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FBI Fingerprint Image Capture System High-Speed-Front-End Throughput Modeling

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ABSTRACT

The Federal Bureau of Investigation (FBI) has undertaken a major modernization effort called the Integrated Automated Fingerprint Identification System (IAFISS). This system will provide centralized identification services using automated fingerprint, subject descriptor, mugshot, and document processing. A high-speed Fingerprint Image Capture System (FICS) is under development as part of the IAFIS program. The FICS will capture digital and microfilm images of FBI fingerprint cards for input into a central data base.

One FICS design supports two front-end scanning subsystems, known as the High-Speed-Front-End (HSFE) and Low-Speed-Front-End, to supply image data to a common data processing subsystem. The production rate of the HSFE is critical to meeting the FBI's fingerprint card processing schedule. A model of the HSFE has been developed to help identify the issues driving the production rate, assist in the development of component specifications, and guide the evolution of an operations plan.

A description of the model development is given, the assumptions are presented, and some HSFE throughput analysis is performed.

1. INTRODUCTION

1.1 BACKGROUND

The Identification Division (ID) of the Federal Bureau of Investigation (FBI) maintains a manual filing system of fingerprint cards called the Fingerprint Card Master File (FCMF). At present, some 23,000,000 cards are in the FCMF, with a projected size of 28,000,000 to 32,000,000 by 1995. The FBI estimates that 30,000 to 40,000 fingerprint cards arrive each day in the FBI mail room.

Processing of these cards involves a search against the FCMF to identify whether the subject whose fingerprints are on the submitted card has a previous record in the FCMF. Searches against the FCMF are performed in an automated fashion using a subset of the information called "minutiae," which is extracted from an image of the fingerprint. When a minutiae "match" provides a possible identification, the candidate card is manually retrieved from the large FCMF, and a side-by-side comparison is made using the cards. With an increasing number of search requests and a continuing demand for faster response times, a more efficient method of processing identification requests is needed.

The FBI has undertaken a major modernization effort called the Integrated Automated Fingerprint Identification System (IAFIS). This system will provide centralized identification services using automated fingerprint, subject descriptor, mugshot, and document processing. Support for IAFIS will be provided by the Image Transmission Network (ITN). The ITN will link the FBI automated systems with state Automated Fingerprint Identification Systems (AFIS) through the National Crime Information Center (NCIC) telecommunications system. Thus, ITN will provide a nationwide means of identifying fingerprint images without the use of inked fingerprint cards. The portion of the ITN which will reside within the FBI ID is known as the ITN/FBI. Once the ITN/FBI is operational, all requests to the FBI for identification services will be processed in digital image format.

In order to implement the ITN/FBI, the fingerprint portion of each card in the FCMF must be "converted" to a digitized format. The Fingerprint Image Capture System (FICS) will provide the image capture technologies required to complete the conversion and implement the ITN/FBI.

1.2 INTRODUCTION TO THE FICS

The purpose of the FICS is to transform fingerprint cards into text records, microfilm records, and digital fingerprint image records, as shown in Fig. 1. A conversion rate of 1000 cards/h is required to complete conversion in the limited time schedule.

Figure 2 shows a greatly simplified block diagram of the FICS. The design consists of five major components. The High-Speed-Front-End (HSFE) and the Low-Speed-Front-End (LSFE) serve as the digital and microfilm image capture systems. The HSFE is streamlined to efficiently process the typical fingerprint card. The anticipated 2 to 3% odd-size cards and cards with other anomalies enter the FICS through the LSFE. Both the HSFE and LSFE systems feed digital image data to a common Image Acquisition Controller (IAC). Front- and back-side images of a given card are assembled into a common record and transferred to the central FICS buffering system, the Buffered Data

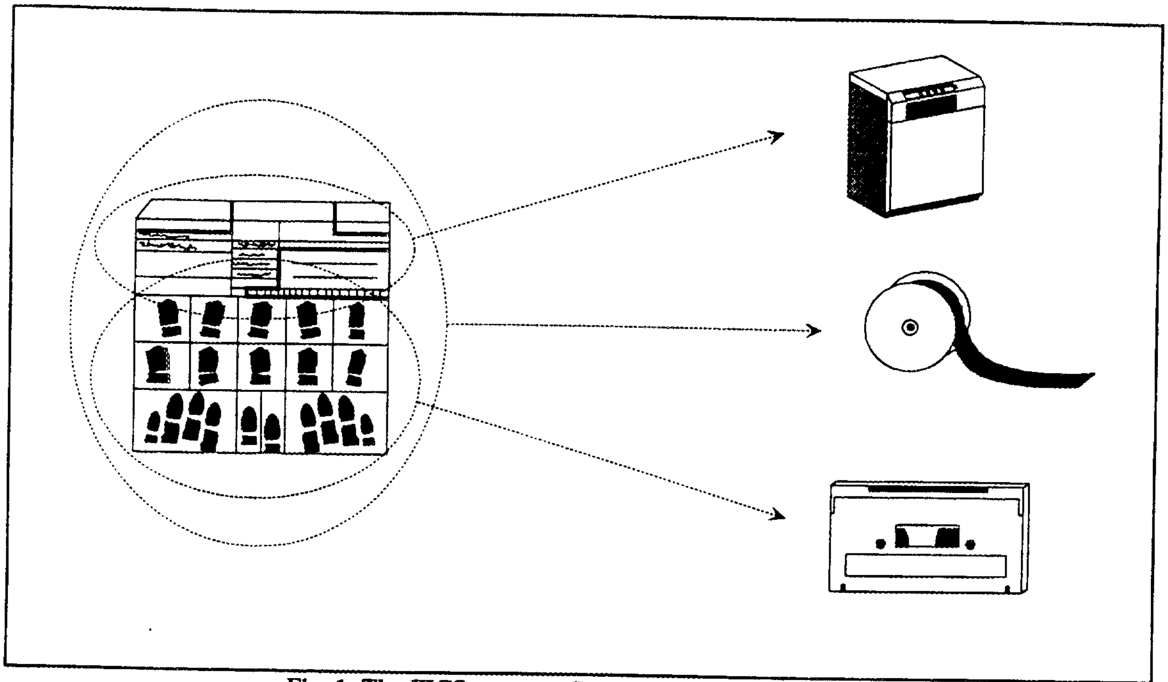

Fig. 1. The FICS converts fingerprint cards to records.

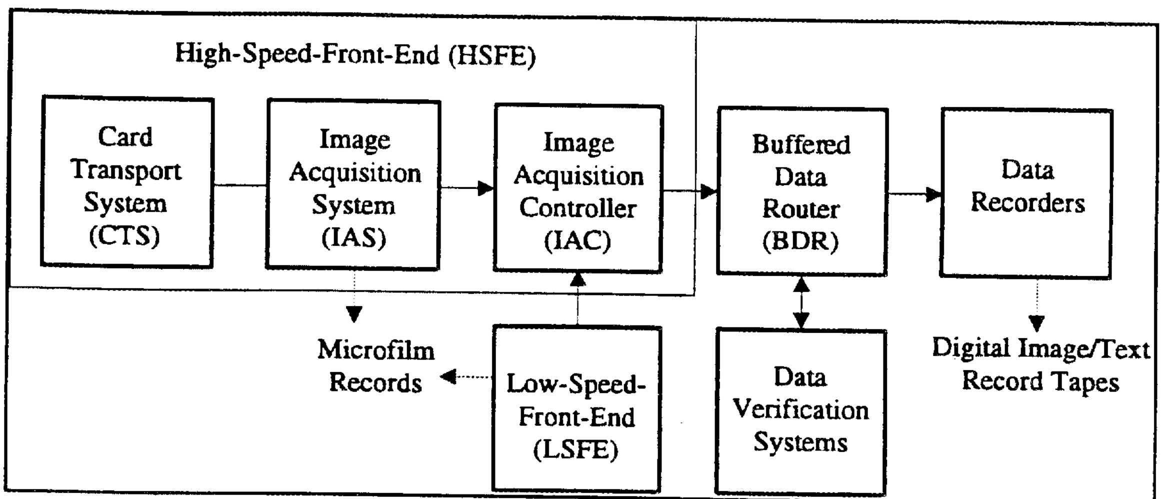

Fig. 2. A simplified block diagram of the FICS components.

Router (BDR). The BDR routes records to the Data Verification Systems, where data integrity is evaluated and minor text entry is performed. Completed text/image data records are then sent to the Data Recorders for storage on tape, and the BDR records are purged.

The Card Transport System (CTS), Image Acquisition System (IAS), and the IAC comprise the HSFE portion of the FTCS. The CTS and IAS hardware layout is shown in Fig. 3. The CTS is a vacuum-belt-driven card-moving machine. The role of the CTS is similar to the role of the mechanical components of a photocopier. It is responsible for accepting cards from a feed station and transporting them to various processing stations before ejecting them to an output hopper. In addition to imaging support, the CTS also performs a labeling/serializing operation on fingerprint cards to provide an audit trail for each document processed. The IAS performs the image-gathering functions of the HSFE. It is composed of a microfilming system and a digital image capture system, which are mounted to the CTS hardware. When the CTS presents a card in the imaging station, the IAS gathers the images. The digital images are transferred from the IAS to a buffer in the IAC. The IAC assembles the front- and back-side images of a given card and submits them to the BDR.

During normal operation, the HSFE will encounter four different types of cards. These are fingerprint cards, marker cards, microfilm test targets, and calibration verification test targets. Marker cards are simply administrative aids that serve as placeholders for other cards removed from the input stream. Microfilm test targets contain test patterns to be filmed at the beginning and/or end of each microfilm roll. The test pattern images are used in the microfilm developing process to adjust film processing

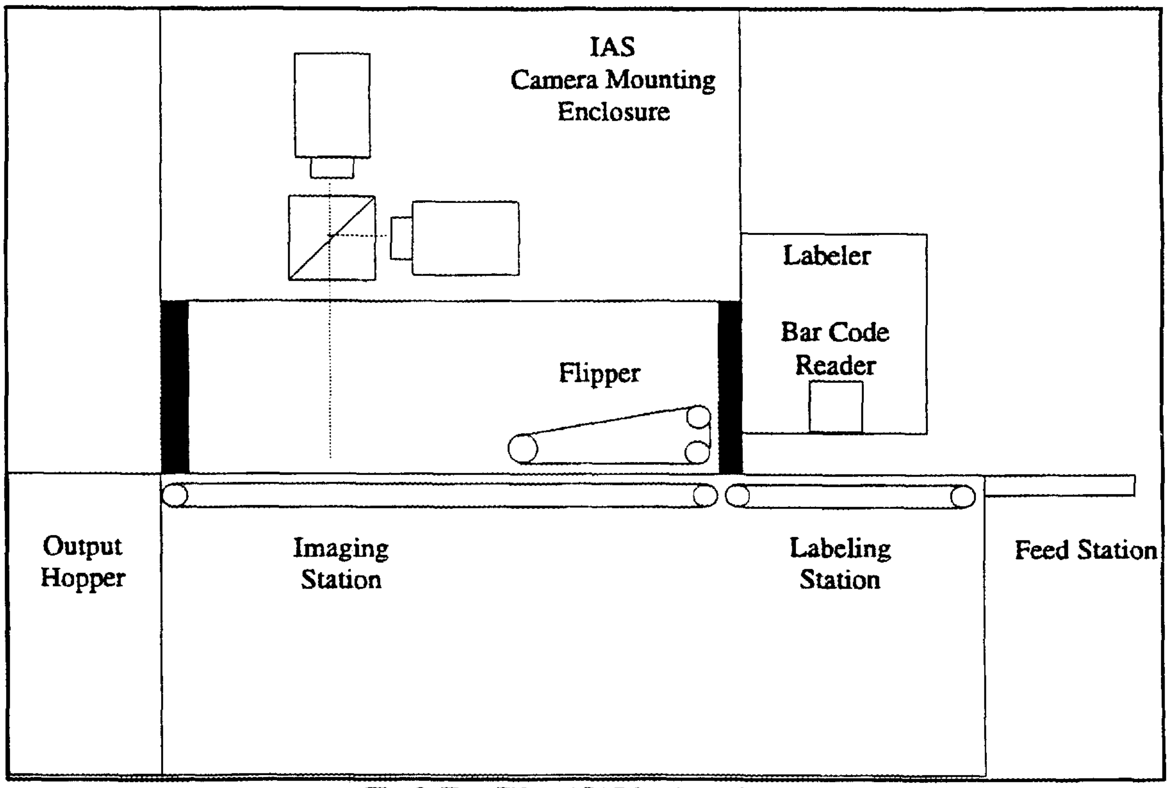

Fig. 3. The CIS and IAS hardware layout.

parameters. Calibration verification test targets are the analog of the microfilm test targets. They contain special test patterns that allow the digital imaging system to check the current calibration. Calibration verifications are performed at fixed intervals to limit the amount of rescanning required if the HSFE were to drift out of calibration. The CTS bar code reader is capable of identifying each type of card and adjusting its operation accordingly.

