       BFLY                ;attach button flys
2180         DEPART      QBFLY
2190         ADVANCE     2832
2200         LEAVE       BFLY
2210         QUEUE       QBEND
2220         ENTER       BEND                ;close band ends
2230         DEPART      QBEND
2240         ADVANCE     12480
2250         LEAVE       BEND
2260         QUEUE       QSLDE
2270         ENTER       SLDE                ;slide stops on zipper
2280         DEPART      QSLDE
2290         ADVANCE     6272
2300         LEAVE       SLDE
2310         TRANSFER    ,COMBIN
2320 *****Model Segment 8*****
2330 COMBIN  QUEUE       QJOIN
2340         ENTER       JOINT               ;join fronts
2350         DEPART      QJOIN
2360         ADVANCE     5584
2370         LEAVE       JOINT
2380         QUEUE       QINS
2390         ENTER       INS                 ;sew inseam
2400         DEPART      QINS
2410         ADVANCE     10784
2420         LEAVE       INS
2430         QUEUE       QBUTB
2440         ENTER       BUTB                ;buttonhole the band
2450         DEPART      QBUTB
2460         ADVANCE     3216
2470         LEAVE       BUTB
2480         QUEUE       QEVRY
2490         TRANSFER    ,FEVRY              ;transfer to attach belt
2500 *****Model segment  9*****
2510 BLUPS   ADVANCE
2520         QUEUE       QLUPS
2530         ENTER       LUPS                ;make belt loops
2540         DEPART      QLUPS
2550         ADVANCE     1232
2560         LEAVE       LUPS
2570         QUEUE       QBL
2580 FEVRY   ASSEMBLE    2
2590         DEPART      QEVRY
2600         DEPART      QBL
2610         QUEUE       QALUP
2620         ENTER       ALUP                ;attach belt loops
2630         DEPART      QALUP
2640         ADVANCE     20688
2650         LEAVE       ALUP
2660         QUEUE       QSLAB
2670         ENTER       SLAB                ;sew labels on
2680         DEPART      QSLAB
```

```
2690          ADVANCE       4720
2700          LEAVE         SLAB
2710          QUEUE         QFOLD
2720          ENTER         FOLD                   ;press/fold
2730          DEPART        QFOLD
2740          ADVANCE       9904
2750          LEAVE         FOLD
2760          QUEUE         QPRES
2770          ENTER         PRES                   ;top press
2780          DEPART        QPRES
2790          ADVANCE       4384
2800          LEAVE         PRES
2810          QUEUE         QINSP
2820          ENTER         INSP                   ;inspect/fold
2830          DEPART        QINSP
2840          ADVANCE       17552
2850          LEAVE         INSP
2860          TABULATE      JIT
2870          TERMINATE
2880 *****Model Segment 9 *****
2890 TIMER    GENERATE      48000
2900          TERMINATE     1
2910 ****Model Segment 10 *****
2920          START         10
2930          RESET
2940          START         20
```

Appendix B

Sample Output from GPSS Model of a Utility Trouser Manufacturing Plant

(Balanced Operation)

GPSS/PC Report file REPORT.GPS. (V 2, # 38796) 05-24-1990 12:17:27 page 1

START_TIME	END_TIME	BLOCKS	FACILITIES	STORAGES	FREE_MEMORY
480002	1440000	239	0	37	148896

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
430	1	GENERATE	1000	0	0
440	2	ENTER	1000	0	0
450	3	ADVANCE	1003	3	0
460	4	LEAVE	1000	0	0
470	5	QUEUE	1000	0	0
480	6	ENTER	1000	0	0
490	7	DEPART	1000	0	0
500	8	ADVANCE	1010	10	0
510	9	LEAVE	1000	0	0
520	10	QUEUE	1000	0	0
530	11	ENTER	1000	0	0
540	12	DEPART	1000	0	0
550	13	ADVANCE	1014	14	0
560	14	LEAVE	1000	0	0
570	15	SPLIT	1000	0	0
580	16	SPLIT	1000	0	0
590	17	SPLIT	1000	0	0
600	18	SPLIT	1000	0	0
610	19	SPLIT	1000	0	0
620	20	SPLIT	1000	0	0
630	21	TRANSFER	1000	0	0
650	BPOCS	ADVANCE	1000	0	0
660	23	QUEUE	1000	0	0
670	24	ENTER	1000	0	0
680	25	DEPART	1000	0	0
690	26	ADVANCE	1002	2	0
700	27	LEAVE	1000	0	0
710	28	QUEUE	1000	0	0
720	29	ENTER	1000	0	0
730	30	DEPART	1000	0	0
740	31	ADVANCE	1002	2	0
750	32	LEAVE	1000	0	0
760	33	QUEUE	1000	0	0
770	34	ENTER	1000	0	0
780	35	DEPART	1000	0	0
790	36	ADVANCE	1002	2	0
800	37	LEAVE	1000	0	0
810	38	QUEUE	1000	0	0
820	39	ENTER	1000	0	0
830	40	DEPART	1000	0	0
840	41	ADVANCE	1004	4	0
850	42	LEAVE	1000	0	0
860	43	QUEUE	1000	0	0
870	44	TRANSFER	1000	0	0
890	BPANS	ADVANCE	1000	0	0
900	46	QUEUE	1000	0	0

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
910	47	ENTER	1000	0	0
920	48	DEPART	1000	0	0
930	49	ADVANCE	1002	2	0
940	50	LEAVE	1000	0	0
950	51	QUEUE	1000	0	0
960	52	ENTER	1000	0	0
970	53	DEPART	1000	0	0
980	54	ADVANCE	1004	4	0
990	55	LEAVE	1000	0	0
1000	56	QUEUE	1000	0	0
1010	57	ENTER	1000	0	0
1020	58	DEPART	1000	0	0
1030	59	ADVANCE	1003	3	0
1040	60	LEAVE	1000	0	0
1050	61	QUEUE	1000	0	0
1060	62	ENTER	1000	0	0
1070	63	DEPART	1000	0	0
1080	64	ADVANCE	1002	2	0
1090	65	LEAVE	1000	0	0
1100	66	QUEUE	1000	0	0
1110	FBACK	ASSEMBLE	2001	1	0
1120	68	DEPART	1000	0	0
1130	69	DEPART	1000	0	0
1140	70	QUEUE	1000	0	0
1150	71	ENTER	1000	0	0
1160	72	DEPART	1000	0	0
1170	73	ADVANCE	1013	13	0
1180	74	LEAVE	1000	0	0
1190	75	QUEUE	1000	0	0
1200	76	TRANSFER	1000	0	0
1220	FLIES	ADVANCE	1000	0	0
1230	78	QUEUE	1000	0	0
1240	79	ENTER	1000	0	0
1250	80	DEPART	1000	0	0
1260	81	ADVANCE	1000	0	0
1270	82	LEAVE	1000	0	0
1280	83	QUEUE	1000	0	0
1290	84	ENTER	1000	0	0
1300	85	DEPART	1000	0	0
1310	86	ADVANCE	1004	4	0
1320	87	LEAVE	1000	0	0
1330	88	QUEUE	1000	0	0
1340	89	ENTER	1000	0	0
1350	90	DEPART	1000	0	0
