Computer-Aided Wiring and Cabling Design as Applied to Aircraft Avionics Systems

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Manufacturers of electronic equipment can greatly benefit from wiring data listed on simplified formats that facilitate fabrication of harnesses and/or cables. Most wiremen would like to see a list supplementing a drawing. This list would be most valuable if the items were sorted by wire types, wire sizes, color, etc. Another list, supplementing the drawing, would be helpful if the items were sorted by connectors and pins. This would aid the wiremen in checking out the completed cable, pin-to-pin, and would easily designate the pins used and show what pins are available as spares. A third list might be desirable which shows the items sorted by signal name. This article describes an automated system of producing such simplified formats and how they were used to cable a portion of the avionics systems of a light attack aircraft. In essence, data are compiled from schematics or functional drawings and punched on IBM cards. These cards are then read by a computer and the data are transferred to magnetic tape which is processed using a 7094 or 360 IBM computer to produce various formats recorded on magnetic tape. The tape is printed on either 8 × 11 or 11 × 17 continuous sheets using an IBM 1403 printer.

I. Data Origin

INTERCONNECTION data originate in the engineering design process. This data are released from the design process as wiring diagrams and harness template drawings. In the past, many formats were used for these release documents causing many problems for assembly departments. There are two main applications for interconnection data: 1) to provide manufacturing with the necessary data to build harnesses and cables and 2) to provide systems integration with the necessary data for system checkout. The following describes the various interconnection data formats still used by many industries.

An electrical schematic shows the electrical connections and functions of a specific circuit arrangement. It is arranged, where possible, so that the elements are in an orderly sequence by function. Electrical and component symbols are drawn in accordance with engineering standards. A components list may be placed on the drawing or on a separate list. Some technicians use this drawing to fabricate cables.

A wiring diagram is a drawing which shows the electrical interconnections of component parts of an item pictorially in the approximate physical position as they appear in the item. It must contain such detail as is required to trace the physical connections that are involved. The wiring diagram is shown as viewed from the wiring side of the assembly.

II. Wiring Harness Drawing and Cable Assembly

The wiring harness drawing consists of a pictorial (template) drawing including dimensions, a wire list and a list of materials. The list of materials is prepared in accordance with engineering standards. A wire list may be placed on the drawing if it does not exceed 10–15 lines. When the wire list is prepared as a separate associated listing, it bears the same part number as the basic drawing. The following drawings are shown in Fig. 1.

In the commercial one/one drawing uses reference numbers at wire terminations, but the number is repeated if it is the same wire. No "from-to" list is required for this drawing.

In the bubble number drawing, wire terminations are assigned unique numbers in sequence starting with Number 1. These numbers are enclosed in a small circle sometimes referred to as a "bubble." A "from-to" list is required to show the "from" terminal number, its corresponding electrical designation, the "to" terminal and its corresponding designation.

The electrical reference drawing shows the actual electrical designations at the wire terminations instead of bubble numbers. Again a "from-to" listing is required to show continuity from one electrical point to another. The "from-to" list is simplified since bubble number references are not required.

The single line drawing requires less detail and is more economical to produce. A computer generated list provides all of the details except connector part numbers (with associated hardware), unit locations, and wire dimensions.

III. Wire List

As stated previously, "from-to" lists must be provided for the bubble type, single line, and electrical reference type wiring harness drawings. These lists may be typed, hand generated, or machine run. Of these three, many times the easiest way out is chosen. In many cases, the method chosen is not the cheapest or the fastest.

In order to arrive at the best solution, the total picture from design through manufacture must be taken into account. Herein is defined the work involved in generating each type of list and the subsequent cost of assembling harnesses and cables from these lists.

At first glance, the cheapest way out may be to manually list the wire data on the proper form. A more legible method might be to have the list typed. The machine generated list seems a lengthy and sophisticated system. If only the originating area is considered, then the above comes close to being correct. But, if we are looking at the total picture, a few constraints must be considered.

First, the wiremen works with many types of wire sizes and colors. He would like to see a wire list that is oriented toward the best way of building a harness or cable, that is, by wire type and color. Sorting, manually, a 100 wire list

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or having a secretary rearrange and type the manual wire list is laborious. The chance of error either by transcription or omission is considerable.