1.3 NEED FOR AN HSFE MODEL

Several design and operations issues may directly impact the production rate, or throughput, of the HSFE. For example, the IAS camera system technology has not yet been selected. Several imaging technologies are under consideration, each with a different image acquisition time. Image acquisition time is a factor in HSFE throughput, and therefore throughput could be a major selection criterion for IAS technology. However, what is the maximum tolerable image acquisition time without dropping HSFE throughput below the target 1000-card/h mark? Also, what effect would removing the microfilm cameras from the IAS and creating a separate microfilming operation have on throughput? What card alignment error rate can be tolerated in the imaging station without sacrificing throughput? How much will throughput suffer if image quality checking is performed while the cards are sitting in the imaging station? The answers to these and many other questions can be found by modeling the system.

2. USING THE HSFE MODEL

The FICS HSFE throughput model is a computational computer program that predicts the throughput of the HSFE portion of the FICS under a set of input conditions specified by the user. Input conditions are stored in an ASCII input file prior to execution of the program. Upon execution, the program reads the input file, performs the calculations, and writes the results to the display and/or an (ASCII) output file.

2.1 CONVENTIONS

The following conventions are used throughout this section:

- Text in an *italic* font represents literals the user must type.
- <CR> indicates that the carriage return key should be depressed.

2.2 PROGRAM INSTALLATION

Before the program can be used, it must first be copied onto the target UNIX machine with a C compiler and be rebuilt. The program requires that the directory in which it is installed contain the following subdirectory structure, where "base" is the parent directory:

base/SOURCE
base/INCLUDE
base/INPUTS
base/OUTPUTS

Once these subdirectories have been created, fill them as follows with the program files:

base/SOURCE/makefile
base/SOURCE/simmain.c
base/SOURCE/cycletm.c
base/SOURCE/process.c
base/SOURCE/setuplib.c
base/SOURCE/utils.c
base/INCLUDE/simulate.h
base//INPUTS/sim.in

At this point, the program is ready to be built. Change to the base/SOURCE subdirectory and type

make sim < CR >.

If all goes well, the parent directory base should contain an executable file called "sim*". If the compilation fails, check the subdirectory structure and the path to the local C compiler.

2.3 PROGRAM EXECUTION

The as-delivered program assumes that all software source code, the executable, and the default input file are installed in directories as specified in Sect. 2.2. To run the program from the command line in the parent directory base, type

sim < CR >.

The program will open the default input file, sim.in, located in the base/INPUTS subdirectory, and will read the default input parameters in for processing. Once processing is complete, the program will write the output to the display screen.

Sim can be called with any combination of three optional arguments from the command line. These arguments are as follows:

-v	Flag to turn off "verbose" mode (i.e., stop the program from writing error and status messages to the display). This option is handy when used in combination with the -o flag to write output to a file.
-o outputFileName	Flag to turn "output file mode" on (i.e., write program output to the file outputFileName).
-i inputFileName	Flag to turn "input file mode" on (i.e., read program input from the file inputFileName rather than from the default input file).

Example:

To read input from a file called sim.in, write output to a file called sim.out, and turn off the bulk of the display terminal messages, the user should enter

sim -i sim.in -o sim.out -v <CR>.

2.4 PROGRAM INPUT FILE

When invoked, sim will open the input file and read in the simulation parameters. The input file contains 75 different input parameters specifying everything from the HSFE configuration and operating scenario to the card processing methods and times.

2.4.1 Input File Structure

The input file is essentially a parameter value list containing imbedded comments. Any line in the file that contains a semicolon in the first column is viewed by the program as a comment. Comment lines may be added or deleted from the standard input file at any time without affecting program operation. However, great care should be exercised when editing an input file. Adding a new comment line(s) without a semicolon in the first column or deleting an existing data line(s) will cause a phase shift between the data values in the file and the target parameters in the program. This phase shift will have unpredictable effects on program operation. Worse yet, the error may go undetected by the program.

2.4.2 Input File Parameter Descriptions

This section steps line-by-line through the program input file describing each parameter. Please refer to the example input Tile contained in Appendix A while reading this section.

1. Simulation length
   Simulation length represents the desired duration of the simulation in hours. For example, if a simulation length of 12.0 is selected, the program will simulate 12 h of system operation (in accelerated time).

2. Number of simulation runs made/averaged for a given data set
   This parameter specifies the number of times the program should repeat a simulation with the same input parameter set. The results of all runs are averaged to develop a more statistically significant result.

3. Advance next card and eject current card simultaneously (1 = on, 0 = off)
   If a 1 (true) is selected, the card in the labeling station will be advanced to the imaging station, while the card in the imaging station is ejected to the output hopper. If a 0 (false) is selected, the card in the imaging station will be moved to the output hopper before the card in the labeling station is advanced to the imaging station.

4. Schedule for image quality check completion (0 = before moving card on the belt, 1 = before ejecting the card, 2 = while the card is moving and is in the hopper)
   This parameter identifies how the image quality checking must be scheduled with the card motion. Selecting a 0 will cause the card to sit still at the imaging station until the check is completed. Selecting a 1 will allow the card to be flipped while the back side image quality check is performed but will hold the card at the imaging station until both the back- and front-side image quality checks are completed. Selecting a 2 will allow the card to begin moving on the belts as soon as the dwell time is complete. Image quality checking will be performed during the card move and may be completed while the card is already in the output hopper.

5. Processing times
   All parameters in this section represent the mean time required to complete each operation. The program assumes that these are representative times for the given operation and applies them directly (without statistical variation) where appropriate. All times are in units of seconds.
   5.1. Time to advance card from feed station to labeling station
   This is the time it takes the CTS to move the card from the feed station to the labeling station, not including operator reaction time.

5.2. Time to read and process a bar code
This is the time for the bar code reader to read a code plus the time for the CTS control system to verify the check digits and identify the card type.

5.3. Time to download the next label data to the label printer
This is the time for the communications link between the CTS controller and the label printer to transmit data for the next label.

5.4. Time to back up label stock in preparation for label printing
Most label printer/applicators require that label stock be "backed up" before printing when printing small labels such as the ones used by FICS. When the length of the label is less than the distance from the print head to the applicator pad, extra label stock must be played out following a print operation in order to move the newly printed label onto the applicator pad. Before printing the next label, the process must be reversed to bring the next (unprinted) label back to the print head.

5.5. Time to print label
This is the time it takes to print the label once the label data have been received and the label stock has been backed up.

5.6. Time to apply the printed label to the card
This is the time required to physically "tamp" the label onto the surface of the card.

5.7. Time to advance card from labeling to the imaging station
This is the time required to move the card on the belts between the two stations.

5.8. Time to eject card from imaging station
This is the time required to move the card out of the imaging station and into the output hopper.

5.9. Minimum time to dwell in imaging station
This is the minimum time the card must remain still in the imaging station for imaging. By definition, imaging time will always be less than or equal to the actual dwell time. The program will automatically increase the dwell time if necessary.

5.10. Time to flip card and return to imaging station
This is the time required to complete the entire flipping operation. This includes moving the card from the imaging station to the flipper, flipping the card, and returning it to the imaging station.

5.11. Time to check card alignment in imaging station
This is the time allotted for an automatic alignment sensing system to check the card alignment each time a card enters the imaging station.

5.12. Time to acquire images (digital and film)
This is the total time the card must remain still while the camera sensors and film are exposed. This time must be less than or equal to the minimum dwell time. If it exceeds the minimum dwell time, the program will adjust it automatically.

5.13. Time to move data out of digital camera sensor
This is the time required to empty the digital image data from the camera sensor(s) in preparation for acquiring the next image.

5.14. Time to check image quality
This it the processing time required to perform any on-line image quality checks. It does not include the time required to move the image data into a buffer for processing (parameter 5.15 below).

5.15. Time to move image data from IAS to IAC
This is the time required for transferring digital image(s) from a buffer in the IAS to a buffer in the IAC.

5.16. Time to move image data from IAC to BDR
Once the image has been captured and moved to an IAC buffer, it must then be moved to the BDR for storage on a disk. This is the time required to perform the latter operation.

6. Error handling method: return card to operator or eject to output hopper (1 = return, 0 = eject)
This flag controls how the system will behave in an error condition. Selecting 1 will cause a card experiencing an error to be returned to the feed operator for handling, allowing the feed operator to handle the error then and there. Selecting a 0 will cause the same card to be sent to the output hopper, and the card error code and serial number to be made available to an operator on the output side of the machine. The card may then be manually pulled from the output stack and reprocessed.

7. Maximum number of refeed attempts for any given card before the card is sent to the LSFE for manual scanning
This parameter places a cap on the number of refeed attempts allowed for a given card that continues to experience processing errors. During operation, this parameter is controlled administratively.

8. Time to return a card from imaging station to the feed station
This is the time required for the card to be moved from the imaging station back to the feed station. This parameter only applies if the card is returned to the operator because of an error (parameter 6).

9. Time for the operator to pick up a returned card, discern why it was returned, and decide what to do to correct the problem
This parameter is applicable only if the card is returned to the operator because of an error (parameter 6).

Labeling Errors

10. Maximum number of labeling retries to attempt following an error before the card must be removed and either refed or sent to the LSFE for manual scanning
This is a cap on the number of automatic relabeling attempts to be made for a given card before the system declares an error.

11. Percentage of labeling errors on the initial label application attempt
This is the rate of failure expected during the first labeling attempt on a given card.

12. Percentage of labeling errors on label retries and refeeds
This is the rate of failure expected for labeling attempts on a given card following a labeling error. This error rate applies to refed cards as well as to labeling retries.

13. Percentage of cards experiencing labeling errors fed back into the HSFE for another processing attempt
This specifies the percentage of cards to be refed into the HSFE after being expelled for a labeling error (or multiple errors).

Back-Side Alignment Errors—Parameters in this section apply only to cards that are imaged on the back side

14. Percentage of back-side card alignment errors on the first feed attempt
This is the rate of back-side alignment errors expected for cards not experiencing back-side alignment errors on previous feed attempts.

15. Percentage of back-side card alignment errors on refeed attempts
This is the rate of back-side alignment errors on refed cards that had previously experienced back-side alignment errors.

16. Percentage of back-side-alignment-error cards fed back into the HSFE for another processing attempt
This specifies the percentage of the cards to be refed into the HSFE after being kicked out in a previous feed attempt for a back-side alignment error.

Back-Side Imaging Errors—Parameters in this section apply only to cards that are imaged on the back side

17. Percentage of back-side digital imaging/quality errors on the first feed attempt
This is the rate of back-side imaging errors expected for cards not experiencing back-side imaging errors on previous feed attempts.

18. Percentage of back-side digital imaging/quality errors on refeed attempts
This is the rate of back-side imaging errors on refed cards that had previously experienced back-side imaging errors.

19. Percentage of back-side-digital-imaging/quality-error cards fed back into the HSFE for another processing attempt
This specifies the percentage of the cards to be refed into the HSFE after being kicked out in a previous feed attempt for a back-side imaging error.

Jam Error Section—Parameters in this section apply only to cards that are either imaged on the front side or flipped for orientation purposes

20. Percentage of cards experiencing jams in the flipper on the first feed attempt
This is the rate of jam errors expected for cards not experiencing jam errors on previous feed attempts.

21. Percentage of cards experiencing jams in the flipper on refeed attempts
    This is the rate of jam errors on refed cards that jammed on a previous feed attempt.

22. Percentage of jammed cards fed back into the HSFE for another processing attempt
    This specifies the percentage of cards to be refed into the HSFE after jamming in a previous feed attempt.

23. Time required to clear a jam from the flipper assembly
    This specifies the time required to remove and/or disassemble the flipper assembly to free a jammed card.

Front-Side Alignment Errors—Parameters in this section apply only to cards that are imaged on the front side

24. Percentage of front-side card alignment errors on the first feed attempt
    This is the rate of front-side alignment errors expected for cards not experiencing front-side alignment errors on previous feed attempts.

25. Percentage of front-side card alignment errors on refeed attempts
    This is the rate of front-side alignment errors on refed cards that had previously experienced front-side alignment errors.

