Reliability Analysis of Emergency Telephone System Models

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RELIABILITY ANALYSIS OF EMERGENCY TELEPHONE SYSTEM MODELS

BY

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RESEARCH REPORT

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ABSTRACT

Several alternate systems for use in implementing the 911 emergency system in Orange County, Florida were investigated. The proposed systems were compared with the already existing systems on the basis of reliability, response time, and cost. System reliability was the prime consideration of the study.

Flow charts of each system were formulated in order to determine the functions required of equipment and humans. The reliability was then determined by examining the difficulty of the tasks that each was required to perform. Reliability models of the present and proposed systems were constructed.

By examining these models and comparing the reliabilities, response times, and costs, the most advantageous system configurations were determined. Two systems, Emergency Operator Call Transfer and Emergency Operator Call Relay, were selected as the most desirable; there were no appreciable differences in their reliability, response time, and cost.

ACKNOWLEDGEMENT

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GLOSSARY

Call Referral System, a system where a central emergency operator refers the proper emergency agency operates telephone number back to the citizen.

Call Relay System, a system where information is relayed from the calling citizen to the emergency operator by a intermediate operator.

Call Transfer System, a system where the actual call is transferred by an intermediate operator to the emergency agency operator.

Direct Dispatch System, a system where the emergency call directly reaches the dispatcher operator.

Redundancy, the addition of non-essential parallel means of accomplishing a function for the purpose of increased system reliability.

Reliability, a proven consistency in providing successful results.

Reliability Block Diagram, the systematic arrangement of functions (using a concise visual shorthand method) in the order that they must be performed for successful system operating.

Stand-By Configuration, the arrangement of system blocks which describes the operation undertaken in the event that the first attempt at operation fails.

I. INTRODUCTION

Purpose

In an emergency situation, it is necessary to summon help by the most expedient and reliable method. Thus, the method of the shortest possible duration would be the most desirable. As the length of the telephone number selected for emergency use is decreased, the dialing time and the number of failures (misdialed numbers) decrease. The logical selection would be to free a single digit for emergency use only. The zero is currently overused mainly for operator assisted long distance connections. If the zero were changed to an emergency use only number, it would remain overburdened with non-emergency callers who were unaware of the change or refused to accept it. Currently, the one on the telephone is utilized for direct, long distance dialing. Similarly, a changeover using the single digit one for emergency dialing would introduce complications not easily solveable. Because the largest segment of population is concentrated in large cities, the eight remaining beginning single digits must remain free in order to accomodate the multitude of working user codes necessary in a particular area code. For each free begining digit of a seven digit user code, one million different number combinations can be realized. Thus; if a single begining digit were reserved for emergency use only, the number of user codes available would be decreased by one million. Similarly a two digit number would decrease user codes by one hundred thousand.

The next option would be to choose a two digit emergency number, which depletes the available user codes by only ten thousand. The numbers selected would logically be the lowest possible in order to shorten dialing time and reduce the number of misdials. Many three digit codes are currently in use and unavailable for emergency use. The digits 200 thru 219 and 300 thru 319 are used for local three digit area codes. The digits 411 are designated as local directory assistance. The numbers 511 and 711 are local office codes. Local repair service is assigned the number 811. 911 is the next logical option in the sequence of choosing the shortest number. The prohibitive cost factors involved in converting existing telephone company equipment to free a three digit code were instrumental in influencing the selection of 911. (Eisenstadt n.d.). The digit location on both dial and touchtone telephones and the relative ease with which the code can be remembered were also important considerations.

Background

"The death rate from fires is approximately four times as high in the United States as in Great Britain." Similarly, the criminal apprehension rate is also much lower in the United States ("Nine-One-One" and Communication Centers, 1970). The three digit national emergency telephone number used in Great Britain must be, at least, partially responsible. The need for a nationwide emergency telephone number was first recognized in Great Britain with the establishment of "999" on a national scale. Many other countries have since provided their citizens with similar uniform emergency telephone numbers. Belgium uses "900", Denmark engages "000", Sweden utilizes "900", and Japan employs "119". (U.S. Executive Office of the President. Office of Telecommunications Policy 1973). Since one half of the telephones of the world are located in the United States, it follows that more emergencies would be reported by telephone in the United States (U.S. Executive Office of the Present. Office of Telecommunications Police 1973). Therefore, a telephone number easy enough to remember under stress and short enough to dial quickly would be beneficial in reducing the danger posed by emergency situations in the United States. In addition, economic conditions are placing increasing pressures on emergency service agencies to either increase available services or to increase their efficiency. Consequently, local municipalities are realizing that a more practical method of furnishing these services is needed.