1360	91	ADVANCE	1004	4	0
1370	92	LEAVE	1000	0	0
1380	93	QUEUE	1000	0	0
1390	94	ENTER	1000	0	0
1400	95	DEPART	1000	0	0
1410	96	ADVANCE	1005	5	0

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
1420	97	LEAVE	1000	0	0
1430	98	QUEUE	1000	0	0
1440	99	TRANSFER	1000	0	0
1460	FPOCS	ADVANCE	1000	0	0
1470	101	QUEUE	1000	0	0
1480	102	ENTER	1000	0	0
1490	103	DEPART	1000	0	0
1500	104	ADVANCE	1002	2	0
1510	105	LEAVE	1000	0	0
1520	106	QUEUE	1000	0	0
1530	107	ENTER	1000	0	0
1540	108	DEPART	1000	0	0
1550	109	ADVANCE	1002	2	0
1560	110	LEAVE	1000	0	0
1570	111	QUEUE	1000	0	0
1580	112	ENTER	1000	0	0
1590	113	DEPART	1000	0	0
1600	114	ADVANCE	1004	4	0
1610	115	LEAVE	1000	0	0
1620	116	QUEUE	1000	0	0
1630	117	TRANSFER	1000	0	0
1650	FPANS	ADVANCE	1000	0	0
1660	119	QUEUE	1000	0	0
1670	FPANL	ASSEMBLE	2008	8	0
1680	121	DEPART	1000	0	0
1690	122	DEPART	1000	0	0
1700	123	QUEUE	1000	0	0
1710	124	ENTER	1000	0	0
1720	125	DEPART	1000	0	0
1730	126	ADVANCE	1012	12	0
1740	127	LEAVE	1000	0	0
1750	128	QUEUE	1000	0	0
1760	FRNT	ASSEMBLE	2007	7	0
1770	130	DEPART	1000	0	0
1780	131	DEPART	1000	0	0
1790	132	QUEUE	1000	0	0
1800	133	ENTER	1000	0	0
1810	134	DEPART	1000	0	0
1820	135	ADVANCE	1007	7	0
1830	136	LEAVE	1000	0	0
1840	137	QUEUE	1000	0	0
1850	138	ENTER	1000	0	0
1860	139	DEPART	1000	0	0
1870	140	ADVANCE	1006	6	0
1880	141	LEAVE	1000	0	0
1890	142	QUEUE	1000	0	0
1900	FBKS	ASSEMBLE	2009	9	0
1910	144	DEPART	1000	0	0
1920	145	DEPART	1000	0	0
1930	146	QUEUE	1000	0	0

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
1940	147	ENTER	1000	0	0
1950	148	DEPART	1000	0	0
1960	149	ADVANCE	1011	11	0
1970	150	LEAVE	1000	0	0
1980	151	QUEUE	1000	0	0
1990	152	ENTER	1000	0	0
2000	153	DEPART	1000	0	0
2010	154	ADVANCE	1005	5	0
2020	155	LEAVE	1000	0	0
2030	156	QUEUE	1000	0	0
2040	157	TRANSFER	1000	0	0
2060	BANDS	ADVANCE	1000	0	0
2070	159	QUEUE	1000	0	0
2080	BNDS	ASSEMBLE	2049	49	0
2090	161	DEPART	1000	0	0
2100	162	DEPART	1000	0	0
2110	163	QUEUE	1000	0	0
2120	164	ENTER	1000	0	0
2130	165	DEPART	1000	0	0
2140	166	ADVANCE	1011	11	0
2150	167	LEAVE	1000	0	0
2160	168	QUEUE	1000	0	0
2170	169	ENTER	1000	0	0
2180	170	DEPART	1000	0	0
2190	171	ADVANCE	1003	3	0
2200	172	LEAVE	1000	0	0
2210	173	QUEUE	1000	0	0
2220	174	ENTER	1000	0	0
2230	175	DEPART	1000	0	0
2240	176	ADVANCE	1013	13	0
2250	177	LEAVE	1000	0	0
2260	178	QUEUE	1000	0	0
2270	179	ENTER	1000	0	0
2280	180	DEPART	1000	0	0
2290	181	ADVANCE	1006	6	0
2300	182	LEAVE	1000	0	0
2310	183	TRANSFER	1000	0	0
2330	COMBIN	QUEUE	1000	0	0
2340	185	ENTER	1000	0	0
2350	186	DEPART	1000	0	0
2360	187	ADVANCE	1006	6	0
2370	188	LEAVE	1000	0	0
2380	189	QUEUE	1000	0	0
2390	190	ENTER	1000	0	0
2400	191	DEPART	1000	0	0
2410	192	ADVANCE	1011	11	0
2420	193	LEAVE	1000	0	0
2430	194	QUEUE	1000	0	0
2440	195	ENTER	1000	0	0
2450	196	DEPART	1000	0	0

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
2460	197	ADVANCE	1004	4	0
2470	198	LEAVE	1000	0	0
2480	199	QUEUE	1000	0	0
2490	200	TRANSFER	1000	0	0
2510	BLUPS	ADVANCE	1000	0	0
2520	202	QUEUE	1000	0	0
2530	203	ENTER	1000	0	0
2540	204	DEPART	1000	0	0
2550	205	ADVANCE	1001	1	0
2560	206	LEAVE	1000	0	0
2570	207	QUEUE	1000	0	0
2580	FEVRY	ASSEMBLE	2102	102	0
2590	209	DEPART	1000	0	0
2600	210	DEPART	1000	0	0
2610	211	QUEUE	1000	0	0
2620	212	ENTER	1000	0	0
2630	213	DEPART	1000	0	0
2640	214	ADVANCE	1021	21	0
2650	215	LEAVE	1000	0	0
2660	216	QUEUE	1000	0	0
2670	217	ENTER	1000	0	0
2680	218	DEPART	1000	0	0
2690	219	ADVANCE	1005	5	0
2700	220	LEAVE	1000	0	0
2710	221	QUEUE	1000	0	0
2720	222	ENTER	1000	0	0
2730	223	DEPART	1000	0	0
2740	224	ADVANCE	1010	10	0
2750	225	LEAVE	1000	0	0
2760	226	QUEUE	1000	0	0
2770	227	ENTER	1000	0	0
2780	228	DEPART	1000	0	0
2790	229	ADVANCE	1005	5	0
2800	230	LEAVE	1000	0	0
2810	231	QUEUE	1000	0	0
2820	232	ENTER	1000	0	0
2830	233	DEPART	1000	0	0
2840	234	ADVANCE	1018	18	0
2850	235	LEAVE	1000	0	0
2860	236	TABULATE	1000	0	0
2870	237	TERMINATE	1000	0	0
2890	TIMER	GENERATE	20	0	0
2900	239	TERMINATE	20	0	0

QUEUE	MAX	CONT.	ENTRIES	ENTRIES(0)	AVE.CONT.	AVE.TIME	AVE.(-0)	RETRY
QCUTR	1	0	1000	1000	0.00	0.00	0.00	0
QCODE	1	0	1000	1000	0.00	0.00	0.00	0
QBHEM	1	0	1000	1000	0.00	0.00	0.00	0
QCLIP	1	0	1000	1000	0.00	0.00	0.00	0

QUEUE	MAX	CONT.	ENTRIES	ENTRIES(0)	AVE.CONT.	AVE.TIME	AVE.(-0)	RETRY
QBHOL	1	0	1000	1000	0.00	0.00	0.00	0
QCRSE	1	0	1000	1000	0.00	0.00	0.00	0
QBPOC	2	1	1001	0	1.08	1038.96	1038.96	0
QBLAB	1	0	1000	1000	0.00	0.00	0.00	0
QDART	1	0	1000	1000	0.00	0.00	0.00	0
QTOPS	1	0	1000	1000	0.00	0.00	0.00	0
QSBTN	1	0	1000	1000	0.00	0.00	0.00	0
QBPAN	1	0	1000	1000	0.00	0.00	0.00	0
QABP	1	0	1000	1000	0.00	0.00	0.00	0
QBCK	10	9	1009	0	9.35	8895.92	8895.92	0
QMFLY	1	0	1000	1000	0.00	0.00	0.00	0
QLFLY	1	0	1000	1000	0.00	0.00	0.00	0
QTOPF	1	0	1000	1000	0.00	0.00	0.00	0
QRFLY	1	0	1000	1000	0.00	0.00	0.00	0
QFLYS	8	7	1007	0	7.72	7356.49	7356.49	0
QFHEM	1	0	1000	1000	0.00	0.00	0.00	0
QSTCH	1	0	1000	1000	0.00	0.00	0.00	0
QCRPC	1	0	1000	1000	0.00	0.00	0.00	0
QFFP	1	0	1000	1000	0.00	0.00	0.00	0
QFPAN	9	8	1008	0	8.23	7841.25	7841.25	0
QFPOC	1	0	1000	1000	0.00	0.00	0.00	0
QFPNL	1	0	1000	1000	0.00	0.00	0.00	0
QSETL	1	0	1000	1000	0.00	0.00	0.00	0
QSETR	1	0	1000	1000	0.00	0.00	0.00	0
QFRT	1	0	1000	1000	0.00	0.00	0.00	0
QSEAM	1	0	1000	1000	0.00	0.00	0.00	0
QSEAT	1	0	1000	1000	0.00	0.00	0.00	0
QBPNL	1	0	1000	1000	0.00	0.00	0.00	0
QBNDS	50	49	1049	0	49.15	44979.89	44979.89	0
QAWB	1	0	1000	1000	0.00	0.00	0.00	0