26. Percentage of front-side-alignment-error cards fed back into the HSFE for another processing attempt
    This specifies the percentage of the cards to be refed into the HSFE after being kicked out in a previous feed attempt for a front-side alignment error.

Front-Side Imaging Errors—Parameters in this section apply only to cards that are imaged on the front side

27. Percentage of front-side digital imaging/quality errors on the first feed attempt
    This is the rate of front-side imaging errors expected for cards not experiencing front-side imaging errors on previous feed attempts.

28. Percentage of front-side digital imaging/quality errors on refeed attempts
    This is the rate of front-side imaging errors on refed cards that had previously experienced front-side imaging errors.

29. Percentage of front-side-digital-imaging/quality-error cards fed back into the HSFE for another processing attempt
    This specifies the percentage of the cards to be refed into the HSFE after being kicked out in a previous feed attempt for a front-side imaging error.

Marker Card Section

30. Population of marker cards in a drawer as a percentage of the drawer contents
    This parameter specifies the average percentage of marker cards expected in a given file drawer to be fed into the HSFE.

Labeling Parameter Section

31. Label printing scheduling—when to print label (0 = Print on demand for the current card, 1 = Print for the current card while it is being fed, 2 = Print next label ahead of time while imaging the current card)
This parameter specifies the scheduling of label printing. If a 0 is selected, the label will be printed while the target card is waiting in the labeling station. If a 1 is selected, the label will begin being printed while the target card is being transported from the feed station to the labeling station. If a 3 is selected, the label will be printed while the previous card is being imaged so that the label is ready and waiting when the target card arrives in the labeling station.

32. Average HSFE downtime while reloading a roll of label stock
This is the time the HSFE must be shut down while the labeler is restocked with labels.

33. Average HSFE downtime while reloading a roll of printer ribbon
This is the time the HSFE must be shut down while the label printer is restocked with printer ribbon.

34. Number of labels on a label roll
This parameter identifies the number of blank labels on a given roll or label stock that are available for printing and application. This does not include labels that are on leader or trailer portions of the roll.

35. Number of labels printed per printer ribbon
This parameter is analogous to parameter 34 but for label printer ribbon rather than label stock.

Microfilming Parameter Section

36. Microfilming on/off (1 = on, 0 = off)
Selecting 1 (on) causes all fingerprint cards to be microfilmed as well as digitized. This also enables microfilming support operations such as microfilm test target filming and film supply reloading. Selecting 0 (false) disables microfilming and all microfilming support operations.

37. Average HSFE downtime while reloading a roll of microfilm
This is the time the HSFE must be shut down while the microfilm is restocked.

38. Filming of test targets at the start of a new microfilm roll on/off (1 = on, 0 = off)
Selecting 1 (on) causes the program to simulate filming a "set" of test targets at the beginning of each roll of microfilm. This is commonly done to help during the film development process.

39. Filming of test targets at the end of a microfilm roll on/off (1 = on, 0 = off)
This parameter is analogous to parameter 38 but for targets at the end of the roll.

40. Number of microfilm test targets in a set
This specifies the number of test target (cards) to be submitted in each set in parameters 38 and 39.

41. Sides of the microfilm test target to be filmed (0 = front, 1 = back, 2 = both)
This parameter identifies which sides of each test target in parameter 40 should be filmed.

42. Number of images to be taken of each side of the microfilm test target
This parameter identifies the number of duplicate images that should be taken of each side of each target.

43. Flipping of the test target if the front side is not filmed on/off (1 = on, 0 = off)
If either a 0 (front) or a 2 (both) is selected for parameter 41, then the film test target is already flipped to present the front side to the camera. If a 1 (back) is selected for parameter 41, however, flipping the target after filming the back becomes an extra operation that may be performed for preservation of card orientation. This parameter provides the option of performing the orientation-preserving flip operation.

44. Spacing between images on the film as a percentage of the image width
This identifies the width of the gap between adjacent images on the microfilm. Entering 100 (%) would cause the gap between images to be as wide as the images themselves.

45. Total length of the microfilm on a roll (feet)
This identifies the length of the film rolls to be used in the microfilm camera.

46. Microfilm reduction ratio
This parameter specifies the numeric ratio between the size of the actual document and the size of the document image on the microfilm. Values should be entered as with an implied reference to 1. For example, if an 8:1 reduction ratio is to be used, an 8 should be entered.

47. Length of film wasted for the film leader/trailer
This parameter specifies the amount of film per roll that will not be used for images because it is being used as either a film leader or trailer.

48. Document width
This parameter specifies the width (inches) of all documents that are to be filmed.

Calibration Verification Parameter Section

49. Number of images to be taken of each side of the calibration verification test target
This parameter is an analog of parameter 42 for calibration verification test target cards.

50. Flipping of the test target if the front side is not imaged (1 = on, 0 = off)
This parameter is an analog of parameter 43 for calibration verification test target cards.

51. Number of calibration test targets in a set
This parameter is an analog of parameter 40 for calibration verification test target cards.

52. Sides of the calibration verification test target to be imaged (0 = front only, 1 = back only, 2 = both front and back)
This parameter is a functional equivalent of parameter 41 for calibration verification test target cards.

53. Interval between calibration verifications
Calibration verifications are assumed to be performed at fixed intervals. This parameter specifies the interval (hours) between scheduled calibration verifications.

54. Image types to be collected during calibration verification (0 = film only, 1 = digital only, 2 = both film and digital)
This parameter specifies the types of fingerprint card images to be collected by the HSFE.

55. Time the HSFE is down after images are collected while awaiting calibration verification approval
This specifies the length of time (minutes) the HSFE is expected to be taken off-line after calibration verification images are taken but before approval is granted.

Operator Efficiency Parameter Section

56. Time between operator breaks
Assuming that operator breaks are scheduled at periodic intervals, this parameter specifies the length of the interval (minutes).

57. Duration of an operator break
This parameter specifies the amount of time (minutes) the HSFE is shut down during an operator break. Note that if a fill-in operator is used, this parameter may approach zero.

58. Operator reaction time per card
This is the time difference between when the HSFE is ready to accept another card from the operator and when the operator delivers the card. This parameter value should reflect the operator training/experience level, approaching zero as the operator becomes more skilled.

Marker Card Handling Parameter Section

59. Marker card flipping for correct orientation in the output stack on/off (1 = on, 0 = off)
This parameter is similar to parameters 43 and 50 for marker cards. The difference is that marker cards are never imaged and therefore never require flipping unless their orientation in the output hopper must be maintained.

60. Refeeding of marker cards when a jam error occurs on/off (1 = on, 0 = off)
This parameter was separated from the generic parameters (13, 16, 19, 22, 26, and 29) since marker cards are assumed to merely be placeholders for operational convenience. If a marker card jams and must be manually removed, it may not be necessary to refeed the card. It may make more sense to place the marker card in the output hopper rather than risking another jam on refeed.

2.4.3 Editing the Input File

The input files are in ASCII text file format, so they may be edited with any standard text editor. To change any of the parameter values, simply open the input file with a text editor and edit the parameter values, being careful not to add any blank lines or delete any parameter entry lines (see warnings in Sect. 2.4.1).

2.5 PROGRAM OUTPUT (FILE)

The program will write output to the display terminal, a file, or both (see Sect. 2.3 for optional calling arguments). Regardless of the options chosen, the format of the program output remains constant. Figure 4 contains a copy of an example output file from Appendix B, with added line numbers for discussion purposes. All numeric data are calculated values.

Referring to the figure, the very first data after the file header are the input and output file names in lines 3 and 4. The file names include the path to get to the files from the current directory. If no input file is specified, the default path/file is INPUTS/sim.in. Line 4 lists the file name as (null) if no output file is requested.

The remaining sections of the output contain three columns of output data for each row. The column headings identify these as the average, minimum, and maximum values. These represent the average, minimum, and maximum values for the given parameter oyer every one of the n runs, where n is specified in the input file and displayed on line 37 of the output file (see Fig. 4).

The next section, lines 5 to 12, is labeled ERROR COUNTS. This section shows how many of each major error type occurred during the run(s). The major error types include labeling errors, back-side alignment errors, back-side imaging errors, jam errors, front-side alignment errors, and front-side imaging errors.

Labeling errors include any error in the printing and application of the labels. Alignment errors are defined as any combination of relative translation and/or rotation between the camera system and the card, which places any portion of the card outside the (limited) field of view of the camera(s). Imaging errors include the occurrence of any digital image quality anomaly that can automatically be detected by the HSFE. Imaging errors apply to digital images only since image quality judgments for microfilming are not performed on-line. A distinction is made between back and front for both alignment and imaging errors. Back refers to the first side presented (before flipping) to the camera (i.e., the side facing up when the card is fed into the HSFE). Front refers to the second side presented (after flipping) to the camera (i.e., the side facing down when the card is fed into the HSFE). Jam errors refer to the number of cards that get lodged in the flipper assembly while being flipped. It is assumed that cards never get jammed anywhere else in the system.

```
RESULTS FROM THE FICS HSFE SIMULATOR
________________________________________
Input file name: INPUTS/sim.in
Output file name: OUTPUTS/sim.out
                                          Avg    (     Min      Max)
ERROR COUNTS:
______________                      =     0.3    (      0,       1)
  Labeling errors                   =    12.5    (      3,      22)
  Backside alignment errors         =     1.3    (      0,       5)
  Back side imaging errors          =     4.6    (      0,      10)
  Jam errors                        =    13.2    (      5,      23)
  Front side alignment errors       =     1.4    (      0,       7)
  Front side imaging errors
CARD COUNTS:
______________
  Gross cards fed (all types)       =  8298.4    (   8005,    8667)
  Total successful cards            =  8265.1    (   7970,    8641)

  Gross fingerprint cards           =  5199.2    (   7904,    8578)
  Successful fingerprint cards      =  8166.0    (   7869,    8552)
  Fingerprint cards refed           =    19.2    (     11,      28)

  Gross marker cards                =    82.4    (     59,     101)
  Successful marker cards           =    82.4    (     59,     101)
  Marker cards refed                =     0.0    (      0,       0)

  Gross film test targets           =    13.8    (     12,      15)
  Successful film targets           =    13.7    (     12,      14)
  Film targets refed                =     0.0    (      0,       1)

  Gross cal-ver targets             =     3.0    (      3,       4)
  Successful cal-ver targets        =     3.0    (      2,       3)
  Cal-ver targets refed             =     0.0    (      0,       1)
EVENT COUNTS:
______________
  Calibration verifications         =     3.0    (      3,       3)
  Operator breaks taken             =     3.0    (      3,       3)
  Number of film changes            =     6.9    (      6,       7)


THROUGHPUT:
______________
Sustained average throughput        =   679.8    (   655.7    712.6)
fingerprint cards per hour, based on 50 runs averaging 12 h, 0.7 min each
```

Fig. 4. Typical program output.

The next section is the CARD COUNTS summary in lines 13 to 28. This section shows how many of each major card type were fed, how many were processed successfully, and how many of the unsuccessfully processed cards were refed in a subsequent attempt. The four major card types include fingerprint cards, marker cards, microfilm test targets, and calibration verification test targets. Summary sections for each of the individual card types are found in lines 17 to 28.

Lines 15 and 16 are sums over all card types fed into the system. Note that in any given column, line 15 does not equal the sum of lines 17, 20, 23, and 26. Similarly, in any given column, line 16 does not equal the sum of lines 18, 21, 24, and 27. Recall, however, that the numbers printed in the three columns represent the average, minimum, and maximum values of all the runs made. Since each run is unique, these numbers should not be expected to add up perfectly unless the number of runs made is equal to one in the input file.

The next section is the EVENT COUNTS summary in lines 29 to 33. Items in this section represent scheduled or otherwise expected downtime events. The one event missing from this section is label supply changes. This parameter normally has so little effect on the system throughput that it was omitted from the program output.

The final section is the THROUGHPUT summary in lines 34 to 37. These lines contain the sustained average throughput, the number of runs made, and the average length of each run. This is the most important section of the output since the program was developed to study the effects of the input parameters on the HSFE throughput. Throughput is measured in terms of the number of fingerprint cards successfully digitized and written to the BDR per hour.

3. MODEL DEVELOPMENT

3.1 TIMING DIAGRAMS

Before the HSFE model was conceived, a series of timing diagrams was developed to help the Oak Ridge National Laboratory (ORNL) FICS team understand the system configuration options and where the throughput bottlenecks might be. Upon generation of several timing diagram variations, an idea evolved to use the timing diagrams as configuration models for input into a computational tool that would predict HSFE throughput. Since the model is based on the timing diagrams, a good understanding of the timing diagrams is needed before the model can be discussed.