In 1967 the Presidents Commission on Law Enforcement and

Administrative Justice recommended that a universal emergency telephone number be established for police emergencies. This generated sufficient interest to stimulate the implementation of a single emergency telephone number. The American Telephone and Telegraph Company announced, in 1968, that the number "911" would be made available for nationwide is as the emergency telephone number ("Nine-One-One" and Communications Centers 1970).

An independent telephone company serving Haley Valley, Alabama implemented the first working system utilizing 911 in 1968 ("Nine-ONe-One" and Communications Centers 1970).

II. PROBLEM STATEMENT

Objective

In order to complement a 911 emergency system within an already existing communications network an integration system must be developed. Prohibitive costs and the nonavailability of sophisticated equipment have hindered the progress in establishing the fully automatic selective routing of telephone calls. Therefore, it is necessary to design practical substitute systems that will suffice during the interim. This paper examines several integration systems capable of converting an existing operation to one more effective. An ideal or perfect system is virtually impossible to attain, but these proposed systems will ease the transition to a 911 emergency system (Eisenstadt n.d.). It is noted that these different 911 integration systems may be more adaptable depending upon the existing system. The decision on a recommended system should be evaluated on the basis of reliability, response time, and cost.

The purpose of this research is to develop reliability models of several 911 system configurations proposed for Orange County Florida. Typically, costs and response time are the primary decision variables considered; however, it is submitted that reliability is equally important. The models will be exercised to determine the configuration most desirable from a reliability standpoint. This information can then be integrated into the decision process. Also, the models will identify the weak points of each configuration in that they can be corrected.

Agencies Involved

Local political competition (inter and intra) among public safety agencies can be a serious deterrent to installation of an operative emergency telephone system (U.S. Executive Office of the President. Office of Telecommunications Policy 1973). Initially, the problem among municipalities and county agencies must be addressed. In addition, the development of an emergency telephone answering service must have the cooperative participation of all safety agencies contained in a community. Typically, however, each agency, especially the fire department and the police department, is reluctant to relinquish its individuality when dispatching resources or handling complaint information. Police departments argue that their agencies receive eighty-five percent of the service calls. Fire departments contend that while the police department does receive the majority of the calls, most of them do not demand immediate attention as do most calls requiring emergency medical treatment or fire fighting equipment. Because the implementation of an emergency telephone service would introduce outside personnel for deciphering, and transferring emergency caller information, local safety agencies fear an increase in mistakes. They fear that the 911 emergency operators would not be as familiar with jurisdictional boundaries as the operators employed by each agency, and possible dispatch equipment to an incorrect location, or dispatch safety agency services where they have no jurisdiction. Responsibility would be more difficult to establish when error results. The safety agencies are not likely to accept responsibility where lawsuits are involved. The resultant consideration among the safety agencies and local government is cost. The municipalities are reluctant to sanction the implementation of an emergency system where the cost to the community would increase. Property damage and personal injury suits could increase cost in the form of legal fees. The possible loss of jobs could increase unemployment insurance. The purchase of the added equipment needed for the new system would also increase community costs. The solution to the cost problem is quite simple. There would not be a loss of jobs because some of the present system personnel will be retained as a back-up system, and the rest of the present system personnel will be used for the new system. In addition, the new system is proposed to increase efficiency and, thus legal costs would decrease. The new hardware needed would increase costs, but not as significantly as the municipal governments and safety agencies believe.

To improve the chances of developing a workable 911 system, all public safety agencies, contained in a community, should be presented, in advance, with complete installation procedure plans. They should also be, periodically, informed of any changes in plans that may directly affect them. Task force meeting should include a representative from each safety agency involved, the meeting should also include a telephone company representative and representatives from concerned citizens groups who wish to attend.

The police departments and fire departments receive the majority of the emergency calls. They constitute the main portion of an emergency system. Hospitals, ambulance services, poison control, drug abuse, suicide prevention, civil defense, weather warning, United States Secret Service, and the Federal Bureau of Investigation must also be included in an emergency telephone answering network.

