INDECS: GENERAL CONVEYORIZED FACILITIES DESCRIPTION AND SIMULATION

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ABSTRACT

This paper describes INDECS, a FORTRAN software system for Integrated Description and Evaluation of Conveyorized Systems. A data base catalog of system equipment is combined with user written control subroutines, GASP-II event routines, and INDECS event routines to provide a conveyor system designer with simple methods for system specification. A simple example illustrates the elements of the simulation system.

I. INTRODUCTION

INDECS (Integrated Description and Evaluation of Conveyorized Systems) was developed (2) to provide a user-oriented tool for designers of conveyorized facilities.

In conveyorized facilities machines or work stations are interconnected by a network of conveyors. Items in production or service are transported automatically between the stations (which may be automated as well) with or without human intervention. Examples of such systems are airport baggage handling facilities, distribution warehouses, and automated production shops.

We can identify two main problem areas in the process of designing conveyorized facilities: 1) describing the relationship and components of the facility, and 2) evaluating the performance of this facility prior to and during its construction. A major issue is the complexity of the conveyorized facilities. (See discussion of this issue in ref. 4). Generally, they include a large number of machines. Consequently, specification of their operations and flow of items requires the formulation of involved scheduling and flow logic rules. INDECS was developed with two distinct objectives. First, to provide a generalized method for describing a wide class of conveyorized facilities. Second, to provide performance simulation modeling which builds on easy assembly of standard modules of conveyor subroutines. INDECS integrates the description and simulation phases, and enables one to obtain the performance evaluation directly from the description data base.

In this paper we first explain the description phase of INDECS, in which the user describes the details of his facility. Next, we discuss how the dynamics of flow are modeled by INDECS to simulate and evaluate the facility performance. A simple example is used to illustrate the software of INDECS, and the paper is concluded with some critical evaluation.

2. The Description Data

The user of INDECS describes a continuous conveyor facility using three types of forms (see example in Figure 1), with the following data:

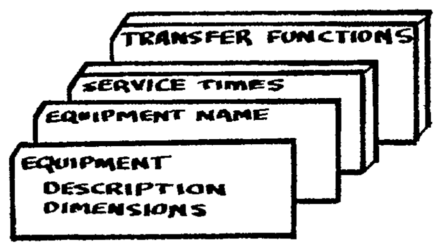


Figure 1. Hardware Equipment Format

1) Attributes associated with each type of part or item which moves on the conveyorized facility. These attributes include the weight of the item, dimensions, quantity in a moving unit (e.g., on a pallet), assembly information, and routes in the layout through which items of this type may flow.

2) Attributes associated with each of the equipment hardware types in the user's catalog. These data include the class of hardware, limitations of usage, parallel service capability, operations performed by this hardware (called here Transfer Function) and standard operation times (service times).

3) Attributes which specify the location and flow connection of the hardware types in the facility. These include the location identification, the hardware at the location, the storage capacity, the direct source and the direct destination locations, and their distances from the location.

Before we proceed to discuss how these data are processed, let us clarify few terms.

A Route in the facility is identified by a sequence of locations and the transfer function to be performed at each location (the transfer function must be specified only if more than one transfer function can be performed there). When alternative locations can serve as the next destination for a moving item, the user's control programs (which are explained below) will select one as the destination.

Hardware: Three classes of hardware are defined in INDECS:

a. Equipment, designated by the symbol E

b. Conveyors, designated by the symbol C

c. Generators, designated by the symbol G

An equipment unit, may be a process or a control equipment. It is stationary, can have several serial process stages, and several parallel, equivalent channels. It can perform several transfer functions, and can have several standard service time distribution

A conveyor has a continuous carrying form (e.g., roller conveyor), constant velocity, one stream of carried items, and can have several transfer functions.

A generator is an artificial module whose purpose is to generate individual items into the conveyorized facility. Using a combination of these elements, a conveyorized facility can be modeled by INDECS (See the example in Figure 7).

The transfer functions which are associated with the hardware describe the operations which can be performed by hardware on items. They are defined as the changes which are effected in items' properties as the items move through a given piece of hardware.