Figure 5 shows a timing diagram for the HSFE. The 16 entries along the left margin, labeled PI to P16, comprise the design parameters important to HSFE timing and throughput. The parameters are grouped vertically with thick black lines according to the subsystem to which they belong. The four groups are labeled along the right margin of

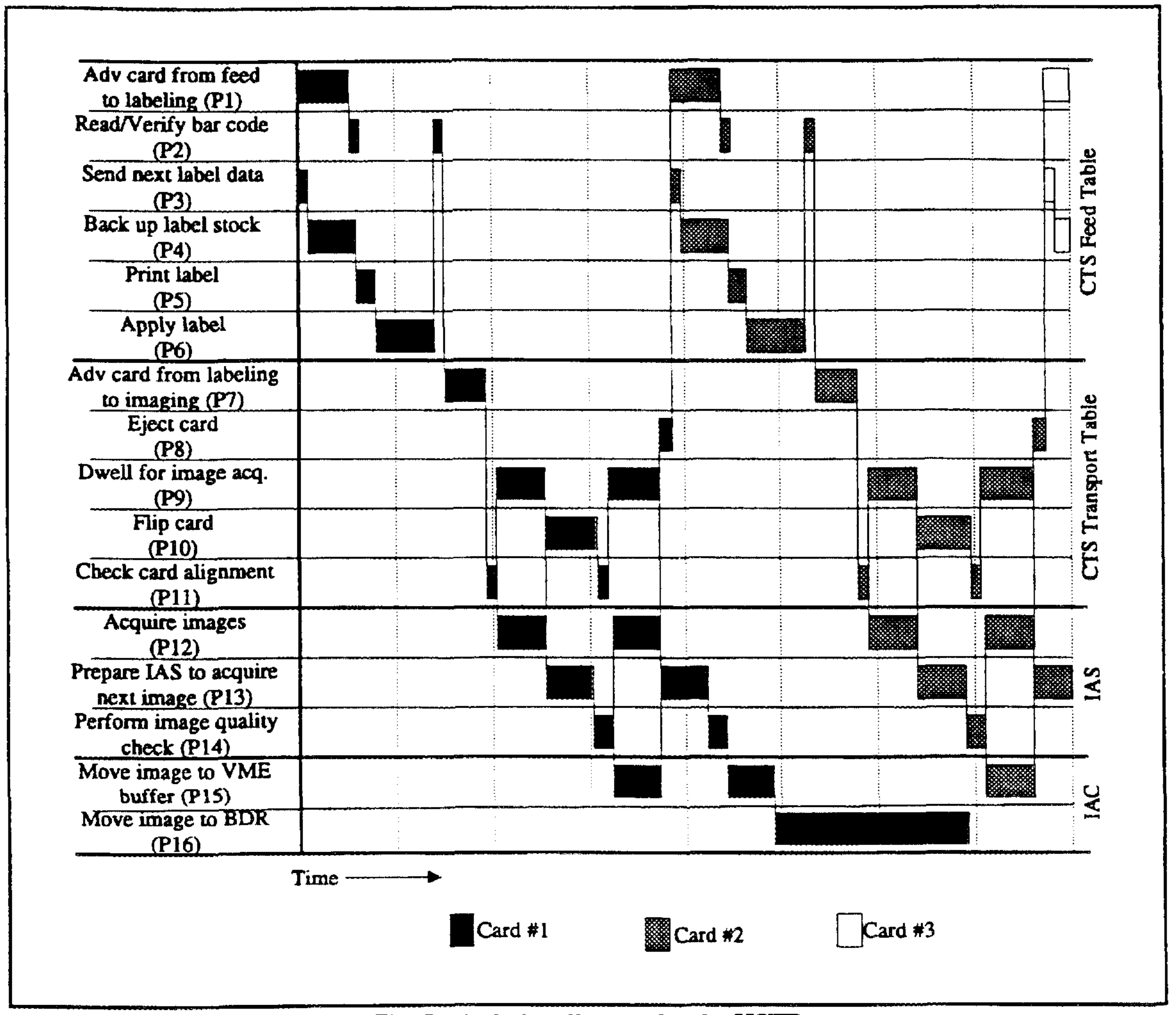

Fig. 5. A timing diagram for the HSFE.

the diagram. From top to bottom, the first two groups, CTS Feed Table and CTS Transport Table, contain the mechanical card-moving and -labeling functions of the CTS. The titles reflect the names of the belts on which the functions are performed. Figure 6 shows that there are actually three belts in the CTS. The third belt is used in the flipper assembly. The feed and transport table belts represent the primary card-moving belts in the system. The card leaves the transport table belt momentarily while being flipped but is returned to the transport table belt for further handling. Since no other card can be moved by the transport table belt while a card is in the flipper, the flipper belt is not considered a primary card-moving belt. For this reason, operation P10, flip card, is listed under the CTS Transport Table Operations rather than under a separate "flipper" group' The next two groups, the IAS and the IAC, represent the image gathering (camera) and storage (disk/buffer) functions respectively.

Referring to Fig. 5, parameter P1 is the time it takes to advance a card from the feed station to the labeling station. Once the card is brought to a stop in the labeling station, it must be scanned for a label. Parameter P2 covers the scanning and data analysis for the bar-code reading operation. If the card needs a label, one must be printed and applied. Parameter P3 is the time required to send the label printing data from the control computer to the label printer through a serial port. Once the data are received, the labeler backs up the label stock in preparation for printing. Backing up the labels must be done when the length of the label is less than the distance from the print head to the applicator pad. This is because extra label stock must be played out following a print operation in order to move the newly printed label onto the applicator pad. Before printing the next label, the process must be reversed to bring the next (unprinted) label

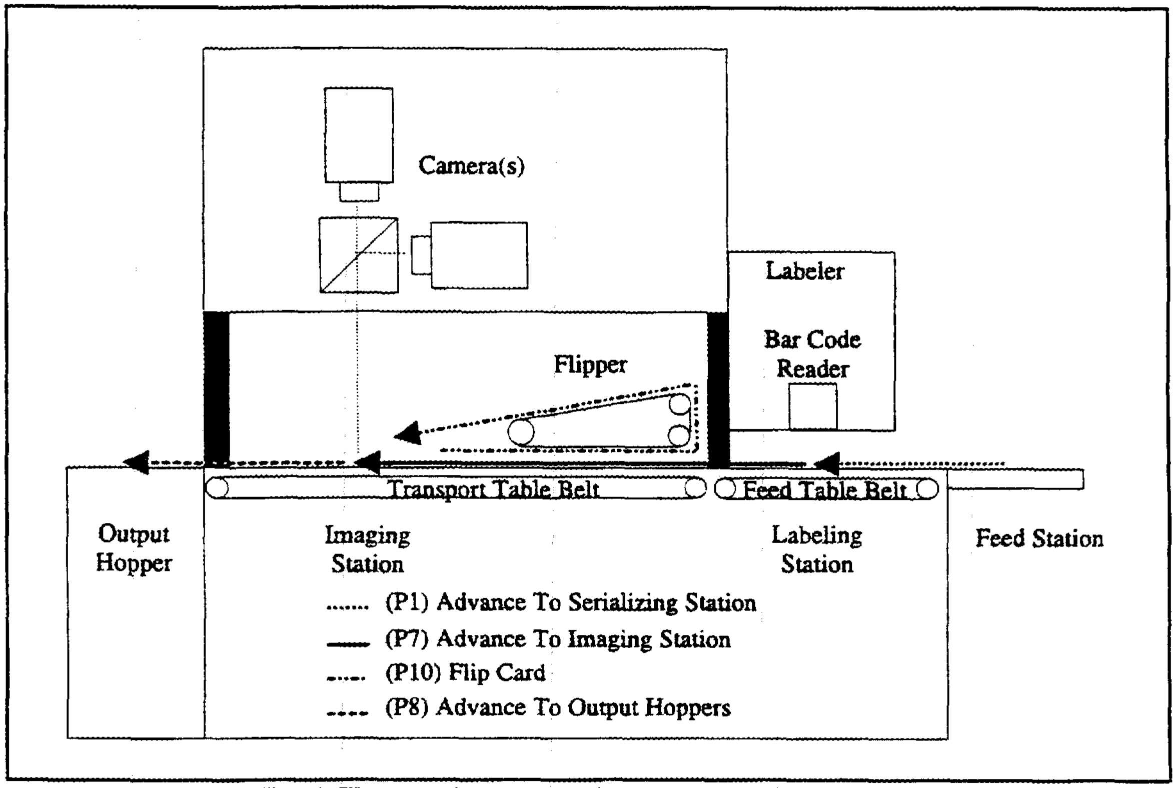

Fig. 6. The three belts controlling card motion in the HSFE.

back to the print head. The only other alternative is to allow a "loop" of printed labels to exist between the print head and the applicator pad. This alternative is not as attractive because it means that the machine cannot have direct control over the "next" label to be applied. This becomes important when a card must be relabeled or in a situation when a special label value must be printed on demand. Parameter P5 represents the time required for the labeler system to actually print the label. Once printed, the label is applied to the card (P6). After the label is verified with the bar-code reader for correct printing, the card is ready to leave the feed table belt.

The card is then transferred from the feed table belt labeling station to the transport table belt imaging station (P7). Once the card is brought to a stop, the card alignment is checked (P11) to ensure that the card is not skewed or otherwise out of view of the camera(s). The card then begins waiting for a dwell time (P9), during which both digital and microfilm images are collected (P12) by the IAS. When the images have been acquired, the digital images must be moved from the digital sensor(s) into an IAS buffer (P13) for some high-level image quality checking (P14). When the dwell is over, the card is flipped (P10) and rechecked for alignment (P11) before beginning another dwell time (P9) for image acquisition. When the dwell is over, the card is ejected from the imaging station to the output hopper (PS). At this point the CTS is cleared of all cards and is ready to begin the cycle over again, advancing another card to the labeling station (P1). The operations in the IAC, left out of the above description, involve moving the digital image data from the IAS buffer into an IAC buffer (P15) in preparation for writing the data to a disk buffer once per card (P16).

3.1.1 Timing Diagram Variations Considered

The timing diagram depicted in Fig. 5 represents one of many possibilities. Without changing hardware, several changes in event scheduling can be made which will have effects on both throughput and functionality. Since a major goal of HSFE modeling was to provide a tool for studying the effects of configuration changes, inputs had to be provided for some of the many possible event scheduling parameters. Three scheduling parameters were selected for modeling.

The first event scheduling variation considered controls when the next card is accepted from the feed operator (P1). Figure 5 shows P1 beginning after the previous card is ejected (P8). To improve throughput, P1 may be started at the same time as P8, as shown in Fig. 7. This scheduling change improves system throughput by P8 s/card.

Another scheduling variation considered is when to perform image quality checking. A careful look at Fig. 5 will reveal that the image quality checking is performed on the back side of the card while the card is being flipped and aligned and on the front side of the card while it is already in the output hopper. This configuration provides the best throughput performance because it minimizes the amount of time the card must remain on the HSFE belts. Since the card image quality check is not necessarily completed before the card is ejected, this approach does not allow all cards with image quality problems to be automatically diverted from the normally processed cards (returned to the operator or ejected to a separate output hopper). Two other image quality check scheduling scenarios are possible: (1) scheduling the image quality checking to be completed before a card is moved on the belt (see Fig. 8) and (2) scheduling the image quality checking to be completed before a card is ejected (see Fig. 9). The first alternative sacrifices throughput the most but gains the ability to automatically divert the card from the normal flow at the conclusion of imaging each side of the card. The second