Existing Systems

In current telephone systems, where the emergency number has not been installed, an emergency caller will usually dial zero when not certain of which seven digit number to dial. The answering operator or the calling citizen must then make a call to the emergency agency which increases response time and operational complexity. Since the telephone operator is not specifically trained for emergency response only, further complications may result.

A system, where the operator passes emergency information to the proper safety agency but does not permit the caller to speak directly to the safety agency, is referred to as a call relay system. This type system could be beneficial if the operator were very highly trained.

When the operator receives an emergency call, determines the emergency type, and transfers the call to the appropriate safety agency, the system is referred to as a call transfer system. The calling party can interact directly with the responding agency while the operator can simultaneously contact additional safety agencies, if they are necessary.

In communities where the emergency telephone number has been installed, the emergency answering operator replaces the telephone operator. Because the emergency oeprators are trained for emergency situations, they are more familiar with the incidents that they encounter and the system will be inherently more reliable.

If an emergency caller contacts a directory assistance operator to obtain a safety agency telephone number, this type of operation is called call referral.

If an emergency telephone reporting plan funnels all calls to a central emergency operating center which dispatches the necessary emergency equipment directly, the method is known as a direct dispatch system.

System Integration

Generally, local emergency service jurisdictions and telephone company central office boundaries do not coincide. (U.S. Executive Office of the President. Office of Telecommunications Policy 1973). If they did a single emergency service center could be established for each community. Emergency calls would automatically reach the proper emergency service center and the emergency operators would be familiar with the service area. The operators could act as combined operator - dispatchers and save the time of relaying information to the dispatcher. Because portions of more than one community are sometimes served by a single telephone central office. (U.S. Executive Office of the President, Office of Telecommunications Policy 1973). It may be advantageous to construct a single emergency communications center to process the calls from the entire region. The emergency communications operator would be required to determine from which municipality a call has originated and the immediate location of the emergency in order to specify which emergency agency presides over that section. To accomplish this task, considerable modification of existing equipment and personnel training policies would be required by both the affected emergency agencies and the involved telephone companies.

The legal, financial, operational, technical and political problems encountered when installing emergency communications systems make each situation unique (U.S. Executive Office of the President. Office of Telecommunications Policy 1973). Although each case is different, the basic structure can be generalized and classified in order to aid in future emergency system implementations. The common patterns can be categorized and analyzed in order to select the appropriate integrating system capable of most effectively facilitating the case encountered.

Reliability/Response Time/Cost Trade-Off

Emergency response time is relative to each particular emergency incidence. A decrease in response time increases the probability of preventing a disaster. How low must the response time be? In emergency situations, where human injuries and lives are involved, the response time must be as low as possible. By definition, as the system reliability decreases, the system failure rate increases. When a system failure occurs, no response will follow in that particular mode of operation, therefore, decreased response time would not be a useful consideration. A second response may follow in another mode of operation. This would increase the response time. The response time would then be mode one response time to failure, plus the delay encountered until a second response is initiated, plus mode two response time to completion. Because a system failure may drastically increase response time, reliability should be the prime consideration when implementing an emergency communications system.

In selecting an integrating system configuration, a trade-off may result between reliability response time, and cost. The

Emergency agency response must be both reliable and immediate. Because the response time depends upon the reliability, a highly reliable system configuration should be established and subsequently response time should be improved.

III. SYSTEM MODELS

Functional Description

The functional flow charts demonstrate the specific functional actions performed by the individuals involved in the transferrence of information in an emergency state. These were generated to identify the interdependence of the system elements.

Figure 1 illustrates a present use method of operation. First, the citizen must recognize the emergency incident location, determine what type assistance is necessary, and what particular agencies have jurisdiction. He must, then, locate the current emergency agency telephone numbers before he can dial the seven digit number. It is assumed that in the number location function, the correct emergency agency number is called. The calling citizen may be required to dial more than one sequence of seven digit numbers due to incorrect dialing, reaching an improper emergency agency, or the necessity of multiple agency assistance. Due to the complexity of his task, the citizen, in this case, is assigned a reliability $R_{c1} = .96$.

Two emergency agency operators are included in the flow chart to demonstrate calls requiring multiple agency assistance which is frequent in emergency situations. The different flow paths establish that the additional emergency agencies can be summoned either by the citizen of by the agency operators. Each emergency agency operator must determine incident location, and the type assistance required before the proper equipment can be dispatched. Because the emergency agency operator is more familiar with emergency call situations and the equipment available to him simplifies his function, his reliability is assumed to be R_{A0}= 99.