QBFLY	1	0	1000	1000	0.00	0.00	0.00	0
QBEND	1	0	1000	1000	0.00	0.00	0.00	0
QSLDE	1	0	1000	1000	0.00	0.00	0.00	0
QJOIN	1	0	1000	1000	0.00	0.00	0.00	0
QINS	1	0	1000	1000	0.00	0.00	0.00	0
QBUTB	1	0	1000	1000	0.00	0.00	0.00	0
QEVRY	1	0	1000	1000	0.00	0.00	0.00	0
QLUPS	1	0	1000	1000	0.00	0.00	0.00	0
QBL	102	102	1102	0	101.63	88537.02	88537.02	0
QALUP	1	0	1000	1000	0.00	0.00	0.00	0
QSLAB	1	0	1000	1000	0.00	0.00	0.00	0
QFOLD	1	0	1000	1000	0.00	0.00	0.00	0
QPRES	1	0	1000	1000	0.00	0.00	0.00	0
QINSP	1	0	1000	1000	0.00	0.00	0.00	0

STORAGE	CAP.	REMAIN.	MIN.	MAX.	ENTRIES	AVL.	AVE.C.	UTIL.	RETRY	DELAY
ABP	13	0	12	13	1013	1	12.55	0.965	0	0
ALUP	22	1	21	22	1021	1	21.55	0.980	0	0
AWB	11	0	10	11	1011	1	10.88	0.989	0	0

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STORAGE	CAP.	REMAIN.	MIN.	MAX.	ENTRIES	AVL.	AVE.C.	UTIL.	RETRY	DELAY
BEND	13	0	12	13	1013	1	13.00	1.000	0	0
BHEM	3	1	2	3	1002	1	2.78	0.928	0	0
BHOL	3	1	2	3	1002	1	2.57	0.856	0	0
BLAB	3	1	2	3	1002	1	2.78	0.928	0	0
BUTB	4	0	3	4	1004	1	3.35	0.837	0	0
BFLY	3	0	2	3	1003	1	2.95	0.983	0	0
CLIP	2	0	1	2	1002	1	1.45	0.725	0	0
CODER	14	0	13	14	1014	1	13.54	0.967	0	0
CRSE	4	0	3	4	1004	1	4.00	1.000	0	0
CRPC	4	0	3	4	1004	1	4.00	1.000	0	0
CUTTR	11	1	10	11	1010	1	10.42	0.947	0	0
DARTS	4	0	3	4	1004	1	3.37	0.842	0	0
FHEM	3	1	2	3	1002	1	2.78	0.928	0	0
FOLD	11	1	10	11	1010	1	10.32	0.938	0	0
FPOC	13	1	12	13	1012	1	12.55	0.965	0	0
INS	12	1	11	12	1011	1	11.23	0.936	0	0
INSP	19	1	18	19	1018	1	18.28	0.962	0	0
JOINT	6	0	5	6	1006	1	5.82	0.969	0	0
LFLY	4	0	3	4	1004	1	3.28	0.821	0	0
LUPS	2	1	1	2	1001	1	1.28	0.642	0	0
MFLY	1	1	0	1	1000	1	0.72	0.717	0	0
PRES	5	0	4	5	1005	1	4.57	0.913	0	0
RFLY	5	0	4	5	1005	1	4.50	0.900	0	0
SBTN	3	1	2	3	1002	1	2.45	0.817	0	0
SEAM	11	0	10	11	1011	1	10.58	0.962	0	0
SEAT	5	0	4	5	1005	1	4.78	0.957	0	0
SETL	7	0	6	7	1007	1	6.73	0.962	0	0
SETR	7	1	6	7	1006	1	6.27	0.895	0	0
SLAB	5	0	4	5	1005	1	4.92	0.983	0	0
SLDE	7	1	6	7	1006	1	6.53	0.933	0	0
SPRED	4	1	3	4	1003	1	3.13	0.781	0	0
STCH	2	0	1	2	1002	1	1.45	0.725	0	0
TOPF	5	1	4	5	1004	1	4.57	0.913	0	0
TOPS	4	1	3	4	1003	1	3.28	0.821	0	0

TABLE	MEAN	STD.DEV.	RETRY	RANGE	FREQUENCY	CUM.%
JIT	182048.00	0.00	0			
				1080 -	1000	100.00

XACT_GROUP	GROUP_SIZE	RETRY
POSITION	0	0

Appendix C

Coding for GPSS Model of a Hi-Tech Trouser Manufacturing Plant

```
; GPSS/PC Program File LPT1:.  (V 2, # 38796)  05-24-1990 11:47:31
10 ***************************************************************************
20 *                        HI-TECH MODEL
30 ***************************************************************************
40 ABL      STORAGE      10
50 ABP      STORAGE      8
60 AFLY     STORAGE      7
70 AFP      STORAGE      8
80 AWB      STORAGE      8
90 BEND     STORAGE      8
100 BHEM    STORAGE      4
110 BHOL    STORAGE      2
120 BLAB    STORAGE      3
130 BUTN    STORAGE      3
140 CODER   STORAGE      5
150 CUTTR   STORAGE      4
160 DARTS   STORAGE      4
170 FHEM    STORAGE      4
180 FINF    STORAGE      6
190 FOLD    STORAGE      11
200 INS     STORAGE      12
210 JOINT   STORAGE      5
220 LFLY    STORAGE      1
230 LUPS    STORAGE      2
240 MBKS    STORAGE      1
250 MFTS    STORAGE      1
260 MFBS    STORAGE      1
270 PRES    STORAGE      5
280 RFLY    STORAGE      5
290 SEAM    STORAGE      5
300 SIDE    STORAGE      11
310 SPRED   STORAGE      3
320 SPEC    STORAGE      19
330 TACK    STORAGE      5
340 TFLY    STORAGE      5
350 TOPS    STORAGE      4
360 UPS     STORAGE      2
370 *************************
380 SNORM   FUNCTION     RN1,C25
0,-5/ .00003,-4/ .00135, -3/ .00621,-2.5/ .02275,-2/ .06681,-1.5/ .11507,-1.2
.15866,-1/ .21186,-.8/ .27425,-.6/.34458,-.4/ .42074,-.2/ .5,0 / .57926,.2
.65542,.4/ .72575,.6/ .78814,.8/ .84134,1/ .88493,1.2/ .93319,1.5/ .97725,2
.99379,2.5/ .99865,3/ .99997,4/ 1,5
390 MEAN    FUNCTION     P4,D33
1,924/ 2,2448/ 3,2472/ 4,1200/ 5,660/ 6,3600/ 7,3600/8,2496/ 9,2364/ 10,2004
11,5760/ 12,3384/ 13,5760/ 14,4848/ 15,3288/ 16,4188/ 17,480/ 18,1200/ 19,7620
20,8088/ 21,5244/ 22,5208/ 23,1572/ 24,7152/ 25,3540/ 26,7428/ 27,3288
28,13164/ 29,1542/ 30,2057/ 31,2572/ 32,480/ 33,480
400 SDEV    FUNCTION     P4,D33
1,139/ 2,367/ 3,371/ 4,180/ 5,99/ 6,540/ 7,540/ 8,374/ 9,355/ 10,301/ 11,364
12,508/ 13,864/ 14,727/ 15,493/ 16,628/ 17,72/ 18,180/ 19,1143/ 20,1213/
21,787/ 22,781/ 23,236/ 24,1073/ 25,531/ 26,1114/ 27,493/ 28,1975/ 29,231
30,309/ 31,386/ 32,72/ 33,72
410 SERVE   FVARIABLE    FN$SDEV#FN$SNORM+FN$MEAN
```

```
415 JIT     TABLE       M1,600,30,9
420 *****Model segment 1 ******
430         GENERATE    685,,2
440         ENTER       SPRED
450         ASSIGN      4,29
460         ADVANCE     V$SERVE
470         LEAVE       SPRED
480         QUEUE       QCUTR
490         ENTER       CUTTR
500         DEPART      QCUTR
510         ASSIGN      4,30
520         ADVANCE     V$SERVE
530         LEAVE       CUTTR
540         QUEUE       QCODE
550         ENTER       CODER
560         DEPART      QCODE
570         ASSIGN      4,31
580         ADVANCE     V$SERVE
590         LEAVE       CODER
600         SPLIT       1,BPOCS
610         SPLIT       1,BPANS
620         SPLIT       1,FLIES
630         SPLIT       1,FPOCS
640         SPLIT       1,FPANS
650         SPLIT       1,BLUPS
660         QUEUE       QBNDS
670         TRANSFER    ,FEVRY
680 *****Model segment 2 *****