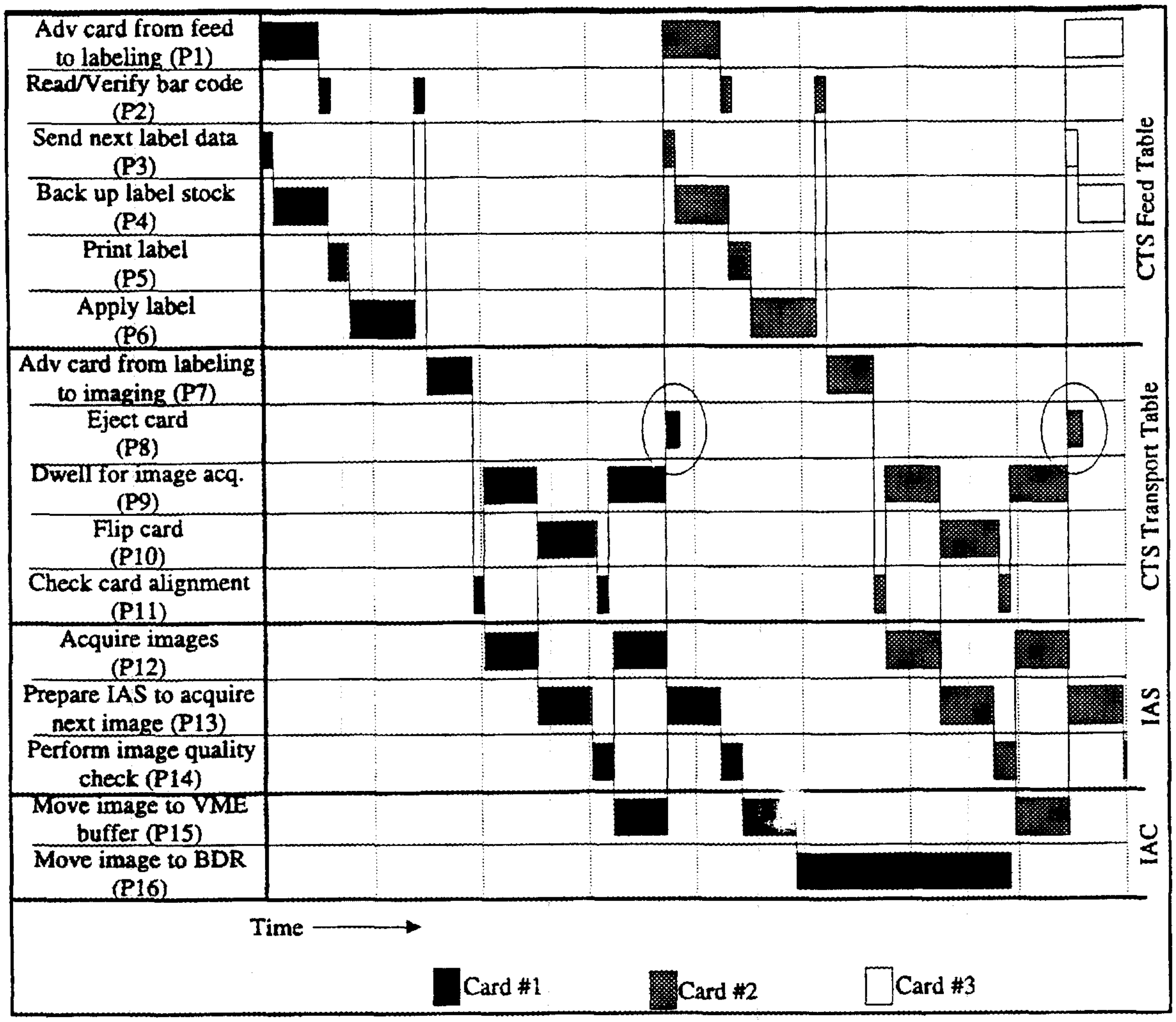

Fig. 7. Implementation of simultaneous card ejection and card advance.

alternative is a compromise between the configurations depicted in Figs. 8 and 5. Throughput should be less than that of Fig. 5 because the card is held still on the transport table during the front-side image quality check and greater than the first alternative because the back-side image check is performed during the flip. Cards with image quality problems may be diverted from the normal flow since image quality checking is completed before the card leaves the transport table belt.

Label printing scheduling provides another area for balancing functionality and flexibility with throughput. The scenario depicted in Fig. 5 has the label being printed and the target card being fed simultaneously. A more functional solution, but one which sacrifices throughput more, is to print the label on demand for the card in the labeling station, as shown in Fig. 10. This solution allows the label value to be determined on demand for each card. No assumptions about the next label value are made. The trade-off is a significant loss of throughput because P1 through P6 become strictly serial operations. Another solution that maximizes throughput at the expense of on-demand print ability is to print the label for the next card while the current card is being imaged, as shown in Fig. 11. Printing during imaging should not produce any vibrations that will

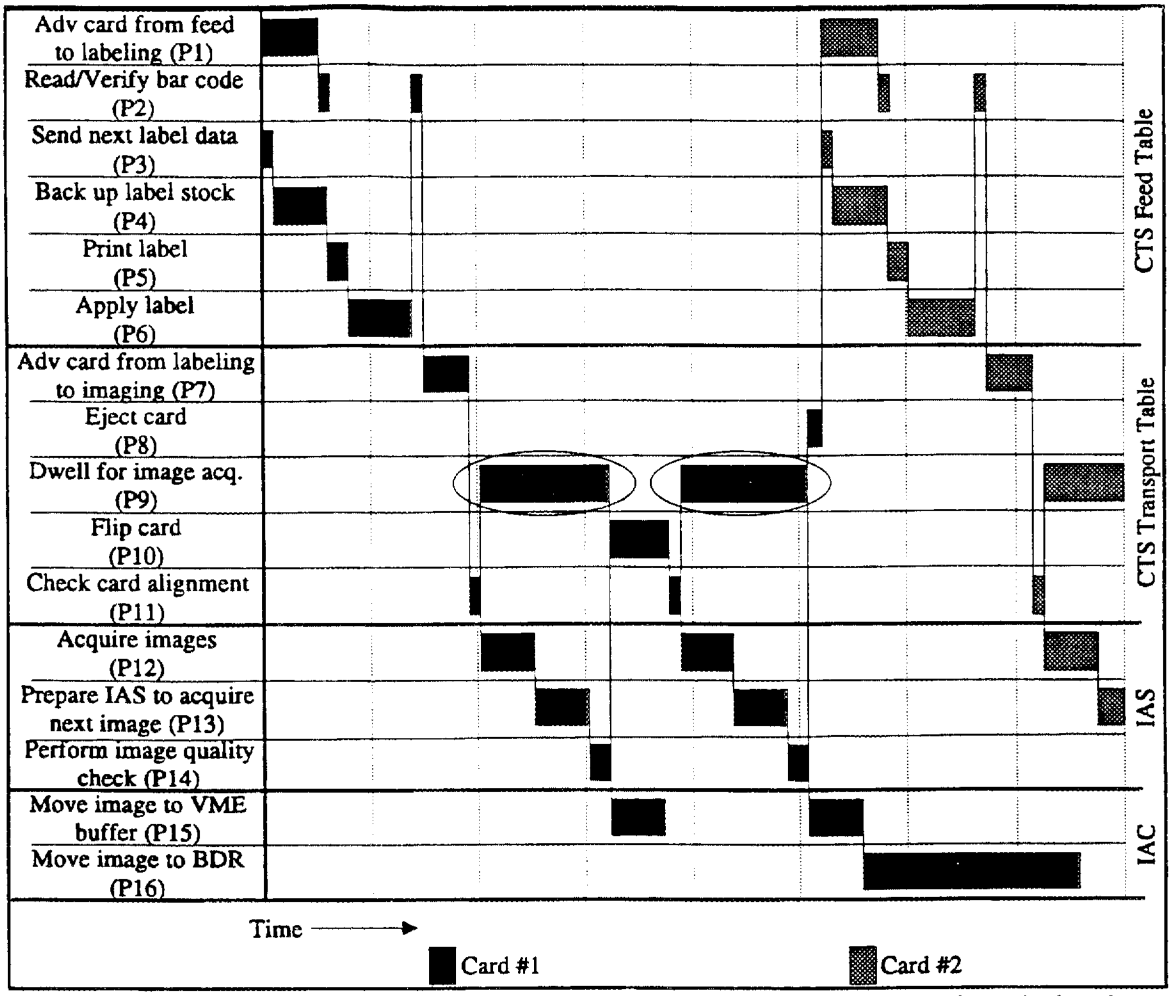

Fig. 8. Implementation of image quality check completion before the card is moved from the imaging station.

adversely affect the image quality since the label printer uses thermal-transfer technology (nonimpact).

3.1.2 Configuration Variations Not Modeled

The most significant variation to Fig. 5 that was not modeled is performing the feed and transport table belt operations concurrently (i.e., in parallel for two cards, as shown in Fig. 12). This variation has tremendous throughput advantages because it allows the imaging/flipping operations to be parallelled with the labeling operation for the next card. The result is a system that is throughput limited by data processing rates rather than by mechanical operation speeds.

Previous analysis showed that the HSFE throughput goals were achievable with a parallelled architecture, but other objectionable effects existed. The same analysis left some question about whether or not the throughput goal was achievable with the nonparallelled architecture. Because time was limited during this development, the effort was directed toward the nonparallelled case.

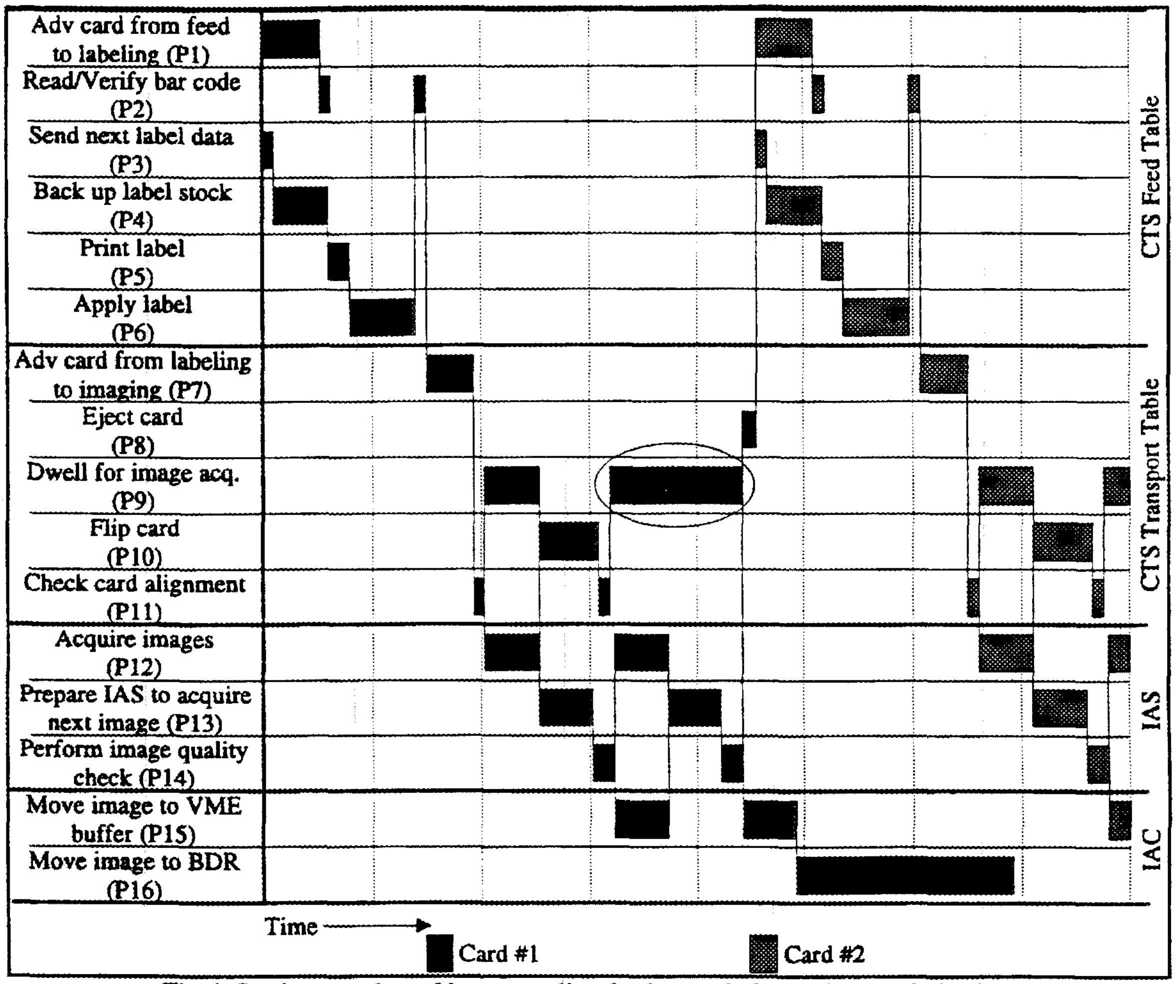

Fig. 9. Implementation of image quality check completion before card ejection.

3.2 MODEL DEVELOPMENT

With a basic understanding of the HSFE timing relationships from Sect. 3.1, the next step was to build a dynamic model of the HSFE equipment in operation. From the timing diagrams, one could predict system throughput based on the period between successive card ejections. This type of "theoretical maximum" prediction, however, does not fold in any of the effects of real-world events such as downtimes for equipment supply reloading, system errors, and operator efficiency. The goal was to build a model that would accurately predict a real-world throughput of an HSFE in normal day-to-day operation.