Besides a listing by wire type, the wireman has a need for a checkout list. The listing, containing the same information as the wire type list, must be in connector sequence to facilitate rapid checkout of the harness and cable. It is also a great aid in laying out the nailboard for harness assembly because the wireman can judge the trunk size required by counting the amount of wires to a specific termination area. The list also provides quick access data on spare connection points. The connector sequence list is computer generated and is not a part of any drawing. It has been proven by comments of manufacturing management that the connector sequence list is an invaluable aid when laying out harness assembly nailboards and when installing hardware to the laced harness assembly.

With these points in mind, one can begin to see that manual or typed lists providing information in the form best suited for the user is a laborious and error prone job. The computer, on the other hand, can perform the data processing task quickly and without error. It should be pointed out that when a wire list is short, say 15 conductors, an argument for manual or typed lists is evident. For larger jobs, the computer should be utilized to provide low-cost, fast turnaround processing to the user. This results in reducing job cost on a system basis which is a prime objective of present cost reduction programs.

The next section provides more detail on the computer-aided system of generating computer listings.

IV. Computer Program

The input to the program is a "from-to" input form. Data pertinent to the wiring task is translated from the electrical schematic by a technician in a form suitable for keypunching. The rest of the process is automatic, resulting in printed outputs of the proper formats. A general block diagram showing data flow is given in Fig. 2.

After the keypunch operation, the cards are loaded on magnetic tape. Another tape called the wire catalog has previously been prepared. This tape contains a catalog of all wire types used for a particular project, along with wire attributes such as part number, size, color, etc. This information is merged with the "from-to" data and then sorted. The next step is to provide vertical spacing of data to group like data. Then a routine is used to provide headings, horizontal spacing, page length, and page numbering. The last step is to print the output data.

The structure of the automated wire list is such that in about 85% of the cases, shield details are not required. There

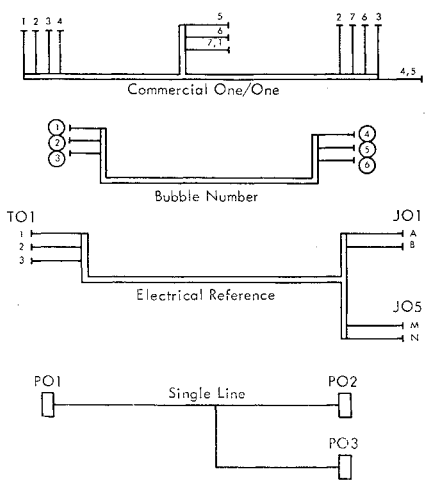

Fig. 1 Harness and cable drawings.

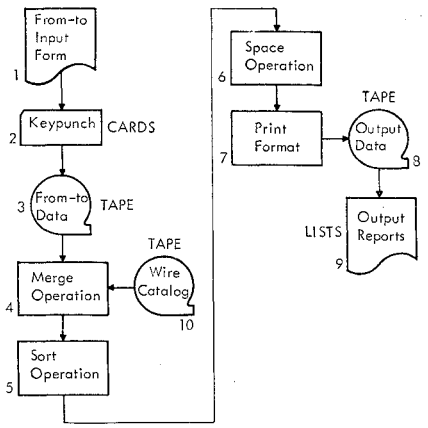

Fig. 2 General block diagram.

is always the unique case to be considered, however, which will warrant a shield detail drawing. This drawing can be included either on the harness template drawing or in the notes portion of the automated list. The previous steps are general and apply to the following types of available output lists: 1) harness wiring, 2) connector sequence, 3) history, and 4) wire identification code. The next sections describe the data input from and the various output lists in a more detailed fashion.

V. Data Input Form

The nucleus of the system is a punched card which can hold 80 characters of alphabetic or numeric information. Each line of information on the data input form will be punched on one IBM tabulating card. Thus, each card will represent a wire connecting two specifically referenced points.

The rules for filling out the data input form are given below. Note that the column numbers go from 1–80 which corresponds to the 80 columns in the card, thus facilitating the keypunching operation (see Table 1).

A standard "from-to" data input form is shown in Fig. 3. Special input forms can be made available to the design area after definition is firm. The output list format remains the same regardless of the style input form used.

General Ground Rules

Some general ground rules for filling out the "from-to" wiring list form are 1) A zero is written as a slashed 0 (Ø), 2) A figure one is written as an inverted T (⊥), 3) The letter "O" is written without a slash (O), and 4) A letter "Z" must have a bar through it (Ƶ).