690 BPOCS   ADVANCE                         ;Back pocket matl dist
700         QUEUE       QBHEM               ;waiting for machine
710         ENTER       BHEM
720         DEPART      QBHEM               ;depart machine waiting line
730         ASSIGN      4,3
740         ADVANCE     V$SERVE
750         LEAVE       BHEM                ;machine finished
760         QUEUE       QBHOL               ;line for button hole machin
770         ENTER       BHOL
780         DEPART      QBHOL
790         ASSIGN      4,4
800         ADVANCE     V$SERVE
810         LEAVE       BHOL
820         QUEUE       QBPOC
830         TRANSFER    ,FBACK
840 *****Model segment 3 ******
850 BPANS   ADVANCE                         ;Back panel matl dist & code
860         QUEUE       QBPAN
870 FBACK   ASSEMBLE    2
880         DEPART      QBPOC
890         DEPART      QBPAN
900         QUEUE       QMBKS
910         ENTER       MBKS
920         DEPART      QMBKS
930         ASSIGN      4,32
940         ADVANCE     V$SERVE
```

```
950         LEAVE       MBKS
960         QUEUE       QDART
970         ENTER       DARTS
980         DEPART      QDART
990         ASSIGN      4,8
1000        ADVANCE     V$SERVE
1010        LEAVE       DARTS
1020        QUEUE       QTOPS
1030        ENTER       TOPS
1040        DEPART      QTOPS
1050        ASSIGN      4,9
1060        ADVANCE     V$SERVE
1070        LEAVE       TOPS
1080        QUEUE       QBLAB
1090        ENTER       BLAB
1100        DEPART      QBLAB
1110        ASSIGN      4,10
1120        ADVANCE     V$SERVE
1130        LEAVE       BLAB
1140        QUEUE       QABP
1150        ENTER       ABP
1160        DEPART      QABP
1170        ASSIGN      4,11
1180        ADVANCE     V$SERVE
1190        LEAVE       ABP
1200        QUEUE       QSEAM
1210        ENTER       SEAM
1220        DEPART      QSEAM
1230        ASSIGN      4,12
1240        ADVANCE     V$SERVE
1250        LEAVE       SEAM
1260        QUEUE       QMB
1270        TRANSFER    ,FEVRY             ;sent to segment 7
1280 *****Model segment 4 *****
1290 FLIES  ADVANCE                        ;fly material dist & coded
1300        QUEUE       QLFLY
1310        ENTER       LFLY
1320        DEPART      QLFLY
1330        ASSIGN      4,5
1340        ADVANCE     V$SERVE
1350        LEAVE       LFLY
1360        QUEUE       QRFLY
1370        ENTER       RFLY
1380        DEPART      QRFLY
1390        ASSIGN      4,6
1400        ADVANCE     V$SERVE
1410        LEAVE       RFLY
1420        QUEUE       QJOIN
1430        ENTER       JOINT
1440        DEPART      QJOIN
1450        ASSIGN      4,7
1460        ADVANCE     V$SERVE
1470        LEAVE       JOINT
1480        QUEUE       QFLYS
1490        TRANSFER    ,FPANL             ;sent to segment 6
```

```
1500 *****Model segment 5 *****
1510 FPOCS  ADVANCE                               ;front pocket matl dist
1520        QUEUE       QFHEM
1530        ENTER       FHEM
1540        DEPART      QFHEM
1550        ASSIGN      4,2
1560        ADVANCE     V$SERVE
1570        LEAVE       FHEM
1580        QUEUE       QFPOC
1590        TRANSFER    ,FPANL                    ;sent to segment 6
1600 *****Model segment 6 *****
1610 FPANS  ADVANCE
1620        QUEUE       QFPAN
1630 FPANL  ASSEMBLE    3                         ;gather and destroy segments
1640        DEPART      QFLYS                     ;destroy segment 4
1650        DEPART      QFPOC                     ;destroy segment 5
1660        DEPART      QFPAN
1670        QUEUE       QMFTS
1680        ENTER       MFTS
1690        DEPART      QMFTS
1700        ASSIGN      4,33
1710        ADVANCE     V$SERVE
1720        LEAVE       MFTS
1730        QUEUE       QAFP
1740        ENTER       AFP
1750        DEPART      QAFP
1760        ASSIGN      4,13
1770        ADVANCE     V$SERVE
1780        LEAVE       AFP
1790        QUEUE       QAFLY
1800        ENTER       AFLY
1810        DEPART      QAFLY
1820        ASSIGN      4,14
1830        ADVANCE     V$SERVE
1840        LEAVE       AFLY
1850        QUEUE       QTFLY
1860        ENTER       TFLY
1870        DEPART      QTFLY
1880        ASSIGN      4,15
1890        ADVANCE     V$SERVE
1900        LEAVE       TFLY
1910        QUEUE       QFINF
1920        ENTER       FINF
1930        DEPART      QFINF
1940        ASSIGN      4,16
1950        ADVANCE     V$SERVE
1960        LEAVE       FINF
1970        QUEUE       QMF
1980        TRANSFER    ,FEVRY                    ;sent to segment 7
1990 *****Model segment 7*****
2000 BLUPS  ADVANCE
2010        QUEUE       QLUPS
2020        ENTER       LUPS
2030        DEPART      QLUPS
2040        ASSIGN      4,1
```

```
2050         ADVANCE     V$SERVE
2060         LEAVE       LUPS
2070         QUEUE       QBL
2080 FEVRY   ASSEMBLE    4
2090         DEPART      QMB               ;segment 3 destroyed
2100         DEPART      QMF
2110         DEPART      QBNDS
2120         DEPART      QBL
2130         QUEUE       QMFBS
2140         ENTER       MFBS
2150         DEPART      QMFBS
2160         ASSIGN      4,17
2170         ADVANCE     V$SERVE
2180         LEAVE       MFBS
2190         QUEUE       QUPS
2200         ENTER       UPS
2210         DEPART      QUPS
2220         ASSIGN      4,18
2230         ADVANCE     V$SERVE
2240         LEAVE       UPS
2250         QUEUE       QSIDE