3.2.1 Methodology

The basic modeling methodology is as follows:

1. Read the input parameter values from an input file.

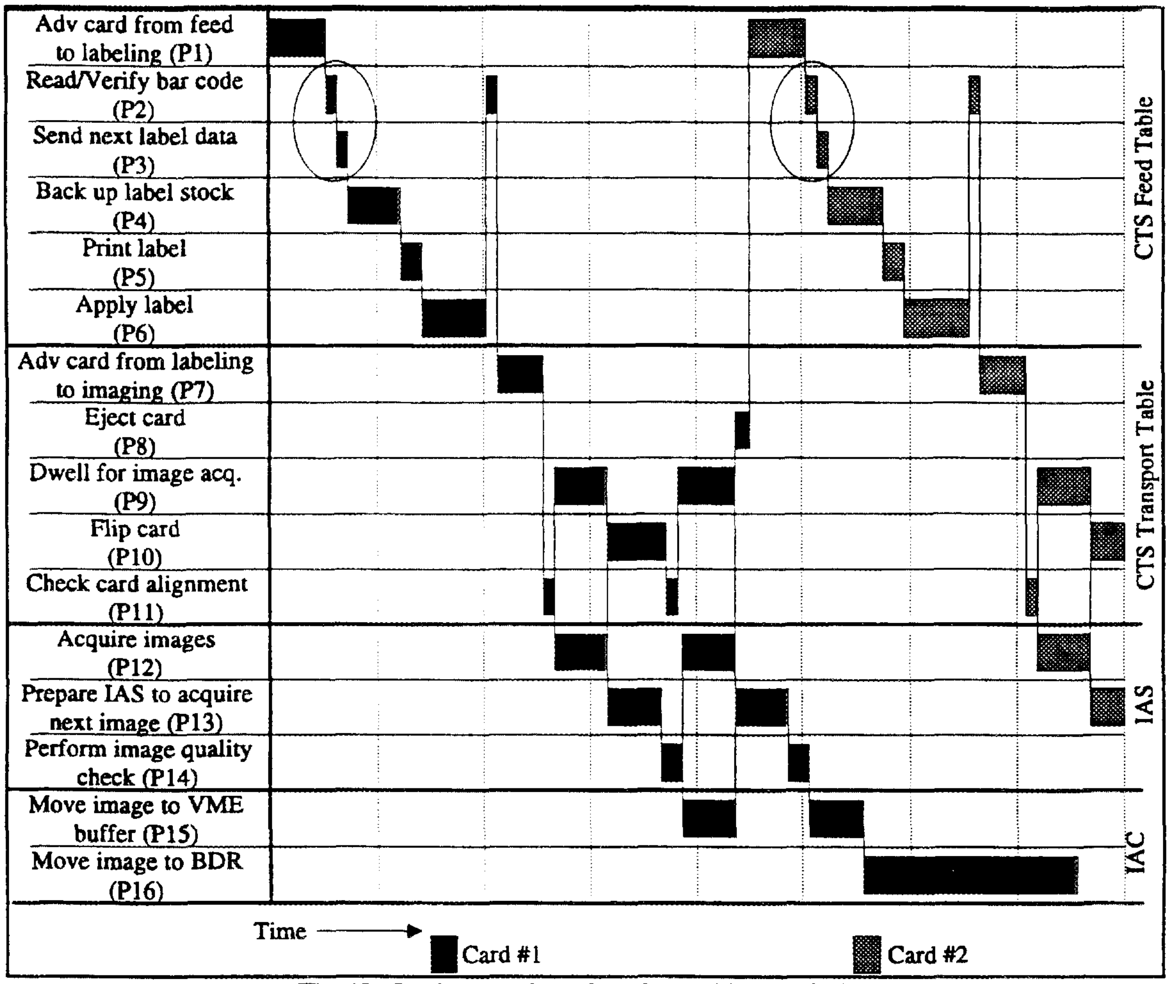

Fig. 10. Implementation of on-demand label printing.

2. Calculate the time required to process each of the four basic types of cards (see Sect. 1.2) using the input parameter values. For each type of card, calculate the processing time under error conditions at each of the six basic stages of processing: labeling, back-side alignment, back-side imaging, flipping, front-side alignment, and front-side imaging.

3. Starting with the elapsed time counter at zero, "feed" one card at a time, adding the card processing time to the elapsed time counter. Use a special "chance generator" function (based on a random number generator) for each card fed to provide the appropriate level of opportunity for an error. Error rates at each stage of processing are described in the input file. When card processing errors are generated by the "chance generator," add the appropriate error recovery time to the elapsed time counter. Use the chance generator rather than fingerprint cards to determine when marker cards are fed.

4. Keep track of the system supply levels and "stop" the system to restock supplies when necessary. When film supplies run out, shoot the appropriate number and type of

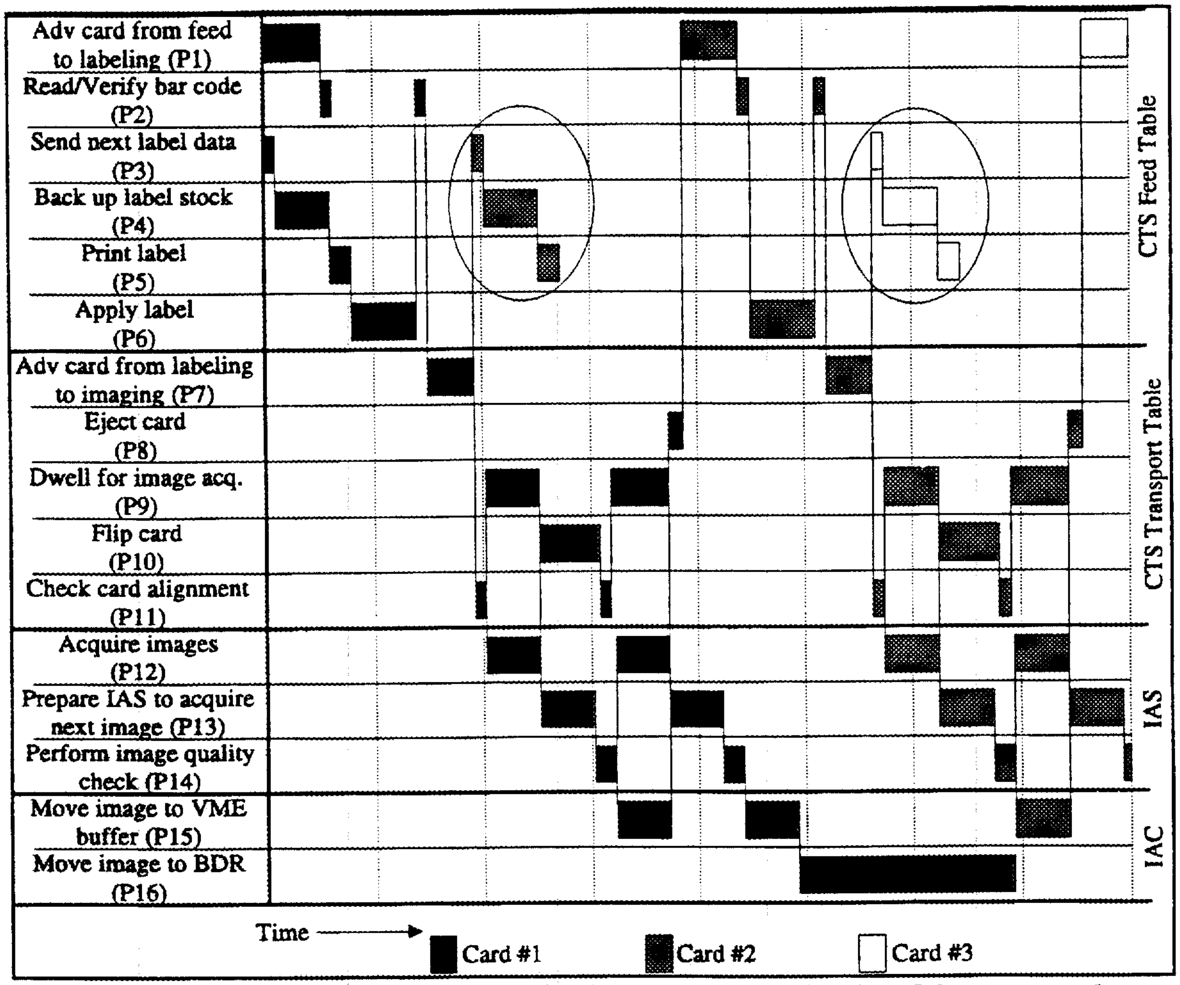

Fig. 11. Implementation of label printing for the next card during imaging of the current card.

microfilm test targets at the beginning and/or end of each roll of film (see input file). Keep track of the elapsed time on the clock to ensure that calibration verifications are performed at the correct interval. "Stop" the system to allow the operator to take breaks at appropriate intervals. Keep track of error statistics throughout the "run."

5. Monitor the elapsed time counter while performing steps 3 and 4 until the desired run duration is reached.

6. Store the statistics data for the run.

7. Perform steps 3 through 6 once for each of the desired runs requested in the input file.

8. Calculate the minimum, maximum, and average values for each of the statistics data.

9. Write out the statistics results.

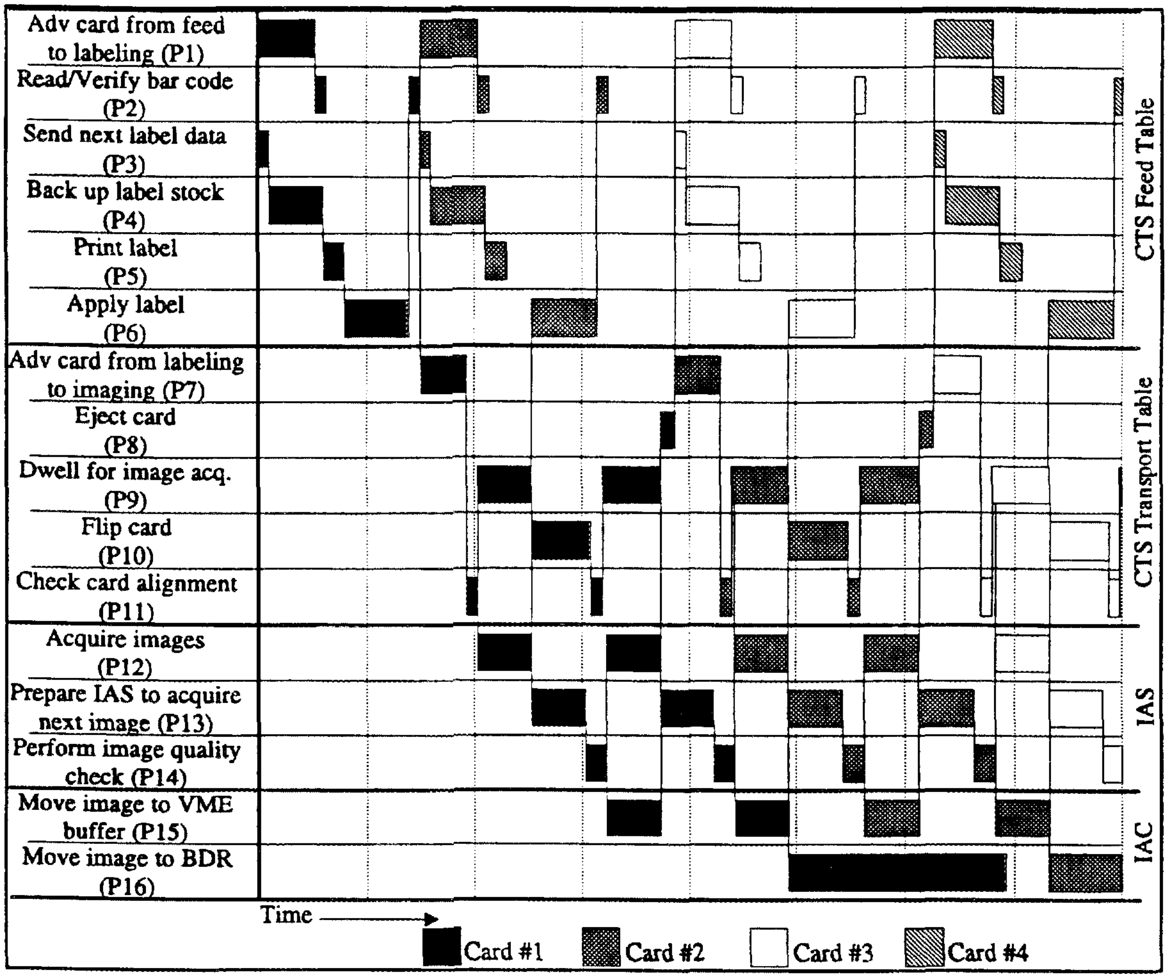

Fig. 12. Implementation of concurrent labeling and imaging operations.