The description data from the uer's forms are processed by INDECS into a data base, whose structure is shown in Figure 2. This data base is managed

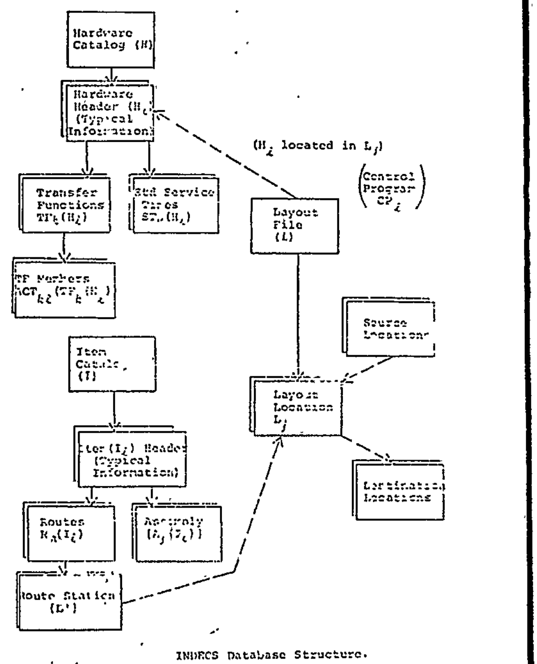


Figure 2. INDECS Database Structure

by the general data base language ADBMS (1), which provides for the network relations specified in the facility layout, and for the hierarchical structure within the data. INDECS data base includes the item catalog, with the item type data; the hardware catalog, with the hardware type data; and the layout file, with the description of the facility layout. The two catalogs have a hierarchical structure. The layout file is constructed in a network structure, with link records containing distance data ssociated with the two linked source-destination records. (See Figure 3).

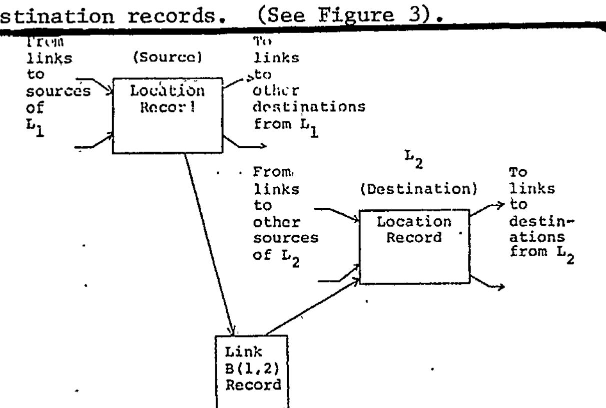


Figure 3 Network Modeling in the Layout File.

A general data base management approach also is adopted for INDECS so that direct access is enable both for ease of modification and updating, and for processing during analysis. A set of forms can be used and processed by INDECS programs to correct, change, add, and delete data in the data base. Because of the general data structure, design modifications during the development of the conveyorized facility require specification of only the modified details, while the bulk of the data remains unchanged.

Other programs produce reports from the data base (see Figure 4), and retrieve relevant data during the performance evaluation, as described in the next section.

```
* * * ITEMS  CATALOG * * *

*** ITEM   130  ITEM C BOX
        LENGTH---WIDTH---HEIGHT----WEIGHT  OTHER  Q./MOVE  COST   #ASH  #RT
         0.22    0.16    0.20       12.00    0       1   $ 65.00   0     2

        ROUTE-I.D.:   1   #-ROUTE-POINTS:      4
        ------------------------------------------
        SERIAL-NO.  DESTINATION  #-REPEAT  T.F.-USED
            1            2           1         C
            2            5           1         1
            3            6           1         0
            4            7           1         C

        ROUTE-I.D.:   2   #-ROUTE-POINTS:      4
        ------------------------------------------
        SERIAL-NO.  DESTINATION  #-REPEAT  T.F.-USED
            1            4           1         0
            2            5           1         1
            3            6           1         0
            4            7           1         0

 * * * EQUIPMENT  CATALOG * * *

 *** EQUIPMENT      1G  SIMPLE CONVRG.,CNE CHAN.

         TYPE CONNECT CAPACITY ORIENT. QUALITY OTHER
          99     1        1.00    0       0       0

         EQ.-LENGTH   EQ.WIDTH   EQ.-HEIGHT  NO.SERVICE-TIMES  NO.-T.F.
            0.0         0.0         0.0             1              1

         SERVICE-TIME  MEAN-S.T.  DISTRIBUTION  PARAMETER
               1          0.0         90            0.0

         TRANSFER-FUNCTION:  1  SERVICE-TIME:  1  NO.-OF-MEMBERS:  1
         VALUE  OPERATION  PARAMETER
           0        4         0.0

 *** EQUIPMENT   1150  LIVE-ROLLER(LIGHT) CONV.

         TYPE CONNECT CAPACITY ORIENT. QUALITY OTHER
         1000  1000      75.00    0       0       0

         EQ.-LENGTH   EQ.WIDTH   EQ.-HEIGHT  NO.SERVICE-TIMES  NO.-T.F.
            1.00        0.30        0.75            3              0

         SERVICE-TIME  MEAN-S.T.  DISTRIBUTION  PARAMETER
               1          0.15        0             0.0
               2          0.12        0             0.0
               3          0.10        0             0.0

 * * * LAYOUT  FILE * * *

 *** NODE  NUMBER      1

         EQUIPMENT  CONTROL  AV.  SPACE  #-IN-SERVICE  SPACE-USED
           9001        0      0    1.00        0           0.0

     * NODE     1 HAS NO SOURCES

     DEST.-FROM-NODE     1: DEST.  MAJOR-DEST.  DIST.-TO-THIS-DEST.
                              2         5              0.0

 *** NODE  NUMBER      2

         EQUIPMENT  CONTROL  AV.  SPACE  #-IN-SERVICE  SPACE-USED
           1150        0      0   30.00        0           0.0

     SOURCES-TO-NODE     2: SOURCE  MAJOR-DEST.  DIST.FROM-THIS-SOURCE
                              1         5              0.0

     DEST.-FROM-NODE     2: DEST.  MAJOR-DEST.  DIST.-TO-THIS-DEST.
                              5         5              30.00
```