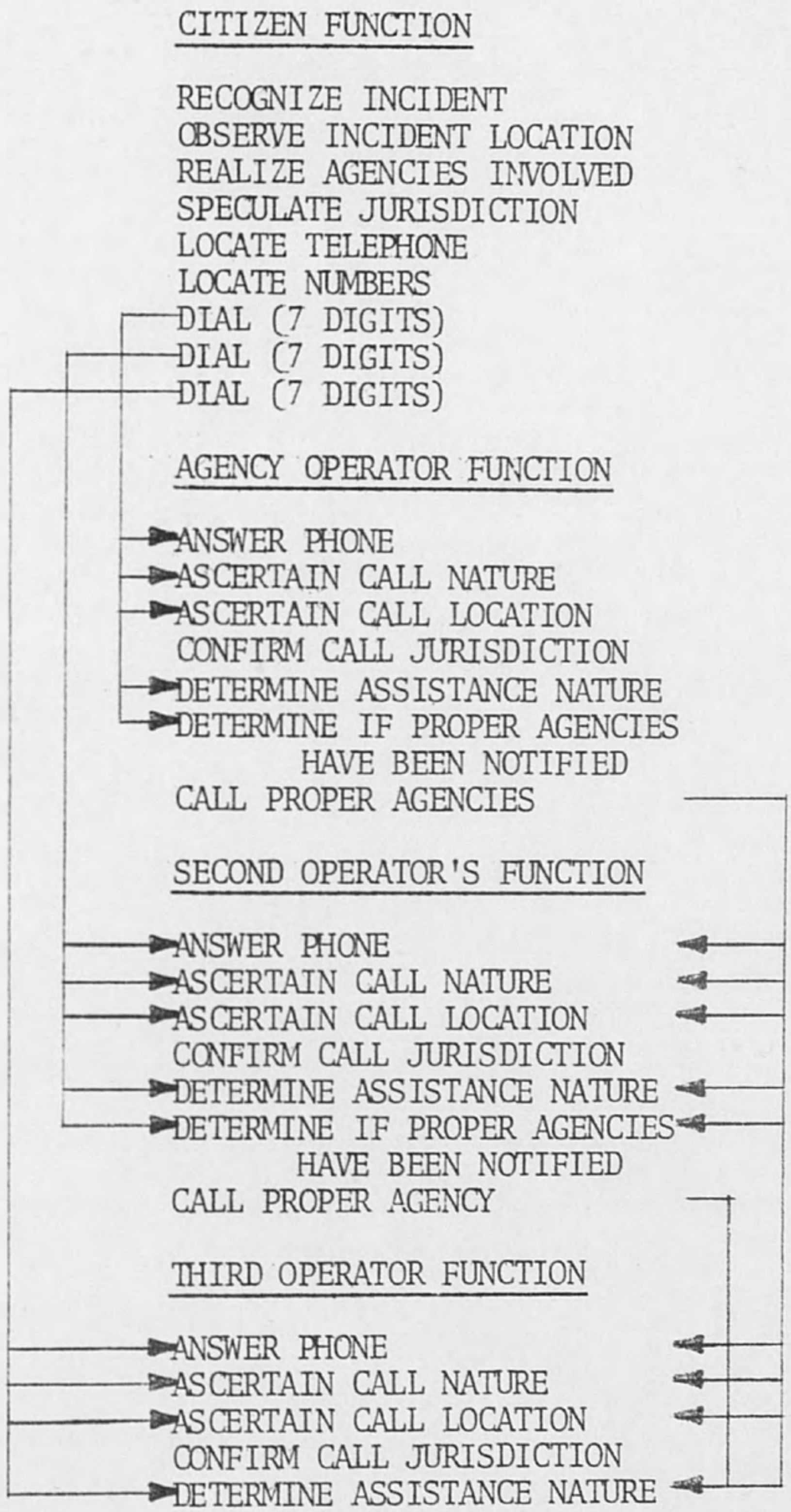

Figure 1. Citizen - Dialed Functional Flow Chart

Another existing method of obtaining the proper emergency assistance is by dialing 0. The citizen need not look for numbers, determine departmental jurisdiction, or even know his location before dialing. However, an additional set of functions is introduced because the telephone company operator is added to the system. This operator may relay or transfer an emergency call to the proper safety agencies.