These rules help the keypunch operators in decoding the Data Input Forms. An asterisk with an upper case letter indicates lower case, e.g., *A indicates "a." To further clarify the terms: bridle, group numbers, and wires-group (see Fig. 4).

Note that the jumper and pigtail contribute an added wire in the shielded assembly and are thus accounted for in the wires-group column. When shielded, coax, and twisted assemblies are properly identified via the wire list requirements, it is estimated that 85% of shield and coax drawings can be eliminated. It is understood that certain unique conditions for grounding and tying off shields will present themselves and in all probability a sketch will be justified to cover those cases not conducive to explanation via the automated format.

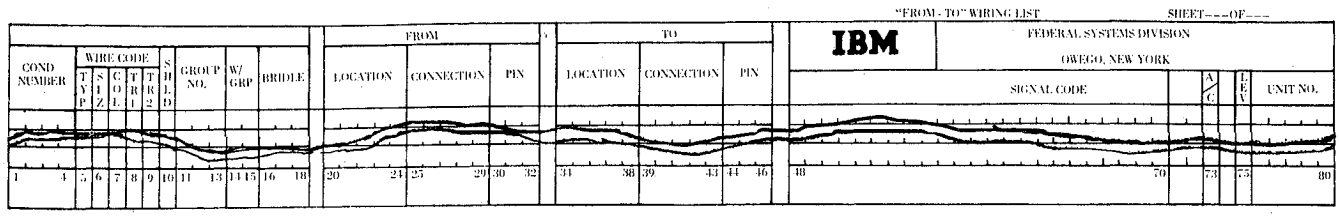

Fig. 3 Arrangement of data input form (complete form holds listings for 36 items).

VI. Output Formats

Output lists are prepared on vellum in a form acceptable for release. The harness wiring list is the basic wire list document. It is used by manufacturing to fabricate harnesses and cables. To put the data in a form most suitable for this process, in Block 5 of Fig. 2, a sort is made on wire code, connector and pin, bridle number and group number. After the sort, the data are spaced on group number (Block 6). The data are then compiled to produce the harness wiring list. An example of the harness wiring list is given in Figs. 5 and 6.

The connector sequence list (a separate program) is used by the wireman and design engineer as a checking device. Up to Block 5 of the general block diagram, the process is identical to the harness wiring list. In Block 5, the data are sorted on "connector from" and "pin from" data. After the sort, the data are then spaced on "connector from" information to vertically separate connector data. Thus, connector J1 data will be grouped separately from connector J2 data. The print format then forms the output list. An example of the connector sequence list is given in Fig. 7. This list is valuable in continuity checking and troubleshooting.

Since all data pertaining to a wire list are kept on punched cards or magnetic tape, it is possible to provide a history list, on demand, of all data previously used. Listing is sorted on revision level. This list is extremely valuable in processing changes.

VII. Wire Identification Codes

This list is used for cable installation requirements. Mil specs. require that all wires installed in aircrafts be stamped with military designation numbers. These numbers are catalogued beforehand and loaded on tape in the same manner as the wire catalog. When generating this list, the identification codes, instead of the wire part numbers, are merged with the "from-to" data. An example of this list is shown in Fig. 8.

VIII. Change Procedure

When it becomes necessary to revise a formally released list, a marked print is prepared by the design department and delivered to systems programming. The affected cards are added, changed, or deleted as required, and a new list processed at the desired change level and returned to the engineering department. The new list is a complete rerun of the original plus new data. The original sequence is maintained.

Changes shall be implemented in such a way that retranscription by engineering systems programming department is not required. Prints shall be marked in red to indicate changes to existing data. New conductors shall be written up on the "from-to" input data form. When input data have not been supplied in a form suitable for key punching and retranscription is required, costs are raised considerably.

Lists can be changed by typewriting the new data at the end of the automated list as long as the engineering systems programming department is kept informed. Cards will be punched to reflect the new data and the deck will once again be at the same level as the automated list. This practice is not recommended where spare space is at a premium on the list or if change activity exceeds ten conductors.

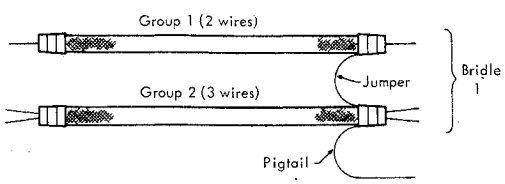

Fig. 4 Bridle assembly.