Excerpts from a Database Report

Figure 4-

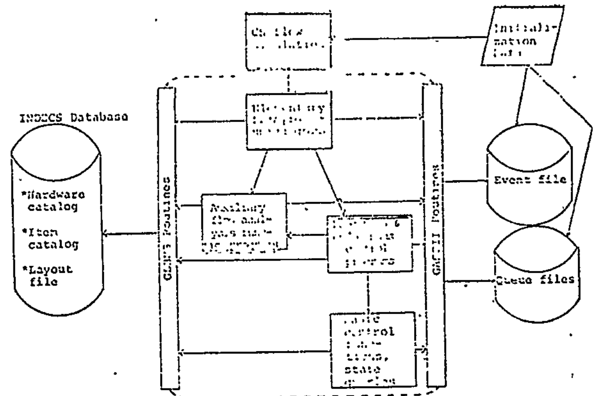
In addition to the specification of items, hardware, and layout, as described above, the user has to define the rules of the dynamic item flow. Examples of such rules are priority rules which govern the flow in intersections, decisions about shut-down or reactivation of hardware based on downstream flow conditions, etc. For this purpose, the user must provide appropriate FORTRAN subroutines which specify the logic of the control used with the conveyorized facility. Control modeling in INDECS is discussed later.

The description data base with the control programs is the basis for documentation and communication about the designed facility. We next explain how it is utilized in the simulation phase of INDECS.

3. The Performance Simulator

Once a data base which describes a given conveyorized facility is completed (according to the details of the previous section), the dynamic behavior of this facility can be analyzed. The analysis is initialized data which activate a discrete event simulation of the item flow in the facility.

The simulation of the item flow is a combined operation, (see Figure 5) which applies INDECS programs



The Interaction of Item Flow Simulation, Database and Files

Figure 5

to model the flow; GASP-II (3) programs to manage transaction files and timing; and ADBMS (1) routines to interface with the conveyorized facility data base.

The simulation is carried out by logically moving item records (by flow and control programs) through the prescribed routes in the layout, and testing at each step whether gates are open, whether machines are ready for service, whether conveyors are operative, whether any changes take place, etc.

Modeling the dynamics of flow is accomplished by:

1). The simulation transactions;

2). Elementary flow procedure programs;

3). Auxilary analysis and flow function programs;

4). Control data and procedure programs.

3.1 The Simulation Transactions

There are two major types of simulation transactions: the item transactions and the control transactions.

The item transactions are records of fixed structure, each of which represents a physical, individual item in flow. Each item transaction contains the item identity and current properties, flow related data (such as the next scheduled procedure type, the route identification, etc.), and time statistics.

Control transactions are records which communicate control signals of various types to generate items; to shut down equipment; to actuate devices; to collect information, etc.

During the simulation, item and control transactions are filed either in the event file, which contains all active, scheduled transactions, or in queue files (one per location in the layout), which contain all waiting items.