If the call relay option (Fig. 2) is chosen, the telephone company operator must determine incident location departmental jurisdication, and assistance required. This information is then passed on the emergency agency operator through the telephone company operator. The telephone company operator decides, on the basis of what information the citizen has supplied, which agencies are necessary, since the citizen's task is greatly simplified and he must remember and dial only a single digit his reliability $R_{c2} = .99$ is increased. Although the functions performed by the telephone company operator and emergency agency operator are the same, the emergency agency operator is more highly trained. This indicates that the telephone company operator's reliability $R_{toT} = .98$ is slightly lower.

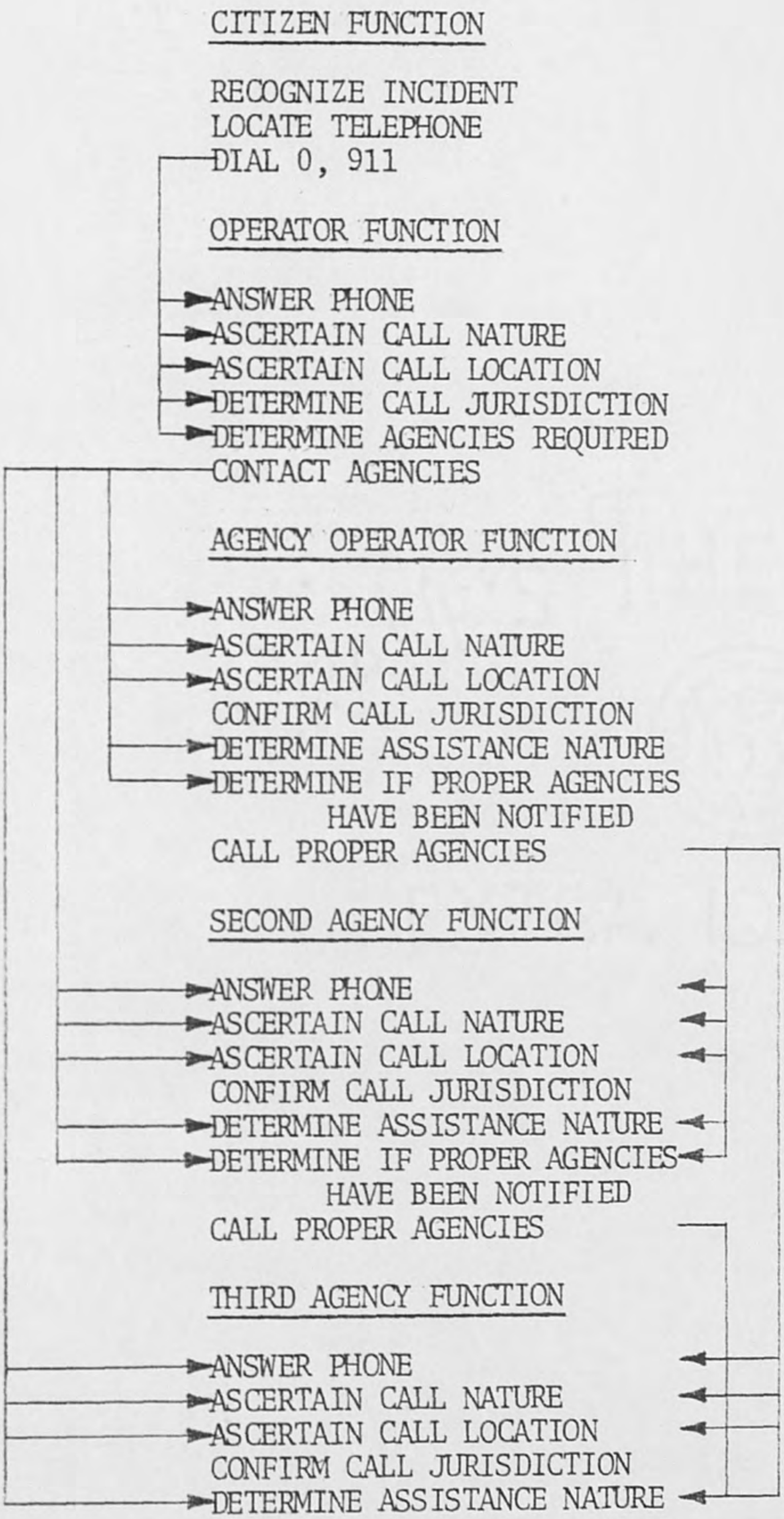

Figure 2. Call Relay - Functional Flow Chart

If the telephone company operator transfers an emergency call (Fig. 3), incident location, departmental jurisdiction, and the assistance required must again be determined before the call can be transferred. However, in this instance, the citizen presents the emergency information directly to each agency operator are presented differently but remain the same. Therefore, the human reliabilities R_{c2} and R_{t0} do not change from those of Fig. 2.