This "simulation" style methodology was selected to accommodate extrapolation of the model into an "HSFE simulator" that would operate in real time. Such a tool would be useful during the development of the FICS to simulate the dynamics of the HSFE hardware before the hardware development is complete. This would allow integration of the HSFE and FICS to begin before the HSFE is operational.

3.2.2 Model Assumptions

The following is a list of some of the major assumptions made during construction of the HSFE throughput model.

- Card alignment checking in the image processing station is performed with dedicated sensors mounted to the CTS rather than by performing image processing techniques on the digital image after it is captured.
- The IAS is double buffered so that image quality checking (P14) may overlap with moving the previous image data to the VME buffer (P15).

- Some level of image quality checking is always performed on the digital image by the IAS.
- The IAC VME system is double buffered to accommodate overlap in moving the current image to the VME buffer (P15) and moving the previous card images to the BDR (P16).
- Only one card image set at a time may be transferred to the BDR (i.e., no two BDR transfers from the IAC may overlap).
- The times for image acquisition, preparing for the next acquisition, and quality checking remain constant whether collecting digital, microfilm, or both types of images. This assumption was made because it was not known how the IAS would be implemented. In reality, the acquisition will probably be faster if either digital images or microfilm images are taken, but not both.
- All cards are fed with the back side facing up, so imaging on the front side requires flipping the card.
- Supplies are full at the beginning of each run. Actual runs will have random initial supply levels.
- Refed cards will be reprocessed completely as if they were never processed before. This is a good assumption except in the case of labeling. If a card is properly labeled, it should never require relabeling if refed into the system.
- All jams occur in the flipper mechanism.
- All imaging/image quality errors are attributed to digital imaging.
- All fingerprint cards are digitized on both sides.
- All fingerprint cards are labeled if they do not already have a label.
- All fingerprint cards are microfilmed on both sides if microfilming is turned on.
- Only fingerprint cards require labeling.
- Calibration verification is performed at fixed intervals. Test targets are fed into the HSFE to allow image collection. Once images are collected, the HSFE may be shut down for a period of time while images are reviewed and the HSFE operation is approved.
- Calibration may include microfilm, digital, or both types of images.

4. HIGH-SPEED-FRONT-END THROUGHPUT ANALYSIS

This section contains an analysis of the effects of several HSFE inputs on system throughput. The goals of these experiments were to (1) identify some of the major throughput drivers, (2) identify some of the areas where operation simplicity/convenience may be traded off for improved system throughput, and (3) provide the reader with a better understanding of HSFE system dynamics. The analysis here is not intended to be comprehensive. Rather, this section was included to stimulate further experimentation by the reader.

Before the series of experiments was designed, a baseline set of model inputs was put together to serve as an experimental control set. The parameter values chosen represent current best-estimates of processing times. Operations parameters are intended to reflect the way the FBI currently plans to use the HSFE. The baseline input parameter set is shown in Appendix A.

A set of 29 experiments was performed to demonstrate the effects of parameter changes on HSFE throughput. In most cases, only one parameter was varied so that direct comparisons with the baseline could be made. The results of these experiments are reviewed in Sect. 4.1, Parameter Evaluation. A second set of experiments was then designed based on the results of the parameter evaluation. The results of this second set can be found in Sect. 4.2, System Evaluation.

4.1 PARAMETER EVALUATION

Figure 13 shows the parameters varied in each of the experiments, the calculated throughput, and the percentage change in throughput from the baseline experiment.

Experiment one was performed to demonstrate that changing the duration of the simulation run may result in some small change in throughput. Changing the duration of the run alters the scheduling of downtime events such as microfilm supply reloading. For example, changing the duration of the run from 8 to 9 h may cause an apparent loss in throughput because the microfilm supplies run out 5 min into the ninth hour. The extra hour of the shift only adds 45 min of operation, resulting in a fall in the average throughput. This small change in throughput is an artifact of the measurement technique and in no way represents long-term real-world performance.

Experiment two demonstrates the throughput loss experienced by not taking advantage of the ejection time to advance the next card to the labeling system, as shown in Fig. 7. These operations should be parallelled because throughput is improved without compromising functionality.

One of the most significant throughput drivers turns out to be the scheduling of the image quality checking function, as shown in experiments three and four. A significant throughput loss over the baseline system was demonstrated in experiment three when image quality checking was scheduled to occur before the card was allowed to move on the belt (see Fig. 8). Conversely, a significant throughput gain was realized by performing image quality checking during the card move (Fig. 5). As discussed in Sect. 3.1.1, the gains in performance in this scenario are traded for operational convenience. The machine's ability to automatically divert a card with poor image quality from the normal flow is lost because the front-side image quality checking may not be completed until the card has already been ejected to the output hopper. The machine could, however, be designed to flag cards with image quality problems by label number while they are in the output hopper. These cards could then be manually pulled from the stack for reprocessing. This is the recommended scenario in light of the low image quality error rate and the large gains to be made in throughput. As a general philosophy, it is more efficient to optimize for the normal case (no image errors) than to optimize for the off-normal (image error) case.

Printing labels on demand in experiment five (Fig. 10) resulted in a 16% loss in throughput over the baseline run. As expected, printing the label during current card feed in experiment six provided a middle-of-the-road solution, resulting in a lower throughput than the baseline approach (printing during imaging) but a higher throughput than the on-demand approach.

Experiments eight and nine showed throughput gains because they reduced the frequency of microfilm reloading; experiment eight increased the film capacity, while experiment nine reduced the film used per image. Experiment seven carried the gains to an extreme by completely eliminating filming at the HSFE and therefore eliminating the need for film reloading. Eliminating filming at the HSFE may, however, cause other operations difficulties elsewhere in the FICS.

Experiments 10 through 12 deal with increasing the image acquisition time from 0.2 s (baseline) to 0.5, 0.75, and 1.0 s respectively. These experiments illustrate the importance of designing the IAS to acquire images as fast as possible. If microfilming is performed on the HSFE, the image acquisition time includes the time for the digital camera sensor(s) to acquire the image and the time required to expose the film in the microfilm camera. Whether these operations are performed serially or in parallel depends on the IAS design. Additionally, increasing the microfilm exposure time to 0.75 or more seconds may result in some improvement in quality. If this is the case, the margin of quality improvement gain will have to be weighed against the margin of throughput loss to determine the best balance between exposure time and throughput.

The second largest throughput gains were made by eliminating HSFE downtime while awaiting calibration verification approval. Comparing experiments 13 to 15 shows that when approval downtime is involved, the interval between calibration verifications has a large effect on throughput. The most economical solution under these circumstances is to balance product (image) quality and production (throughput) by scheduling calibration verifications less frequently. However, a better solution is available. Experiments 16 to 19 show that the calibration verification interval has a lesser effect on throughput when calibration-verification-approval-downtime are reduced and a negligible effect when approval-downtime are eliminated. Because the calibration verifications are performed on a scheduled periodic basis, the system is assumed to be operating within specification in the interval between calibration verifications. It is not logical to assume that the system is calibrated correctly for the last card before the calibration verification and then to assume that it is out of calibration for the very next (calibration verification) card. It makes the most sense, again, to optimize for the normal case and assume that the system is always calibrated. This simple philosophy change allows the system to run during the approval process until it is shown to be out of calibration. Because the throughput cost of performing calibration verifications becomes much less significant, calibration verifications may be performed more frequently. The result is an improvement in quality without sacrificing throughput.

An 8% throughput gain was realized in experiment 24 by simulating an "operator switch" during the 15-min operator break every 4 h. A 1-min interruption of HSFE operation was provided to allow time for the substitute operator to get organized. This approach gains 3.5 min of HSFE operation per hour over the baseline approach.

Increasing the percentage of marker cards in the drawer from 1% to 5% causes an expected loss in throughput in experiment 20. The loss is due to the fact that the increased percentage causes the HSFE to spend more time processing marker cards, leaving less time to process fingerprint cards.

Experiments 21-23 attempt to improve throughput by eliminating flipping calibration test targets, microfilm test targets, and marker cards respectively. As can be seen in Fig. 13, none of these approaches made a significant contribution to average throughput. This is because in these experiments the percentages of these types of cards are small, so the throughput gained by saving 0.5 s/card is not significant. These parameters will become more significant if the percentages of these types of cards should increase.

Experiment	Parameter Description	Throughput (cards/hr)	Throughput Change (%)
0	Baseline run	683	N/A
1	8 hour run	692	1
2	Don't advance next card during current ejection	663	-3
3	Perform image quality check before moving card	598	-12
4	Perform image quality check during card move	**791**	**16**
5	Print labels on-demand	576	-16
6	Print labels for current card during card feed	661	-3
7	No microfilming	777	14
8	1000 ft microfilm rolls	761	11
9	12:1 microfilm reduction ratio	713	4
10	.50 second for image acquisition	600	-12
11	.75 second for image acquisition	547	-20
12	1.0 second image acquisition	497	-27
13	1 hr interval between calibration verifications	**375**	**-45**
14	8 hr interval between calibration verifications	720	5
15	12 hr interval between calibration verifications	757	11
16	Experiment #13 with zero approval time	784	15
17	Experiment #15 with zero approval time	788	15
18	Experiment #13 with 15 min approval time	578	-15
19	Experiment #15 with 15 min approval time	769	13
20	5% marker cards in the drawer	672	-2
21	Image only back of calibration verification targets	683	0
22	Film only back of microfilm test targets	684	0
23	Don't flip marker cards	683	0
24	1 minute for operator break (fill-in operator)	736	8
25	.2 seconds operator reaction time	660	-3
26	Allow maximum of 3 re-feed attempts	674	-1
27	Never re-feed cards	696	2
28	1% alignment errors	595	-13
29	Eject cards on error rather than returning them	683	0

Fig. 13. Results from the parameter evaluation experiments.

Experiment	Parameter Description	Throughput (cards/hr)	Throughput Change (%)
0	Baseline run	683	N/A
30	Perform image quality check during card move, Zero calibration verification approval time, 1 minute for operator break (fill-in operator)	967	42
31	Perform image quality check during card move, No microfilming, Zero calibration verification approval time, 1 minute for operator break (fill-in operator	1120	64
32	Perform image quality check during card move, 1000 ft microfilm rolls, Zero calibration verification approval time, 1 minute for operator break (fill-in operator	1087	59

Fig. 14. Results from the system evaluation experiments.

Experiment 25 showed a 3% loss in HSFE throughput when the operator reaction time was increased from 0.01 to 0.20 s/card. This experiment was performed to illustrate the effect an inexperienced operator may have on HSFE performance. As an operator gains experience using the HSFE, his/her reaction time should be expected to drop, thus resulting in improved system throughput.

A maximum of three refeed attempts (rather than one) was allowed in experiment 26, for a loss in throughput of ~1%. Experiment 27 took the opposite approach from experiment 26 by eliminating refeeding any card into the HSFE. Unlike experiment 26, this approach showed a small throughput gain. The results of experiments 26 and 27 are very dependent on the refeed error rates in the input file. If the refeed error rates were to fall significantly, the results of experiments 26 and 27 could end up being swapped.

Experiment 28 helps evaluate the sensitivity of the HSFE to card alignment reliability by increasing the alignment errors by an order of magnitude. The result of increasing the alignment errors is a drop in throughput of 13%. If the measured alignment error rate turns out to be too high, it may be worth using the model to determine the maximum tolerable alignment error rate for input into an alignment system design. The time required by an alignment system can be folded into the model by increasing the card alignment checking time to include both alignment and alignment checking operations (parameter P11 on Fig. 5).

Ejecting all cards experiencing errors rather than returning them to the operator showed no throughput improvement in experiment 29. However, this change combined with other parameter changes such as (1) lower refeed error rates or (2) never refeeding cards could result in throughput savings greater than those found by each change individually. This is because some of the time savings made by not returning the card to the operator are lost when a card is refed unsuccessfully.

4.2 SYSTEM EVALUATION

Examining the throughput column in Fig. 13 shows that throughput ranged from 375 to 791 fingerprint cards/h in the first set of experiments. These numbers are far short of the FBI's sustained throughput goal of 1000 fingerprint cards/h. For this reason, a second set of experiments was designed to evaluate the throughput potential of the HSFE as a system (i.e., combining parameter values to bring the HSFE throughput above the 1000-card/h goal).