3.2 The Elementary Flow Procedure Programs

The model of the dynamic flow in INDECS is based on the fact that all flow in conveyorized facilities is comprised of general, basic procedures, which are common to all varieties of flow (see Figure 6).

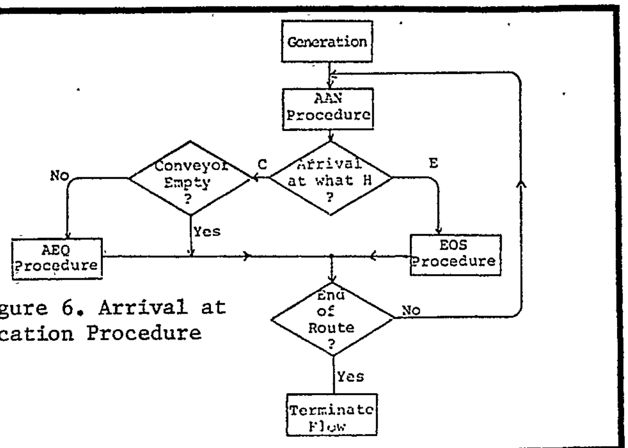


Figure 6. Arrival at Location Procedure

Particular patterns of item flow may differ in some details, but all patterns will have the following elementary flow procedures:

a. Arrival at a location;

b. Arrival at end of queue on a conveyor;

c. End of service at a location;

d. Joining the queue to a location, or blocking the current location;

e. Unblocking a location;

f. Generation of items.

Each elementary flow procedure was programmed as an event subroutine from the point of view of GASP-II. When a procedure is scheduled for an item during the simulation of the flow, it means that at the scheduled time, the item's transaction will be retrieved from the event file, and the appropriate procedure, or event subroutines will be executed.

3.3 Auxilary Analysis and Flow Function Programs

The auxiliary analysis and flow function programs include:

a) Several programs to monitor the simulation, to select procedure and control programs, to collect and print statistics; and

b) Several programs of flow functions, which are called by the elementary flow procedures, and can be applied by any control programs as follows:

1. Transfer functions program, which modifies item properties data in the item transaction, based on the hardware's transfer function;

2. Item's itinerary data program, which retrieves for a given item the appropriate transfer function to be used at a location;

3. Service time program, which generates a random value from a given service time distribution;

4. Next item's stop program, which finds the next location (destination) for a given item on a given route;

5. Free queue space program, which evaluates whether a given item can join the queue at given location and time, based on the item's dimensions and the available space.

6. Critical dimension program, which finds the critical dimension of an item (the item's physical dimension along the direction of its flow) at a given time, based on its spatial orientation.

3.4 Modeling Control Procedures

Control in a conveyorized facility can be considered as a combination of exogenous control which includes the prescheduled system changes (actuations), and endogenous control which includes actuations based on dynamic conditions.

Exogenous control is specified in INDECS as part of the initialization data. Since it is predetermined, it is formulated as a list of control transactions, which are either prescheduled, or random, system changes. To implement these changes, INDECS has a procedure which processes the exogenous control actions to change the availability of locations, shut down a conveyor, change the speed of a conveyor, change the service time of an equipment unit, etc.

To model the endogenous control, INDECS has a control communication scheme. If a location or several locations are controlled by a control program, signals are transmitted from sensing locations whenever an event occurs. There are five types of such signals: at the start and at the end of arrival at a location procedure; at the start of end of service; arrival at the end of queue on a conveyor, and of unblocking a location procedures. Each control program, according to the logic specified by the user, will select and utilize the appropriate information based on the relevant signals. A sixth type of control signal enables communication between two or more different control programs which share information or depend on each other.

Once a decision was reached by the control logic, it can be implemented by the change procedure.

Basic control functions which are developed in INDECS include timers, limit switches, counters, and identifiers.

Performance Statistics

The performance of the conveyorized facility is measured during the simulation by collecting statistical data about the flow of items from generation to termination. The statistics can be summarized during the simulation, at given points of simulated time, or in the end of the simulation run according to the user specification.

Summary statistics which are produced by INDECS include measures of the number of items produced, the total time from entry to exit, the number of items which occupy at the same time each location or are waiting at each queue.

4. Illustration

We illustrate INDECS implementation with a simple conveyorized facility example. First, the facility is presented, and then analyzed by INDECS.