CITIZEN FUNCTION

RECOGNIZE INCIDENT
LOCATE TELEPHONE
DIAL 911, 0

OPERATOR FUNCTION

ANSWER PHONE
ASCERTAIN CALL NATURE
ASCERTAIN CALL LOCATION
DETERMINE CALL JURISDICTION
DETERMINE AGENCIES REQUIRED
DIAL AGENCY (S)

FIRST AGENCY FUNCTION

ANSWER PHONE
ASCERTAIN CALL NATURE
ASCERTAIN CALL LOCATION
CONFIRM CALL JURISDICTION
DETERMINE ASSISTANCE NATURE
DETERMINE IF PROPER AGENCIES HAVE BEEN NOTIFIED
CALL PROPER AGENCIES

SECOND AGENCY FUNCTION

ANSWER PHONE
ASCERTAIN CALL NATURE
ASCERTAIN CALL LOCATION
CONFIRM CALL JURISDICTION
DETERMINE ASSISTANCE NATURE
DETERMINE IF PROPER AGENCIES HAVE BEEN NOTIFIED
CALL PROPER AGENCIES

THIRD AGENCY FUNCTION

ANSWER PHONE
ASCERTAIN CALL NATURE
ASCERTAIN CALL LOCATION
CONFIRM CALL JURISDICTION
DETERMINE ASSISTANCE NATURE

Figure 3. Call Transfer - Functional Flow Chart

If the three digits 911 are substituted for the single digit 0, the basic functional structure for call relay, (Fig. 2) and call transfer (Fig. 3) systems is not altered. The citizen must dial three digits instead of one digit which minutely increases the dialing function time. The operator becomes a specialist, dealing, only, with emergency calls; although the emergency functions that he is required to perform are identical to those of the telephone company operator. He is trained how to quickly and accurately extract pertinent information from a citizen who is under stress. The more specialized training of the answering operator lowers the possibility that mistakes will be made and this raises reliability during $R_{EO} = .99$ information transmission. The response time will also be lowered because the emergency use only operators are more available to the citizens. The citizen function has not changed. He must now dial three digits but this does not significantly decrease his reliability. The citizen is again assigned a reliability value of $R_{C3} = .99$.

Another suggested method of providing emergency service is by the use of the call referral system (Fig. 4). As in Figures 2 and 3 the citizen would dial all without poor knowledge of incident location, departmental jurisdiction, or the type emergency assistance required. The emergency operator would perform the same functions as those of the emergency operator of Figures No. 2 and 3 except that the emergency telephone number is referred back to the citizen instead of being directly connected by the operator. From this point the functions performed are similar to those of Figure No. 1 where the citizen finds the emergency agency number in a directory. The referral operator's function is limited to feedback to the calling citizen; therefore, his reliability is high R_{EO} = .99. He does not communicate with the emergency agency personnel. The functions of the citizen become more complicated than those of the call relay and call transfer of Figures 2 and 3, but remain less complex than those of the citizen dialed system of Figure 1. His reliability falls between the two, R_{C4} = .98.