2260         ENTER       SIDE
2270         DEPART      QSIDE
2280         ASSIGN      4,19
2290         ADVANCE     V$SERVE
2300         LEAVE       SIDE
2310 ******Model segment 8 *******
2320         QUEUE       QINS
2330         ENTER       INS
2340         DEPART      QINS
2350         ASSIGN      4,20
2360         ADVANCE     V$SERVE
2370         LEAVE       INS
2380         QUEUE       QAWB
2390         ENTER       AWB
2400         DEPART      QAWB
2410         ASSIGN      4,21
2420         ADVANCE     V$SERVE
2430         LEAVE       AWB
2440         QUEUE       QBEND
2450         ENTER       BEND
2460         DEPART      QBEND
2470         ASSIGN      4,22
2480         ADVANCE     V$SERVE
2490         LEAVE       BEND
2500         QUEUE       QBUTN
2510         ENTER       BUTN
2520         DEPART      QBUTN
2530         ASSIGN      4,23
2540         ADVANCE     V$SERVE
2550         LEAVE       BUTN
2560         QUEUE       QABL
2570         ENTER       ABL
2580         DEPART      QABL
```

```
2590          ASSIGN       4,24
2600          ADVANCE      V$SERVE
2610          LEAVE        ABL
2620          QUEUE        QTACK
2630          ENTER        TACK
2640          DEPART       QTACK
2650          ASSIGN       4,25
2660          ADVANCE      V$SERVE
2670          LEAVE        TACK
2680          QUEUE        QFOLD
2690          ENTER        FOLD
2700          DEPART       QFOLD
2710          ASSIGN       4,26
2720          ADVANCE      V$SERVE
2730          LEAVE        FOLD
2740          QUEUE        QPRES
2750          ENTER        PRES
2760          DEPART       QPRES
2770          ASSIGN       4,27
2780          ADVANCE      V$SERVE
2790          LEAVE        PRES
2800          QUEUE        QSPEC
2810          ENTER        SPEC
2820          DEPART       QSPEC
2830          ASSIGN       4,28
2840          ADVANCE      V$SERVE
2850          LEAVE        SPEC
2855          TABULATE     JIT
2860          TERMINATE
2870 ******Model segment 9*****
2880 TIMER    GENERATE     48000
2890          TERMINATE    1
2900 *****Control Statements*****
2910          START        10
2920          RESET
2930          START        20
```

Appendix D

Sample Output from GPSS Model of a Hi-Tech Trouser Manufacturing Plant (Base Case of 15% Stochasticism)

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START_TIME	END_TIME	BLOCKS	FACILITIES	STORAGES	FREE_MEMORY
480032	960000	240	0	33	89424

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
430	1	GENERATE	701	0	0
440	2	ENTER	701	0	0
450	3	ASSIGN	701	0	0
460	4	ADVANCE	703	2	0
470	5	LEAVE	701	0	0
480	6	QUEUE	701	0	0
490	7	ENTER	701	0	0
500	8	DEPART	701	0	0
510	9	ASSIGN	701	0	0
520	10	ADVANCE	703	3	0
530	11	LEAVE	700	0	0
540	12	QUEUE	700	0	0
550	13	ENTER	700	0	0
560	14	DEPART	700	0	0
570	15	ASSIGN	700	0	0
580	16	ADVANCE	705	4	0
590	17	LEAVE	701	0	0
600	18	SPLIT	701	0	0
610	19	SPLIT	701	0	0
620	20	SPLIT	701	0	0
630	21	SPLIT	701	0	0
640	22	SPLIT	701	0	0
650	23	SPLIT	701	0	0
660	24	QUEUE	701	0	0
670	25	TRANSFER	701	0	0
690	BPOCS	ADVANCE	701	0	0
700	27	QUEUE	701	0	0
710	28	ENTER	701	0	0
720	29	DEPART	701	0	0
730	30	ASSIGN	701	0	0
740	31	ADVANCE	705	4	0
750	32	LEAVE	701	0	0
760	33	QUEUE	701	0	0
770	34	ENTER	701	0	0
780	35	DEPART	701	0	0
790	36	ASSIGN	701	0	0
800	37	ADVANCE	703	2	0
810	38	LEAVE	701	0	0
820	39	QUEUE	701	0	0
830	40	TRANSFER	701	0	0
850	BPANS	ADVANCE	701	0	0
860	42	QUEUE	701	0	0
870	FBACK	ASSEMBLE	1408	6	0
880	44	DEPART	701	0	0
890	45	DEPART	701	0	0
900	46	QUEUE	701	0	0

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
910	47	ENTER	701	0	0
920	48	DEPART	701	0	0
930	49	ASSIGN	701	0	0
940	50	ADVANCE	701	1	0
950	51	LEAVE	700	0	0
960	52	QUEUE	700	0	0
970	53	ENTER	700	0	0
980	54	DEPART	700	0	0
990	55	ASSIGN	700	0	0
1000	56	ADVANCE	704	3	0
1010	57	LEAVE	701	0	0
1020	58	QUEUE	701	0	0
1030	59	ENTER	701	0	0
1040	60	DEPART	701	0	0
1050	61	ASSIGN	701	0	0
1060	62	ADVANCE	705	4	0
1070	63	LEAVE	701	0	0
1080	64	QUEUE	701	4	0
1090	65	ENTER	697	0	0
1100	66	DEPART	697	0	0
1110	67	ASSIGN	697	0	0
1120	68	ADVANCE	700	3	0
1130	69	LEAVE	697	0	0
1140	70	QUEUE	731	70	0
1150	71	ENTER	661	0	0
1160	72	DEPART	661	0	0
1170	73	ASSIGN	661	0	0
1180	74	ADVANCE	669	8	0
1190	75	LEAVE	661	0	0
1200	76	QUEUE	662	0	0
1210	77	ENTER	662	0	0
1220	78	DEPART	662	0	0
1230	79	ASSIGN	662	0	0
1240	80	ADVANCE	667	4	0
1250	81	LEAVE	663	0	0
1260	82	QUEUE	663	0	0
1270	83	TRANSFER	663	0	0
1290	FLIES	ADVANCE	701	0	0
1300	85	QUEUE	702	1	0
1310	86	ENTER	701	0	0
1320	87	DEPART	701	0	0
1330	88	ASSIGN	701	0	0
1340	89	ADVANCE	702	1	0
1350	90	LEAVE	701	0	0
1360	91	QUEUE	744	80	0
1370	92	ENTER	664	0	0
1380	93	DEPART	664	0	0
1390	94	ASSIGN	664	0	0
1400	95	ADVANCE	669	5	0
1410	96	LEAVE	664	0	0

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
1420	97	QUEUE	664	4	0
1430	98	ENTER	660	0	0
1440	99	DEPART	660	0	0
1450	100	ASSIGN	660	0	0
1460	101	ADVANCE	663	5	0
1470	102	LEAVE	658	0	0
1480	103	QUEUE	658	0	0
1490	104	TRANSFER	658	0	0
1510	FPOCS	ADVANCE	701	0	0
1520	106	QUEUE	701	0	0
1530	107	ENTER	701	0	0
1540	108	DEPART	701	0	0
1550	109	ASSIGN	701	0	0
1560	110	ADVANCE	704	4	0
1570	111	LEAVE	700	0	0
1580	112	QUEUE	700	0	0
1590	113	TRANSFER	700	0	0
1610	FPANS	ADVANCE	701	0	0
1620	115	QUEUE	701	0	0
1630	FPANL	ASSEMBLE	2112	96	0
1640	117	DEPART	658	0	0
1650	118	DEPART	658	0	0
1660	119	DEPART	658	0	0