4.1 The System

Items are unloaded from trucks and placed on n parallel belt conveyors (see Figure 7 (a)). The

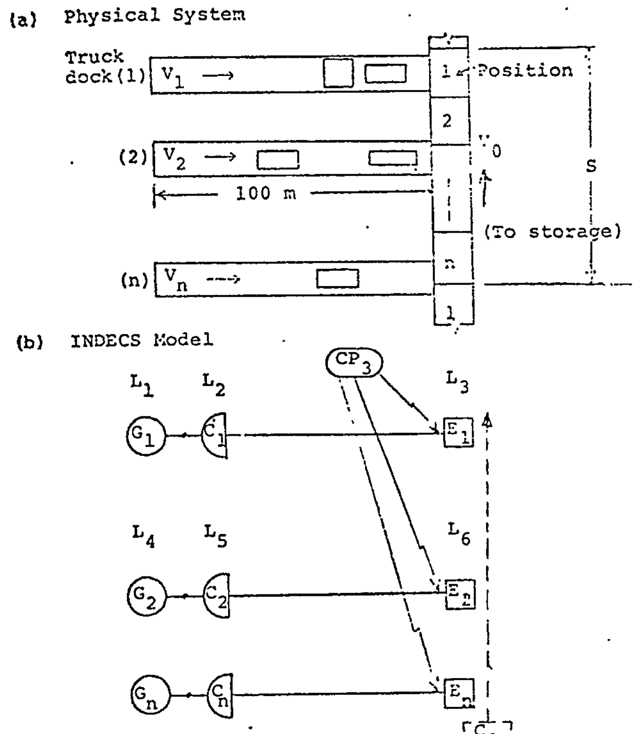


Figure 7. Conveyor Merge Example

items are conveyed (at a constant speed V_i) to main conveyor, which will move them away to storage (at a constant speed V_0). In order to prevent collisions, the following merging procedure is applied to move the items from the input lanes to the main conveyor: The main conveyor is divided into positions (buckets, trays, or hooks), each designed to received one item at a time from only one, particular lane. In other words, the positions are designated 1, 2,...,n,1,2,... etc., per the matching input lane. The physical, controlled merge can be accomplished, for instance, by a positive-action pneumatic ram, or by a gated, gravity roller section.

4.2 INDECS Analysis

INDECS model of the system is presented in Figure 7(b). Three locations are required to specify each input lane. For instance, the first lane includes location L_1 of the generator G_1 (which represents the unloading process at lane 1; L_2, the beginning of the conveyor; and L_3, where E_3 is the equipment which models the merging area.

The item types, hardware types, and locations have to be specified according to the previous discussion. For example, location L_2 has one source, L_1, and one destination at a distance of 100 m., L_3; conveyor C_1 has a velocity of 150 m/min.; gate E_1 has a constant service time which can be calculated as the passage time from C_1 to the main conveyor.

Since each lane is independent, and has its designated "server", the main conveyor itself does not have to be modeled.

To model the fact that the main conveyor is discrete, and to allow passage of only one item at a time, two control procedures are employed:

1. The merging locations (e.g., L_3) are initialized to be unavailable. Since proper positions arrive at the merge point of each lane every S/V_0 min., we can specify a generator which regenerates the change availability procedure automatically at the scheduled times. As the gate becomes available, the unblocking procedure moves the first item from the queue to the main conveyor.

2. A control program (C_3) shuts the gate immediately after one item is passed to the main conveyor. This is accomplsihed by making the gate unavailable when the signal is given that an item has arrived and been served at the gate.

During the simulation, item transactions are initiated by the generators, and prepared by the generation procedure. The items are advanced to the input conveyor, and scheduled to arrive at the merge gate, or at the end of queue of items on the conveyor. When an item is advanced to the gate (by the unblocking procedure) it is moved to the main conveyor and in this example - exits the system.

5. Conclusion

INDECS is a useful design tool for the detailed description and analysis of conveyorized facilities. It can be applied for the study of partial modules in a large facility, as well as the whole facility.

The interaction of the simulation with the description data base, and the flow modeling with elementary procedures and control programs provide considerable flexibility in the analysis. The computational cost is relatively high: a large, real case handling system with 280 locations, 50 hardware types, 40 item types, and 30,000 unit loads was simulated at a cost of 1 CPU minute per 10 simulated minutes on an IBM 370/158. However, the complexity of large conveyorized facilities makes a tool like INDECS a forerunner of further developments for the control of designer's description data and analysis of performance capabilities.

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