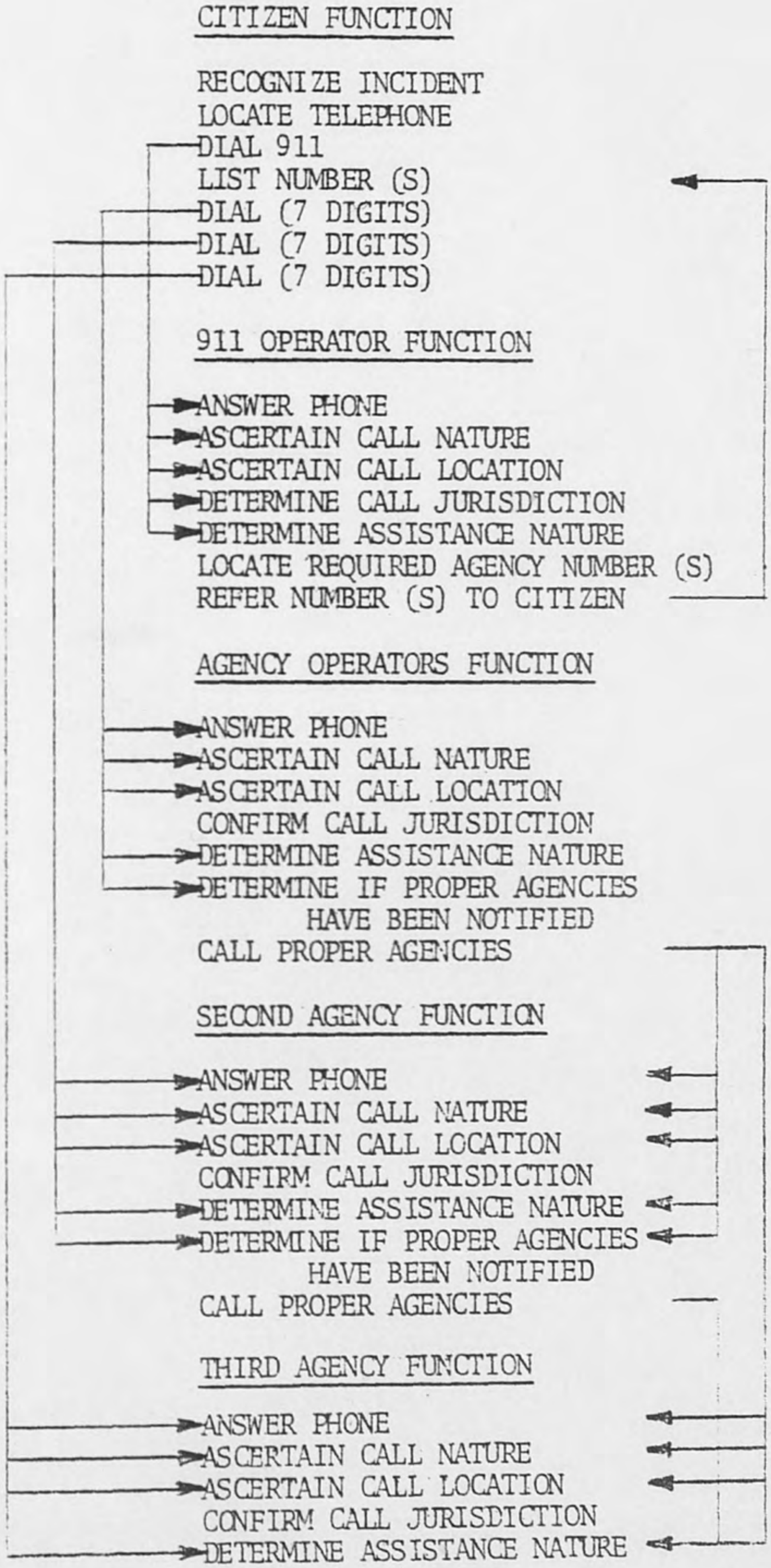

Figure 4. Call Referral - Functional Flow Chart

When the telephone company operator of Figures 7, 8, and 9 is replaced with a specialized central emergency operator the margin for error and the time to extract essential information are reduced. If the specialized central emergency operator and the emergency agency operator are combined into a single answering operator the system efficiency further improves. The set of telephone company operator performed functions are omitted. The information flow then resembles that of Figure 1 where the citizen directly contacts the emergency agency operator. However, more functions are performed by the citizen of Figure 1. The citizen, of the direct dispatch system of Figure 5, must merely dial an easily remembered three digit number without having to determine the proper emergency assistance number from a directory of call referral personnel. R_{c5} is assigned the value .99. Furthermore, since the emergency answering operator and the dispatcher are combined into one individual capable of dispatching the necessary emergency assistance equipment, the need to contact additional agencies is erased. The tasks required of this individual become more complicated, but his level of training is higher; thus R_{oD} is assigned the value .99. Because the necessary personnel and the functions that they perform in the direct dispatch system are minimal, the system possesses the capacity to exhibit the maximum model efficiency.