Table 1 Definition of data input fields

Column no.	Heading	Usage
1–4	Cond. no.	A control number assigned to the wire.
5–10[a]	Wire code	To be filled out in accordance with the "wire catalog" to allow printout of complete conductor description, i.e., part number, color, size and type.
11–13	Group no.	Shielded, coax, and twisted wire control number.
14–15	W/GRP	Number of wires comprising a group.
16–18	Bridle	A number to define those shield braids which are common to the same ground point (see text).
20–24	Location	The major assembly from which the conductor starts.
25–29	Connection	The subassembly and/or component from which the wire starts.
30–32	Pin	The actual termination point from which the wire starts.
34–38	Location	The major assembly to which the wire goes.
39–43	Connection	The subassembly and/or component to which the wire goes.
44–46	Pin	The actual termination point to which the wire goes.
48–70	Signal code	The identification of the signal which is carried by the wire identified in the previous columns.
73	A/C	To indicate by writing an "A" or a "C" what action has taken place with the wire. The "A" means added, while the "C" means changed. In those cases where a wire has been deleted a "D" is written in column 5 under wire code. In this case the word "deleted" will replace the wire part number.
75	LEV	The revision level at which certain adds, changes, or deletes have affected the specific wire.
76–80	Unit no.	To be filled in with the last 5 digits of the list part number (used for filing cards).

[a] Since a wire code is used on the data input form there is no restriction on part number length, which can be expanded on the catalog tape. Columns 8 and 9 can be used for wires with multiple tracers (TR1, TR2) or for modifiers if wire characteristics are the same but part numbers differ.

CARD NO.	CONDUCTOR DESCRIPTION IBM P/N	SZ	COLOR	TYPE	BDL	GRP	W/ GP	FROM UNIT	CONN	PIN	TO UNIT	CONN	PIN	LEV	SIGNAL NAME
0787	6032141	22	BLACK	SH GND	011	158	04	CONV	GRP	158	CONV	GRP	159	C	SHIELD JUMPER
0785	6032839	20	RED	2 SH CD	011	158	04	CONV	SCP4	*H	DIM	P07	A	B	ACKNOWLEDGE
0786	6032839	20	BLUE	2 SH CD	011	158	04	CONV	SCP4	*W	DIM	P07	*A	C	ACKNOWLEDGE COMP
0860	6032141	22	BLACK	SH GND	011	159	04	DIM	GRP	159	DIM	GRP	160	C	SHIELD JUMPER
0790	6032141	22	BLACK	SH GND	011	159	04	CONV	GRP	159	CONV	GRP	160	C	SHIELD JUMPER
0788	6032839	20	RED	2 SH CD	011	159	04	CONV	SCP4	*U	DIM	P07	B	C	D/A BUSY
0789	6032839	20	BLUE	2 SH CD	011	159	04	CONV	SCP4	*B	DIM	P07	*B	C	D/A BUSY COMP
0861	6032141	22	BLACK	SH GND	011	160	04	DIM	GRP	160	DIM	P07	LL	C	SHIELD RET
0793	6032141	22	BLACK	SH GND	011	160	04	CONV	GRP	160	CONV	SCP4	H	C	SHIELD GROUND
0791	6032839	20	RED	2 SH CD	011	160	04	CONV	SCP4	*G	DIM	P07	D	C	DATA READY
0792	6032839	20	BLUE	2 SH CD	011	160	04	CONV	SCP4	*V	DIM	P07	*D	C	DATA READY COMP
0840	6032141	22	BLACK	SH GND	012	161	03	DIM	GRP	161	DIM	GRP	162	B	SHIELD JUMPER
0838	6032839	20	RED	2 SH CD	012	161	03	FLREC			DIM	P10	A	B	SERIAL DATA
0839	6032839	20	BLUE	2 SH CD	012	161	03	FLREC			DIM	P10	B	B	SERIAL DATA COMP

INTERNATIONAL BUSINESS MACHINES FEDERAL SYSTEMS DIVISION OWEGO, N. Y.	03640	L-L91-002	F
	CODE	SHEET 46	REV

Fig. 5 Harness wiring list (with jumpers).