Figure 14 shows the results of the second set of three experiments. Each of the experiments in this set is composed of parameter values that showed positive throughput gains in the first set of experiments. The objective was to change the baseline experiment parameters as little as possible while achieving the throughput goal. Because such a large improvement in throughput was needed, the major throughput drivers identified in experiments 1–29 were modified first.

Experiment 30 shows that a 42% throughput gain was achieved by performing image quality checking while the card is moved, eliminating HSFE downtime during calibration verification approval and providing fill-in operators during feed-operator breaks. While experiment 30 shows a major throughput improvement, it is still short of the goal by 3%.

Despite the microfilming operation containing two of the largest throughput drivers, the microfilming parameters were left alone in experiment 30. Removing microfilming from the HSFE is an unattractive alternative to the FICS because it moves operational difficulties elsewhere in the FICS. Moving up to 1000-ft rolls of film is unattractive because it causes the microfilm system to run "open loop" for almost five times longer. The longer the system is allowed to run without checking the film image quality (developing the film), the greater the impact of the errors. Because experiment 30 fell short of the throughput goal, the microfilming parameters were the only other place to look for throughput gains. Experiment 31 builds on experiment 30 by removing the microfilming operation from the HSFE altogether. The result is an 1120-card/h throughput, which exceeds the goal by 12%. Removing the microfilm improved the throughput by ~16%, which is in line with expectations from experiment 7. According to experiment 8, gains in the neighborhood of 11% over experiment 30 can be expected by restoring the microfilming operation but lengthening the rolls to 1000 ft. Experiment 32 makes this substitution, resulting in actual gains of ~12% over experiment 30. The configuration in experiment 32 is likely the best possible balance of operations vs throughput available with this HSFE architecture.

4.3 CONCLUSIONS AND RECOMMENDATIONS

After studying the results presented in Sects. 4.1 and 4.2, it should be clear that the nonparallelled architecture modeled here is marginal, at best, at achieving the 1000-card/h throughput goal. While the model indicates that meeting the goal is possible, any small design parameter change or modeling error may drop the actual system throughput below the desired level.

It is ORNL's recommendation that a parallelled architecture such as that depicted in Fig. 12 be considered. This type of architecture, while more complex, will vastly improve the HSFE throughput. Prior to the work reported here, a simple HSFE throughput model for both the parallelled and nonparallelled architectures was developed. While the early model did not include many of the input parameters included in the model discussed in this report, it did provide ballpark throughput estimates. These early estimates indicated that the parallel architecture should easily yield greater than 1000-cards/h throughput. The parallelled architecture was not included in the scope of this work because of the increased complexity of such a model.

Appendix A

AN EXAMPLE INPUT FILE

```
;== File:          sim.in                                                ==
;== Date:          June 22, 1993                                         ==
;== Last Mod:                                                            ==
;== Programmer:    P.M. Rathke                                           ==
;== Purpose:       This file is used for input to the HSFE simulator     ==
;
;
;— Test Configuration                                                    —
;
; Simulation length                                                (hours)
12.0
; Number of simulation runs made/averaged for a given data set
50
; Advance next card and eject current card simultaneously (1 = on, 0 = off)
1
; Schedule for image-quality-check completion (0 = before moving the card on the
; belt, 1 = before ejecting the card, 2 = while card is moving and/or is in the
; output hopper)
1
;
;
;— Process Times                                                         —
;
; Not used
0.0
; Time to advance card from feed station to labeling station  (measured)(sec)
.53
; Time to read and process a bar code                                  (sec)
.10
; Time to download the next label data to the label printer            (sec)
.10
; Time to backup label stock in preparation for label printing         (sec)
.50
; Time to print label                                                  (sec)
.20
; Time to apply the printed label to the card                          (sec)
.60
; Time to advance card from labeling to the imaging station   (measured)(sec)
.43
; Time to eject card from imaging station                     (measured)(sec)
.14
; Minimum time to dwell in imaging station                             (sec)
.20
; Time to flip card and return to imaging station             (measured)(sec)
.55
```

```
; Time to check card alignment in imaging station                    (sec)
.10
; Time to acquire images (digital & film)                            (sec)
.20
; Time to move data out of digital camera sensor                     (sec)
.40
; Time to check image quality                                        (sec)
.20
; Time to move image data from IAS to IAC                            (sec)
.40
; Time to move image data from IAC to BDR                            (sec)
2.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; Not used
0.0
; ----------------------------------------------------------------------
;
; — Error Handling                                                      —
; ----------------------------------------------------------------------
;
; Error handling method: return card to operator or eject to output hopper
; (1 = return, 0 = eject)
1
; Maximum number of re-feed attempts for any given card before the card is
; sent to the LSFE manual scanning
1
; Time to return a card from imaging station to the feed station
```

```
; Only applicable if card is returned to the operator on error          (sec)
1.0
; Time for the operator to pick up a returned card, discern why it was
; returned and decide what to do to correct the problem
; Only applicable if card is returned to the operator on error          (sec)
30.0
;
;
; Labeling Errors
; ---------------
;   Maximum number of labeling retries to attempt following an error
;   before the card must be removed and either refed or sent to the LSFE
;   for manual scanning
1
;   Percentage of labeling errors on the initial label application attempt
.0056
;   Percentage labeling errors on label retries and card re-feeds
.0056
;   Percentage of cards experiencing labeling errors fed back into the HSFE
;   for another processing attempt
100.0
;
;
; Back-Side Alignment Errors (only applies to cards that are imaged on back)
; --------------------------
;   Percentage of back-side card alignment errors on the first feed attempt
.10
;   Percentage of back-side card alignment errors on re-feed attempts
50.0
;   Percentage of back-side-alignment-error cards fed back into the HSFE
;   for another processing attempt
100.0
;
;
; Back-Side Imaging Errors (only applies to cards that are imaged on back)
; ------------------------
;   Percentage of back-side digital imaging/quality errors on the first
;   feed attempt
.01
;   Percentage of back-side digital imaging/quality errors on re-feed attempts
50.0
;   Percentage of back-side-imaging/quality-error cards fed back into the
;   HSFE for another processing attempt
100.0
;
;
; Jam Errors (only applies to cards which are flipped)
; ----------
;   Percentage of cards experiencing jams in the flipper on the first feed
;   attempt
.05
;   Percentage of cards experiencing jams in the flipper on re-feed attempts
90.0
```

```
;   Percentage of jammed cards fed back into the HSFE for another processing
;   attempt
0.0
;   Time required to clear a jam from the flipper assembly                  (minutes)
5.0
;
; Front-Side Alignment Errors (only applies to cards that are imaged on front)
; ----------------------------
;   Percentage of front-side card alignment errors on the first feed attempt
.10
;   Percentage of front-side card alignment errors on re-feed attempts
50.0
;   Percentage of front-side-alignment-error cards fed back into the HSFE
;   for another processing attempt
100.0
;
;
; Front-Side Imaging Errors (only applies to cards that are imaged on front)
; ---------------------------
;   Percentage of front-side digital imaging/quality errors on the first feed
;   attempt
.01
;   Percentage of front-side digital imaging errors on re-feed attempts
50.0
;   Percentage of front-side-digital-imaging/quality error cards fed back into
;   the HSFE for another processing attempt
100.0
;
; ------------------------------------------------------------------------------
; — Drawer Composition                                                          —
; ------------------------------------------------------------------------------
; Population of marker cards in a drawer as a percentage of the drawer contents
1.0
;
; ------------------------------------------------------------------------------
; — Labeling Parameters                                                         —
; ------------------------------------------------------------------------------
; Label printing scheduling- when to print label
; (0 = Print on demand for the current card, 1 = Print for the current card while
;  it is being fed, 2 = Print next label ahead of time while imaging the current
;  card.
2
; Average HSFE down time while reloading a roll of label stock             (min/roll)
5.0
; Average HSFE down time while reloading a roll of printer ribbon          (min/roll)
5.0
; Number of labels on a label roll                                       (labels/roll)
9600
; Number of labels printed per printer ribbon                          (labels/ribbon)
18000
;
```

```
;-------------------------------------------------------------------------
; — Microfilming Parameters                                              —
;-------------------------------------------------------------------------
; Microfilming on/off (1 = on, 0 = off)
1
; Average HSFE down-time while reloading a roll of microfilm    (minutes/roll)
10.0
; Filming of test targets at the start of a new microfilm roll on/off
; (1 = on, 0 = off)
1
; Filming of test targets at the end of a microfilm roll on/off
; (1 = on, 0 = off)
1
; Number of microfilm test targets in a set
1
; Sides of the microfilm test target to be filmed?
; (0 = front, 1 = back, 2 = both)
0
; Number of images to be taken of each side of the microfilm test target
6
; Flipping of the test target if the front side is not filmed on/off
; (1 = on, 0 = off)
0
; Spacing between images on the film as a percentage of the image width
10.0
; Total length of a microfilm roll                                       (feet)
215.0
; Microfilm reduction ratio
8.0
; Length of film wasted for the film leader/trailer                 (feet/roll)
3.0
; Document width                                                       (inches)
8.0
;
;-------------------------------------------------------------------------
; — Calibration Verification Parameters                                  —
;-------------------------------------------------------------------------
; Number of images to be taken of each side of the calibration verification
; test target
6
; Flipping of the test target if the front side is not imaged on/off
; (1 = on, 0 = off)
0
; Number of calibration test targets in a set
1
; Sides of the calibration verification test target to be imaged
; (0 = front only, 1 = back only, 2 = both front and back)
0
; Interval between calibration verifications                            (hours)
4
; Image types to be collected during calibration verification
; (0 = film only, 1 = digital only, 2 = both film and digital)
1
```

```
;
; Time the HSFE is down after images are collected while awaiting calibration
; verification approval                                              (minutes)
30
;
; ------------------------------------------------------------------------------
;
; — Operator Efficiency Parameters                                           —
; ------------------------------------------------------------------------------
;
; Time between operator breaks                                       (minutes)
240.0
; Duration of an operator break                                      (minutes)
15.0
; Operator reaction time per card                                        (sec)
.01
;
; ------------------------------------------------------------------------------
;
; — Marker Card Handling Parameters                                          —
; ------------------------------------------------------------------------------
;
; Marker card flipping for correct orientation in the output stack on/off
; (1 = on, 0 = off)
1
; Re-feeding of marker cards when a jam error occurs on/off
; (1 = on, 0 = off)
1
;
; ------------------------------------------------------------------------------
;
; END OF FILE
; ------------------------------------------------------------------------------
; ------------------------------------------------------------------------------
;
```

Appendix B

AN EXAMPLE OUTPUT FILE

```
RESULTS FROM THE FICS HSFE SIMULATOR
____________________________________
Input file name:  INPUTS/sim.in
Output file name: OUTPUTS/sim.out

ERROR COUNTS:                           Avg (   Min,     Max)
_____________                           _____________________
  Labeling errors              =        0.3 (      0,       1)
  Back side alignment errors =         12.5 (      3,      22)
  Back side imaging errors     =        1.3 (      0,       5)
  Jam errors                   =        4.6 (      0,      10)
  Front side alignment errors=         13.2 (      5,      23)
  Front side imaging errors    =        1.4 (      0,       7)

CARD COUNTS:                            Avg (   Min,     Max)
____________                            _____________________
  Gross cards fed (all types)= 8298.4 (  8005,    8667)
  Total successful cards       = 8265.1 (  7970,    8641)

  Gross fingerprint cards      = 8199.2 (  7904,    8578)
  Successful fingerprnt cards= 8166.0 (  7869,    8552)
  Fingerprint cards re-fed     =   19.2 (     11,      28)

  Gross marker cards           =   82.4 (     59,     101)
  Successful marker cards      =   82.4 (     59,     101)
  Marker cards re-fed          =    0.0 (      0,       0)

  Gross film test targets      =   13.8 (     12,      15)
  Successful film targets      =   13.7 (     12,      14)
  Film targets re-fed          =    0.0 (      0,       1)

  Gross cal-ver targets        =    3.0 (      3,       4)
  Successful cal-ver targets =      3.0 (      2,       3)
  Cal-ver targets re-fed       =    0.0 (      0,       1)

EVENT COUNTS:                           Avg (   Min,     Max)
_____________                           _____________________
  Calibration verifications    =    3.0 (      3,       3)
  Operator breaks taken        =    3.0 (      3,       3)
  Number of film changes       =    6.9 (      6,       7)

THROUGHPUT:                             Avg (   Min,     Max)
___________                             _____________________
Sustained average throughput =   679.8 ( 655.7,   712.6)
fingerprint cards per hour, based on 50 runs averaging 12
Hrs, 0.7 Min each
```

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