1670	120	QUEUE	658	0	0
1680	121	ENTER	658	0	0
1690	122	DEPART	658	0	0
1700	123	ASSIGN	658	0	0
1710	124	ADVANCE	659	1	0
1720	125	LEAVE	658	0	0
1730	126	QUEUE	660	2	0
1740	127	ENTER	658	0	0
1750	128	DEPART	658	0	0
1760	129	ASSIGN	658	0	0
1770	130	ADVANCE	666	8	0
1780	131	LEAVE	658	0	0
1790	132	QUEUE	659	0	0
1800	133	ENTER	659	0	0
1810	134	DEPART	659	0	0
1820	135	ASSIGN	659	0	0
1830	136	ADVANCE	666	7	0
1840	137	LEAVE	659	0	0
1850	138	QUEUE	659	0	0
1860	139	ENTER	659	0	0
1870	140	DEPART	659	0	0
1880	141	ASSIGN	659	0	0
1890	142	ADVANCE	664	5	0
1900	143	LEAVE	659	0	0
1910	144	QUEUE	659	0	0
1920	145	ENTER	659	0	0
1930	146	DEPART	659	0	0

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
1940	147	ASSIGN	659	0	0
1950	148	ADVANCE	665	6	0
1960	149	LEAVE	659	0	0
1970	150	QUEUE	659	0	0
1980	151	TRANSFER	659	0	0
2000	BLUPS	ADVANCE	701	0	0
2010	153	QUEUE	701	0	0
2020	154	ENTER	701	0	0
2030	155	DEPART	701	0	0
2040	156	ASSIGN	701	0	0
2050	157	ADVANCE	703	2	0
2060	158	LEAVE	701	0	0
2070	159	QUEUE	701	0	0
2080	FEVRY	ASSEMBLE	2807	125	0
2090	161	DEPART	659	0	0
2100	162	DEPART	659	0	0
2110	163	DEPART	659	0	0
2120	164	DEPART	659	0	0
2130	165	QUEUE	659	0	0
2140	166	ENTER	659	0	0
2150	167	DEPART	659	0	0
2160	168	ASSIGN	659	0	0
2170	169	ADVANCE	660	1	0
2180	170	LEAVE	659	0	0
2190	171	QUEUE	659	0	0
2200	172	ENTER	659	0	0
2210	173	DEPART	659	0	0
2220	174	ASSIGN	659	0	0
2230	175	ADVANCE	660	2	0
2240	176	LEAVE	658	0	0
2250	177	QUEUE	658	0	0
2260	178	ENTER	658	0	0
2270	179	DEPART	658	0	0
2280	180	ASSIGN	658	0	0
2290	181	ADVANCE	669	11	0
2300	182	LEAVE	658	0	0
2320	183	QUEUE	658	0	0
2330	184	ENTER	658	0	0
2340	185	DEPART	658	0	0
2350	186	ASSIGN	658	0	0
2360	187	ADVANCE	670	11	0
2370	188	LEAVE	659	0	0
2380	189	QUEUE	659	0	0
2390	190	ENTER	659	0	0
2400	191	DEPART	659	0	0
2410	192	ASSIGN	659	0	0
2420	193	ADVANCE	666	8	0
2430	194	LEAVE	658	0	0
2440	195	QUEUE	658	1	0
2450	196	ENTER	657	0	0

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
2460	197	DEPART	657	0	0
2470	198	ASSIGN	657	0	0
2480	199	ADVANCE	664	8	0
2490	200	LEAVE	656	0	0
2500	201	QUEUE	656	0	0
2510	202	ENTER	656	0	0
2520	203	DEPART	656	0	0
2530	204	ASSIGN	656	0	0
2540	205	ADVANCE	659	3	0
2550	206	LEAVE	656	0	0
2560	207	QUEUE	658	1	0
2570	208	ENTER	657	0	0
2580	209	DEPART	657	0	0
2590	210	ASSIGN	657	0	0
2600	211	ADVANCE	667	10	0
2610	212	LEAVE	657	0	0
2620	213	QUEUE	657	2	0
2630	214	ENTER	655	0	0
2640	215	DEPART	655	0	0
2650	216	ASSIGN	655	0	0
2660	217	ADVANCE	660	5	0
2670	218	LEAVE	655	0	0
2680	219	QUEUE	655	0	0
2690	220	ENTER	655	0	0
2700	221	DEPART	655	0	0
2710	222	ASSIGN	655	0	0
2720	223	ADVANCE	665	10	0
2730	224	LEAVE	655	0	0
2740	225	QUEUE	655	1	0
2750	226	ENTER	654	0	0
2760	227	DEPART	654	0	0
2770	228	ASSIGN	654	0	0
2780	229	ADVANCE	658	5	0
2790	230	LEAVE	653	0	0
2800	231	QUEUE	653	1	0
2810	232	ENTER	652	0	0
2820	233	DEPART	652	0	0
2830	234	ASSIGN	652	0	0
2840	235	ADVANCE	670	19	0
2850	236	LEAVE	651	0	0
2855	237	TABULATE	651	0	0
2860	238	TERMINATE	651	0	0
2880	TIMER	GENERATE	10	0	0
2890	240	TERMINATE	10	0	0

QUEUE	MAX	CONT.	ENTRIES	ENTRIES(0)	AVE.CONT.	AVE.TIME	AVE.(-0)	RETRY
QCUTR	1	0	701	675	0.01	8.25	222.31	0
QCODE	2	0	700	662	0.01	10.15	187.00	0
QBNDS	127	125	784	0	105.73	64730.97	64730.97	0

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QUEUE	MAX	CONT.	ENTRIES	ENTRIES(0)	AVE.CONT.	AVE.TIME	AVE.(-0)	RETRY
QBHEM	3	0	701	390	0.29	201.00	453.05	0
QBHOL	3	0	701	322	0.34	235.60	435.77	0
QBPOC	1	0	701	701	0.00	0.00	0.00	0
QBPAN	9	6	707	0	5.98	4062.28	4062.28	0
QMBKS	1	0	701	454	0.11	76.67	217.60	0
QDART	3	0	700	377	0.26	176.33	382.13	0
QTOPS	3	0	701	470	0.14	97.38	295.50	0
QBLAB	5	4	701	124	0.98	668.15	811.74	0
QABP	73	70	731	0	54.20	35588.85	35588.85	0
QSEAM	5	0	662	255	0.72	524.75	853.52	0
QMB	26	22	681	659	19.94	14050.46	434925.50	0
QLFLY	4	1	702	75	1.02	696.49	779.80	0
QRFLY	82	80	744	0	62.77	40494.86	40494.86	0
QJOIN	6	4	664	108	1.95	1406.22	1679.37	0
QFLYS	2	0	658	658	0.00	0.00	0.00	0
QFHEM	4	0	701	394	0.28	189.10	431.79	0
QFPOC	93	92	750	658	72.73	46545.93	379450.54	0
QFPAN	97	96	754	0	76.61	48768.61	48768.61	0
QMFTS	3	0	658	303	0.28	200.60	371.81	0
QAFP	8	2	660	131	1.81	1314.20	1639.64	0
QAFLY	4	0	659	298	0.60	435.03	794.14	0
QTFLY	4	0	659	347	0.42	305.17	644.58	0
QFINF	4	0	659	223	0.70	507.09	766.45	0
QMF	1	0	659	659	0.00	0.00	0.00	0
QLUPS	3	0	701	527	0.12	82.58	332.68	0
QBL	125	123	782	659	104.27	63995.50	406865.72	0
QMFBS	3	0	659	311	0.27	198.01	374.97	0
QUPS	2	0	659	336	0.20	146.91	299.74	0
QSIDE	4	0	658	316	0.47	346.20	666.08	0
QINS	4	0	658	444	0.30	221.65	681.51	0
QAWB	3	0	659	380	0.40	294.61	695.87	0
QBEND	4	1	658	415	0.32	235.73	638.32	0
QBUTN	3	0	656	460	0.18	134.21	449.18	0
QABL	6	1	658	175	1.37	997.12	1358.39	0
QTACK	7	2	657	137	1.35	982.70	1241.60	0
QFOLD	4	0	655	430	0.25	185.64	540.40	0
QPRES	4	1	655	350	0.41	302.62	649.89	0
QSPEC	6	1	653	463	0.30	221.18	760.16	0

STORAGE	CAP.	REMAIN.	MIN.	MAX.	ENTRIES	AVL.	AVE.C.	UTIL.	RETRY	DELAY
ABL	10	0	6	10	667	1	9.75	0.975	0	1
ABP	8	0	7	8	669	1	8.00	1.000	0	70
AFLY	7	0	3	7	666	1	6.58	0.941	0	0
AFP	8	0	5	8	666	1	7.86	0.983	0	2
AWB	8	0	2	8	666	1	7.17	0.897	0	0
BEND	8	0	3	8	664	1	7.22	0.903	0	1
BHEM	4	0	1	4	705	1	3.60	0.900	0	0
BHOL	2	0	0	2	703	1	1.75	0.873	0	0
BLAB	3	0	0	3	700	1	2.91	0.970	0	4

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STORAGE	CAP.	REMAIN.	MIN.	MAX.	ENTRIES	AVL.	AVE.C.	UTIL.	RETRY	DELAY