CARD NO.	CONDUCTOR DESCRIPTION IBM P/N	SZ	COLOR	TYPE	BDL	GRP	W/ GP	FROM UNIT	CONN	PIN	TO UNIT	CONN	PIN	LEV	SIGNAL NAME
0119	6032141	22	BLACK	1 COND	030	002	02	NWDC	1P08	025	IMS	2P5	21	A	LATITUDE RET
0118	6032513	22	WHITE	1 SH CD	030	002	02	NWDC	1P08	024	IMS	2P5	20	A	LATITUDE
0121	6032141	22	BLACK	1 COND	031	001	02	NWDC	1P08	086	IMS	2P5	28	A	IMS READY RET
0120	6032513	22	WHITE	1 SH CD	031	001	02	NWDC	1P08	085	IMS	2P5	22	A	IMS READY
0123	6032141	22	BLACK	1 COND	031	002	02	NWDC	1P08	084	IMS	2P5	28	A	IMS FAIL RET
0122	6032513	22	WHITE	1 SH CD	031	002	02	NWDC	1P08	083	IMS	2P5	23	A	IMS FAIL
0113	6032141	22	BLACK	1 COND	032	001	02	NWDC	1P08	023	IMS	2P5	37	A	AZIMUTH SLEW SENSE RET
0112	6032513	22	WHITE	1 SH CD	032	001	02	NWDC	1P08	022	IMS	2P5	18	A	AZIMUTH SLEW SENSE
0115	6032141	22	BLACK	1 COND	032	002	02	NWDC	1P08	045	IMS	2P5	37	A	AUTO CAL LITE RET
0114	6032513	22	WHITE	1 SH CD	032	002	02	NWDC	1P08	044	IMS	2P5	26	A	AUTO CAL LITE

INTERNATIONAL BUSINESS MACHINES FEDERAL SYSTEMS DIVISION OWEGO, N. Y.	03640	L-L91-006	C
	CODE	SHEET 23	REV

Fig. 6 Harness wiring list (without jumpers).

CARD NO.	CONDUCTOR DESCRIPTION IBM P/N	SZ	COLOR	TYPE	BDL	GRP	W/ GP	FROM UNIT	CONN	PIN	TO UNIT	CONN	PIN	LEV	SIGNAL NAME
0175	6032289	22	BLUE	3 SH CD	027	001	04	FLR	W1P1	L	IMS	2P6	43	A	PITCH 2 X
0176	6032289	22	YELLOW	3 SH CD	027	001	04	FLR	W1P1	M	IMS	2P6	44	A	PITCH 2 Y
0177	6032289	22	RED	3 SH CD	027	001	04	FLR	W1P1	N	IMS	2P6	45	A	PITCH 2 Z
0178	6032141	22	BLACK	1 COND	027	001	04	FLR	W1P1	Y	IMS	2P6		A	PITCH 2 SHLD RET
0182	6032141	22	BLACK	1 COND	015	002	04	FLR	W1P1	Z	IMS	2P6		A	ROLL 2 SHLD RET
0147	6032289	22	BLUE	3 SH CD	002	006	04	HSI	P01	F	IMS	2P6	23	A	MAG HEADING 4 X
0148	6032289	22	YELLOW	3 SH CD	002	006	04	HSI	P01	G	IMS	2P6	24	A	MAG HEADING 4 Y
0149	6032289	22	RED	3 SH CD	002	006	04	HSI	P01	H	IMS	2P6	25	A	MAG HEADING 4 Z
0150	6032141	22	BLACK	1 COND	002	006	04	HSI	P01	GND	IMS	2P6		A	MAG HDG 4 SHLD RET
0048	6032141	22	BLACK	1 COND	008	001	04	IMS	1P1		NWDC	1P04	091	A	PITCH 1 SHIELD RET
0052	6032141	22	BLACK	1 COND	008	002	04	IMS	1P1		NWDC	1P04	091	A	ROLL 1 SHIELD RET
0053	6032513	22	WHITE	1 SH CD		045	02	IMS	1P1	01	NWDC	1P08	063	A	X SLEW SENSE
0045	6032289	22	YELLOW	3 SH CD	008	001	04	IMS	1P1	03	NWDC	1P04	011	A	PITCH 1 Y
0065	6029808	30	WHITE	RG195CX		082	02	IMS	1P1	04	NWDC	1P08	031	A	GYRO TORQUE CLOCK
0054	6032141	22	BLACK	1 COND		045	02	IMS	1P1	05	NWDC	1P08	064	A	X SLEW SENSE RET

INTERNATIONAL BUSINESS MACHINES FEDERAL SYSTEMS DIVISION OWEGO, N. Y.	03640	L-L91-007	C
	CODE	SHEET 6	REV

Fig. 7 Connector sequence list.