BUTN	3	0	0	3	659	1	2.17	0.722	0	0
CODER	5	1	1	5	705	1	3.73	0.746	0	0
CUTTR	4	1	1	4	703	1	3.01	0.753	0	0
DARTS	4	1	1	4	704	1	3.66	0.916	0	0
FHEM	4	0	1	4	704	1	3.60	0.901	0	0
FINF	6	0	2	6	665	1	5.71	0.951	0	0
FOLD	11	1	6	11	665	1	10.16	0.924	0	0
INS	12	1	6	12	670	1	11.02	0.919	0	0
JOINT	5	0	2	5	663	1	4.91	0.983	0	4
LFLY	1	0	0	1	702	1	0.96	0.964	0	1
LUPS	2	0	0	2	703	1	1.35	0.674	0	0
MBKS	1	0	0	1	701	1	0.70	0.703	0	0
MFTS	1	0	0	1	659	1	0.66	0.661	0	0
MFBS	1	0	0	1	660	1	0.65	0.655	0	0
PRES	5	0	1	5	658	1	4.46	0.892	0	1
RFLY	5	0	4	5	669	1	5.00	1.000	0	80
SEAM	5	1	1	5	667	1	4.68	0.936	0	0
SIDE	11	0	6	11	669	1	10.49	0.954	0	0
SPRED	3	1	1	3	703	1	2.25	0.749	0	0
SPEC	19	0	12	19	670	1	17.85	0.939	0	1
TACK	5	0	2	5	660	1	4.84	0.968	0	2
TFLY	5	0	1	5	664	1	4.51	0.903	0	0
TOPS	4	0	1	4	705	1	3.45	0.862	0	0
UPS	2	0	0	2	660	1	1.65	0.823	0	0

TABLE	MEAN	STD.DEV.	RETRY	RANGE	FREQUENCY	CUM.%
JIT	142477.13	10211.37	0			
			810 -		651	100.00

XACT_GROUP	GROUP_SIZE	RETRY
POSITION	0	0

Appendix E

Sample Output from GPSS Model of a Hi-Tech Trouser Manufacturing Plant (Ideal Case of Perfect Balancing and No Stochasticism)

START_TIME	END_TIME	BLOCKS	FACILITIES	STORAGES	FREE_MEMORY
480005	1440000	240	0	33	167504

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
430	1	GENERATE	1333	0	0
440	2	ENTER	1333	0	0
450	3	ASSIGN	1333	0	0
460	4	ADVANCE	1335	2	0
470	5	LEAVE	1333	0	0
480	6	QUEUE	1333	0	0
490	7	ENTER	1333	0	0
500	8	DEPART	1333	0	0
510	9	ASSIGN	1333	0	0
520	10	ADVANCE	1336	3	0
530	11	LEAVE	1333	0	0
540	12	QUEUE	1333	0	0
550	13	ENTER	1333	0	0
560	14	DEPART	1333	0	0
570	15	ASSIGN	1333	0	0
580	16	ADVANCE	1336	3	0
590	17	LEAVE	1333	0	0
600	18	SPLIT	1333	0	0
610	19	SPLIT	1333	0	0
620	20	SPLIT	1333	0	0
630	21	SPLIT	1333	0	0
640	22	SPLIT	1333	0	0
650	23	SPLIT	1333	0	0
660	24	QUEUE	1333	0	0
670	25	TRANSFER	1333	0	0
690	BPOCS	ADVANCE	1333	0	0
700	27	QUEUE	1333	0	0
710	28	ENTER	1333	0	0
720	29	DEPART	1333	0	0
730	30	ASSIGN	1333	0	0
740	31	ADVANCE	1337	4	0
750	32	LEAVE	1333	0	0
760	33	QUEUE	1333	0	0
770	34	ENTER	1333	0	0
780	35	DEPART	1333	0	0
790	36	ASSIGN	1333	0	0
800	37	ADVANCE	1335	1	0
810	38	LEAVE	1334	0	0
820	39	QUEUE	1334	0	0
830	40	TRANSFER	1334	0	0
850	BPANS	ADVANCE	1333	0	0
860	42	QUEUE	1333	0	0
870	FBACK	ASSEMBLE	2673	5	0
880	44	DEPART	1334	0	0
890	45	DEPART	1334	0	0
900	46	QUEUE	1334	0	0

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LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETR
910	47	ENTER	1334	0	0
920	48	DEPART	1334	0	0
930	49	ASSIGN	1334	0	0
940	50	ADVANCE	1334	1	0
950	51	LEAVE	1333	0	0
960	52	QUEUE	1333	0	0
970	53	ENTER	1333	0	0
980	54	DEPART	1333	0	0
990	55	ASSIGN	1333	0	0
1000	56	ADVANCE	1337	3	0
1010	57	LEAVE	1334	0	0
1020	58	QUEUE	1334	0	0
1030	59	ENTER	1334	0	0
1040	60	DEPART	1334	0	0
1050	61	ASSIGN	1334	0	0
1060	62	ADVANCE	1337	4	0
1070	63	LEAVE	1333	0	0
1080	64	QUEUE	1333	0	0
1090	65	ENTER	1333	0	0
1100	66	DEPART	1333	0	0
1110	67	ASSIGN	1333	0	0
1120	68	ADVANCE	1336	2	0
1130	69	LEAVE	1334	0	0
1140	70	QUEUE	1334	0	0
1150	71	ENTER	1334	0	0
1160	72	DEPART	1334	0	0
1170	73	ASSIGN	1334	0	0
1180	74	ADVANCE	1342	8	0
1190	75	LEAVE	1334	0	0
1200	76	QUEUE	1334	0	0
1210	77	ENTER	1334	0	0
1220	78	DEPART	1334	0	0
1230	79	ASSIGN	1334	0	0
1240	80	ADVANCE	1338	5	0
1250	81	LEAVE	1333	0	0
1260	82	QUEUE	1333	0	0
1270	83	TRANSFER	1333	0	0
1290	FLIES	ADVANCE	1333	0	0
1300	85	QUEUE	1333	0	0
1310	86	ENTER	1333	0	0
1320	87	DEPART	1333	0	0
1330	88	ASSIGN	1333	0	0
1340	89	ADVANCE	1334	1	0
1350	90	LEAVE	1333	0	0
1360	91	QUEUE	1333	0	0
1370	92	ENTER	1333	0	0
1380	93	DEPART	1333	0	0
1390	94	ASSIGN	1333	0	0
1400	95	ADVANCE	1338	5	0
1410	96	LEAVE	1333	0	0

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
1420	97	QUEUE	1333	0	0
1430	98	ENTER	1333	0	0
1440	99	DEPART	1333	0	0
1450	100	ASSIGN	1333	0	0
1460	101	ADVANCE	1338	5	0
1470	102	LEAVE	1333	0	0
1480	103	QUEUE	1333	0	0
1490	104	TRANSFER	1333	0	0
1510	FPOCS	ADVANCE	1333	0	0
1520	106	QUEUE	1333	0	0
1530	107	ENTER	1333	0	0
1540	108	DEPART	1333	0	0
1550	109	ASSIGN	1333	0	0
1560	110	ADVANCE	1337	3	0
1570	111	LEAVE	1334	0	0
1580	112	QUEUE	1334	0	0
1590	113	TRANSFER	1334	0	0
1610	FPANS	ADVANCE	1333	0	0
1620	115	QUEUE	1333	0	0
1630	FPANL	ASSEMBLE	4011	11	0
1640	117	DEPART	1333	0	0
1650	118	DEPART	1333	0	0
1660	119	DEPART	1333	0	0
1670	120	QUEUE	1333	0	0
1680	121	ENTER	1333	0	0
1690	122	DEPART	1333	0	0
1700	123	ASSIGN	1333	0	0
1710	124	ADVANCE	1334	1	0
1720	125	LEAVE	1333	0	0
1730	126	QUEUE	1333	0	0
1740	127	ENTER	1333	0	0
1750	128	DEPART	1333	0	0
1760	129	ASSIGN	1333	0	0
1770	130	ADVANCE	1341	8	0
1780	131	LEAVE	1333	0	0
1790	132	QUEUE	1333	0	0
1800	133	ENTER	1333	0	0
1810	134	DEPART	1333	0	0
1820	135	ASSIGN	1333	0	0
1830	136	ADVANCE	1340	6	0
1840	137	LEAVE	1334	0	0
1850	138	QUEUE	1334	0	0
1860	139	ENTER	1334	0	0
1870	140	DEPART	1334	0	0
1880	141	ASSIGN	1334	0	0
1890	142	ADVANCE	1338	5	0
1900	143	LEAVE	1333	0	0
1910	144	QUEUE	1333	0	0
1920	145	ENTER	1333	0	0
1930	146	DEPART	1333	0	0

LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
1940	147	ASSIGN	1333	0	0
1950	148	ADVANCE	1339	6	0
1960	149	LEAVE	1333	0	0
1970	150	QUEUE	1333	0	0
1980	151	TRANSFER	1333	0	0
2000	BLUPS	ADVANCE	1333	0	0
2010	153	QUEUE	1333	0	0
2020	154	ENTER	1333	0	0
2030	155	DEPART	1333	0	0
2040	156	ASSIGN	1333	0	0
2050	157	ADVANCE	1335	1	0
2060	158	LEAVE	1334	0	0
2070	159	QUEUE	1334	0	0
2080	FEVRY	ASSEMBLE	5370	37	0
2090	161	DEPART	1333	0	0
2100	162	DEPART	1333	0	0
2110	163	DEPART	1333	0	0
2120	164	DEPART	1333	0	0
2130	165	QUEUE	1333	0	0
2140	166	ENTER	1333	0	0
2150	167	DEPART	1333	0	0
2160	168	ASSIGN	1333	0	0
2170	169	ADVANCE	1334	0	0
2180	170	LEAVE	1334	0	0
2190	171	QUEUE	1334	0	0
2200	172	ENTER	1334	0	0
2210	173	DEPART	1334	0	0
2220	174	ASSIGN	1334	0	0
2230	175	ADVANCE	1335	2	0
2240	176	LEAVE	1333	0	0
2250	177	QUEUE	1333	0	0
2260	178	ENTER	1333	0	0
2270	179	DEPART	1333	0	0
2280	180	ASSIGN	1333	0	0
2290	181	ADVANCE	1344	11	0
2300	182	LEAVE	1333	0	0
2320	183	QUEUE	1333	0	0
2330	184	ENTER	1333	0	0
2340	185	DEPART	1333	0	0
2350	186	ASSIGN	1333	0	0
2360	187	ADVANCE	1344	11	0
2370	188	LEAVE	1333	0	0
2380	189	QUEUE	1333	0	0
2390	190	ENTER	1333	0	0
2400	191	DEPART	1333	0	0
2410	192	ASSIGN	1333	0	0
2420	193	ADVANCE	1341	7	0
2430	194	LEAVE	1334	0	0
2440	195	QUEUE	1334	0	0
2450	196	ENTER	1334	0	0

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LINE	LOC	BLOCK_TYPE	ENTRY_COUNT	CURRENT_COUNT	RETRY
2460	197	DEPART	1334	0	0
2470	198	ASSIGN	1334	0	0
2480	199	ADVANCE	1341	7	0
2490	200	LEAVE	1334	0	0
2500	201	QUEUE	1334	0	0
2510	202	ENTER	1334	0	0
2520	203	DEPART	1334	0	0
2530	204	ASSIGN	1334	0	0
2540	205	ADVANCE	1336	3	0
2550	206	LEAVE	1333	0	0
2560	207	QUEUE	1333	0	0
2570	208	ENTER	1333	0	0
2580	209	DEPART	1333	0	0
2590	210	ASSIGN	1333	0	0
2600	211	ADVANCE	1343	10	0
2610	212	LEAVE	1333	0	0
2620	213	QUEUE	1333	0	0
2630	214	ENTER	1333	0	0
2640	215	DEPART	1333	0	0
2650	216	ASSIGN	1333	0	0
2660	217	ADVANCE	1338	4	0
2670	218	LEAVE	1334	0	0
2680	219	QUEUE	1334	0	0
2690	220	ENTER	1334	0	0
2700	221	DEPART	1334	0	0
2710	222	ASSIGN	1334	0	0
2720	223	ADVANCE	1344	11	0
2730	224	LEAVE	1333	0	0
2740	225	QUEUE	1333	0	0
2750	226	ENTER	1333	0	0
2760	227	DEPART	1333	0	0
2770	228	ASSIGN	1333	0	0
2780	229	ADVANCE	1338	4	0
2790	230	LEAVE	1334	0	0
2800	231	QUEUE	1334	0	0
2810	232	ENTER	1334	0	0
2820	233	DEPART	1334	0	0
2830	234	ASSIGN	1334	0	0
2840	235	ADVANCE	1352	19	0
2850	236	LEAVE	1333	0	0
2855	237	TABULATE	1333	0	0
2860	238	TERMINATE	1333	0	0
2880	TIMER	GENERATE	20	0	0
2890	240	TERMINATE	20	0	0

QUEUE	MAX	CONT.	ENTRIES	ENTRIES(0)	AVE.CONT.	AVE.TIME	AVE.(-0)	RETF
QCUTR	1	0	1333	1333	0.00	0.00	0.00	(
QCODE	1	0	1333	1333	0.00	0.00	0.00	(
QBNDS	37	37	1370	0	36.70	25716.71	25716.71	(

QUEUE	MAX	CONT.	ENTRIES	ENTRIES(0)	AVE.CONT.	AVE.TIME	AVE.(-0)	RETR
QBHEM	1	0	1333	1333	0.00	0.00	0.00	0
QBHOL	1	0	1333	1333	0.00	0.00	0.00	0
QBPOC	1	0	1334	1334	0.00	0.00	0.00	0
QBPAN	6	5	1339	0	5.10	3656.42	3656.42	0
QMBKS	1	0	1334	1334	0.00	0.00	0.00	0
QDART	1	0	1333	1333	0.00	0.00	0.00	0
QTOPS	1	0	1334	1334	0.00	0.00	0.00	0
QBLAB	1	0	1333	1333	0.00	0.00	0.00	0
QABP	1	0	1334	1334	0.00	0.00	0.00	0
QSEAM	1	0	1334	1334	0.00	0.00	0.00	0
QMB	9	9	1342	1333	8.70	6223.57	928003.00	0
QLFLY	1	0	1333	1333	0.00	0.00	0.00	0
QRFLY	1	0	1333	1333	0.00	0.00	0.00	0
QJOIN	1	0	1333	1333	0.00	0.00	0.00	0
QFLYS	1	0	1333	1333	0.00	0.00	0.00	0
QFHEM	1	0	1333	1333	0.00	0.00	0.00	0
QFPOC	8	8	1341	1333	7.52	5380.95	901982.50	0
QFPAN	11	11	1344	0	10.92	7797.59	7797.59	0
QMFTS	1	0	1333	1333	0.00	0.00	0.00	0
QAFP	1	0	1333	1333	0.00	0.00	0.00	0
QAFLY	1	0	1333	1333	0.00	0.00	0.00	0
QTFLY	1	0	1334	1334	0.00	0.00	0.00	0
QFINF	1	0	1333	1333	0.00	0.00	0.00	0
QMF	1	0	1333	1333	0.00	0.00	0.00	0
QLUPS	1	0	1333	1333	0.00	0.00	0.00	0
QBL	36	36	1369	1333	35.42	24835.52	944439.67	0
QMFBS	1	0	1333	1333	0.00	0.00	0.00	0
QUPS	1	0	1334	1334	0.00	0.00	0.00	0
QSIDE	1	0	1333	1333	0.00	0.00	0.00	0
QINS	1	0	1333	1333	0.00	0.00	0.00	0
QAWB	1	0	1333	1333	0.00	0.00	0.00	0
QBEND	1	0	1334	1334	0.00	0.00	0.00	0
QBUTN	1	0	1334	1334	0.00	0.00	0.00	0
QABL	1	0	1333	1333	0.00	0.00	0.00	0
QTACK	1	0	1333	1333	0.00	0.00	0.00	0
QFOLD	1	0	1334	1334	0.00	0.00	0.00	0
QPRES	1	0	1333	1333	0.00	0.00	0.00	0
QSPEC	1	0	1334	1334	0.00	0.00	0.00	0

STORAGE	CAP.	REMAIN.	MIN.	MAX.	ENTRIES	AVL.	AVE.C.	UTIL.	RETRY	DELA
ABL	10	0	9	10	1343	1	9.93	0.993	0	0
ABP	8	0	7	8	1342	1	8.00	1.000	0	0
AFLY	7	1	6	7	1340	1	6.73	0.962	0	0
AFP	8	0	7	8	1341	1	8.00	1.000	0	0
AWB	8	1	7	8	1341	1	7.28	0.910	0	0
BEND	8	1	7	8	1341	1	7.23	0.904	0	0
BHEM	4	0	3	4	1337	1	3.43	0.858	0	0
BHOL	2	1	1	2	1335	1	1.67	0.833	0	0
BLAB	3	1	2	3	1336	1	2.78	0.928	0	0

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STORAGE	CAP.	REMAIN.	MIN.	MAX.	ENTRIES	AVL.	AVE.C.	UTIL.	RETRY	DEL
BUTN	3	0	2	3	1336	1	2.18	0.728	0	(
CODER	5	2	3	4	1336	1	3.57	0.714	0	(
CUTTR	4	1	2	3	1336	1	2.86	0.714	0	(
DARTS	4	1	3	4	1337	1	3.47	0.867	0	(
FHEM	4	1	3	4	1337	1	3.40	0.850	0	(
FINF	6	0	5	6	1339	1	5.82	0.969	0	(
FOLD	11	0	10	11	1344	1	10.32	0.938	0	(
INS	12	1	11	12	1344	1	11.23	0.936	0	(
JOINT	5	0	4	5	1338	1	5.00	1.000	0	(
LFLY	1	0	0	1	1334	1	0.92	0.917	0	(
LUPS	2	1	1	2	1335	1	1.28	0.642	0	(
MBKS	1	0	0	1	1334	1	0.67	0.667	0	(
MFTS	1	0	0	1	1334	1	0.67	0.667	0	(
MFBS	1	1	0	1	1334	1	0.67	0.667	0	(
PRES	5	1	4	5	1338	1	4.57	0.913	0	(
RFLY	5	0	4	5	1338	1	5.00	1.000	0	(
SEAM	5	0	4	5	1338	1	4.70	0.940	0	(
SIDE	11	0	10	11	1344	1	10.58	0.962	0	(
SPRED	3	1	2	3	1335	1	2.14	0.714	0	(
SPEC	19	0	18	19	1352	1	18.28	0.962	0	(
TACK	5	1	4	5	1338	1	4.92	0.983	0	(
TFLY	5	0	4	5	1338	1	4.57	0.913	0	(
TOPS	4	0	3	4	1337	1	3.28	0.821	0	(
UPS	2	0	1	2	1335	1	1.67	0.833	0	(

TABLE	MEAN	STD.DEV.	RETRY	RANGE	FREQUENCY	CUM.%
JIT	96579.00	0.00	0			
			810 -		1333	100.00

XACT_GROUP	GROUP_SIZE	RETRY
POSITION	0	0