CARD NO.	WIRE IDENT CODE	TYPE	BDL	GRP	W/ GP	FROM UNIT	CONN	PIN	TO UNIT	CONN	PIN	LEV	SIGNAL NAME
0257	ASN90-146A22	2 TW CD		080	02	NWDC	1P08	027	IMS	3P1	03		GND ALIGN MODE
0276	ASN90-148A22	2 TW CD		084	02	NWDC	1P08	050	IMS	3P1	06		INERTIAL MODE RET
0275	ASN90-148A22	2 TW CD		084	02	NWDC	1P08	049	IMS	3P1	05		INERTIAL MODE
0274	ASN90-150A22	2 TW CD		083	02	NWDC	1P08	048	IMS	3P1	08		NORMAL MODE RET
0273	ASN90-150A22	2 TW CD		083	02	NWDC	1P08	047	IMS	3P1	07		NORMAL MODE
0669	ASN91-001A20	1 COND				NWDC	1P05	070	NWDP	2P01	039		-5VDC
0733	ASN91-002A20N	1 COND				NWDC	1P09	003	ACFT	GND			NWDC SIGNAL POINT GND
0136	ASN91-003A22	1 COND				NWDC	1P07	001	HSI	P01	Y		1000 NM DIGIT
0181	ASN91-004A22	1 COND				NWDC	1P07	020	ACP	P239	15	A	COMPUTER SYSTEM FAIL
0160	ASN91-006A22	1 COND				NWDC	1P07	061	ACP	P2068	14	A	NON ALIGN
0718	ASN91-007A22	DELETED				NWDC	1P07	081	MAP			A	COMPUTER RELIABLE
0351	ASN91-008A22	1 COND				NWDC	1P09	031	FLR	6P6	G		COMPUTER RELIABLE HI
0345	ASN91-009A22	1 COND				NWDC	1P09	041	FLR	5P1	J		CURSOR ENABLE
0346	ASN91-010A22	1 COND				NWDC	1P09	043	FLR	5P1	*H		ANTENNA SLAVE COMMAND
0826	ASN91-011A22	1 COND				NWDC	2P01	056	ACFT				LAMP TEST
0063	ASN91-012A20	2 TW CD		002	02	NWDC	1P04	079	SINS				SINS SYNCHRO EXC HI
0064	ASN91-013A20	2 TW CD		002	02	NWDC	1P04	080	SINS				SINS SYNCHRO EXC LO

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	CODE	SHEET 74	REV

Fig. 8 Wire identification codes.

IX. Cost Analysis

Although it may appear to the uninitiated that the cost of a design automated wire list is excessive, it has been proven by the users that the automation process can result in lists which are cheaper than typed or handwritten lists.

It should be pointed out that the cost per sheet varies inversely with the number of cards (wires). Thus, for larger lists the cost per page will decrease and not in a linear fashion. On the other end of the spectrum, processing, say one card, would be prohibitive since there is a minimal time to run through a program. It is estimated that for 100 cards, the program time would be approximately three minutes for a harness wiring list. However, several low-volume lists can be batch-processed if the lists are related and are time coincident in order to lower costs. If batch processing is not feasible, past experience has shown that computer automation will not save money when less than 100 wires are involved. Some companies have gone to Electronic Accounting Machines (EAM) for these low-volume jobs. Others have used typewriters.

Cost comparison of computer vs manual processes, such as typing, cannot be used as a sole criteria for making a choice of whether to automate or not. The over-all cost and time picture must be considered. For instance, there is a savings in time in manufacturing for fabrication of harness and cables using automated lists. There is also the added benefit of better control and more accurate information using automation. This also saves time, and time is money.

X. Summary

After many years of operation, the computerized system was found to have the following advantages over the earlier manual system: 1) an over-all labor savings, especially in the highly skilled category by eliminating many of the monotonous routine tasks; 2) reduction in the time required to design and build a system; 3) quick economical production of wire lists in the sequence best suited to various uses (manufacture, system test, maintenance); 4) ease of controlling and implementing engineering changes; 5) reduction of errors as well as more effective error checking.