CITIZEN FUNCTION

RECOGNIZE INCIDENT
LOCATE TELEPHONE
DIAL 911

911 OPERATOR - DISPATCHER

→ANSWER PHONE
→ASCERTAIN CALL NATURE
→ASCERTAIN CALL LOCATION
CONFIRM CALL JURISDICTION
→DETERMINE ASSISTANCE NATURE
DISPATCH PROPER EQUIPMENT
CALL CORRECT OPERATOR-DISPATCHER

SECOND OPERATOR - DISPATCHER

→ANSWER PHONE
→ASCERTAIN CALL NATURE
→ASCERTAIN CALL LOCATION
CONFIRM CALL JURISDICTION
→DETERMINE ASSISTANCE NATURE
DISPATCH PROPER EQUIPMENT

Figure 5. Direct Dispatch - Functional Flow Chart

During the examination of each functional flow chart, expected emergency response times can be speculated by inspecting the difficulty of the required functions and the number of functions necessary to complete the emergency response. The expected duration of each individual task can be predicted from previous records. Since each emergency response alternative exhibits several possible paths that the response may follow when multiple agency responses are necessary, the response time may vary widely according to the assistance required. The expected response time is that which is the most probable or occurs the most frequently, but the path demonstrating the greatest response time must be foremost when dealing with emergencies. If the most time consuming routes for each emergency scheme are compared, the differences in response times become more obvious. The individual response times necessary to perform each emergency function have not been listed because each community is unique and the recorded times would not be accurate.

The average response time for emergencies encountered in Orange County is three to five minutes. In this text, a response must occur within five minutes of an incident to be considered a success.

System Configurations for Study

When an emergency telephone number is installed, the present means of reporting emergencies, dialing 411 for directory assistance referral, dialing 0 for the telephone company relay or transfer, and dialing the sevel digit agency number will, generally, be retained as back up systems. The system models of these present emergency reporting methods have been illustrated in order to demonstrate their weaknesses and the advantages in modifying their structure to a 911 emergency configuration.

In the reliability diagrams, each element of the possible emergency system configurations is displayed in a block which represents its reliability. The different system model block diagrams contain basically the same elements but they are arranged in different configurations. The difference in reliability of each diagram is modified by the introduction of parallel structure (active redundancy) and switching sequences, decision devices, and feed back loops (all forms of standby redundancy). The reliability of each human involved in each different configuration has been assigned according to the complexity of the tasks that he is required to perform. (School of Aerospace Medicine 1971). The degree of training of the answering operators also partially determines their reliability. Each block diagram begins with citizen and continues to the point of emergency dispatch. The abbreviations used in the reliability models are displayed in Table 1.

TABLE 1

RELIABILITY DIAGRAM ABBREVIATIONS

Reliability element	Abbreviation
Citizen	CIT
Telephone	TEL.
Telephone System	TEL. SYST.
Telephone Operator	TEL. OP.
Telephone Line	TEL. LIN.
Information Line	INF. LIN.
Recorder	REC.
Digital Computer	DIG. COM.
Video Display	VID. DIS.
Keypunch	KEYP.
Keypunch Operator	KEYP. OP.
Emergency Operator	EM. OP.
Agency Operator	AG. OP.
Dispatcher Operator	OP. DISP.
Dispatcher	DISP.
Other Agency	OT. AG.
Agency (to response)	AG.

The first case considered is the present system where a citizen, in an emergency situation, dials a 7 digit telephone number to reach the appropriate emergency agency. Figure 6 represents the reliability block diagram for this system. The call is initiated by the citizen. It follows a path through the citizen telephone and telephone system; to the responding agency operator telephone and recorder, and responding agency operator; then on the to the dispatcher; and finally through the internal agency workings, which remain constant throughout all cases considered. Two decision blocks are encountered. If the jurisdiction is correct, no switching occurs and the emergency call follows its normal path, but, if the jurisdiction is incorrect, the responding agency operator must contact the proper safety agency. The other decision is whether the given information is correct, when the given information is correct, the responding agency operator either re-checks the facts with the calling citizen or opens the switch which plays back the recorded conversation. The recorder and the telephone of the responding agency are connected actively parallel. Two responding agency operators and two dispatchers are represented by a redundent circuit with a switching device. This represents standby redundancy where the second operator or dispatcher will take over if the first fails. This is typical of a supervisor assuming command if the operator or dispatcher has difficulty.

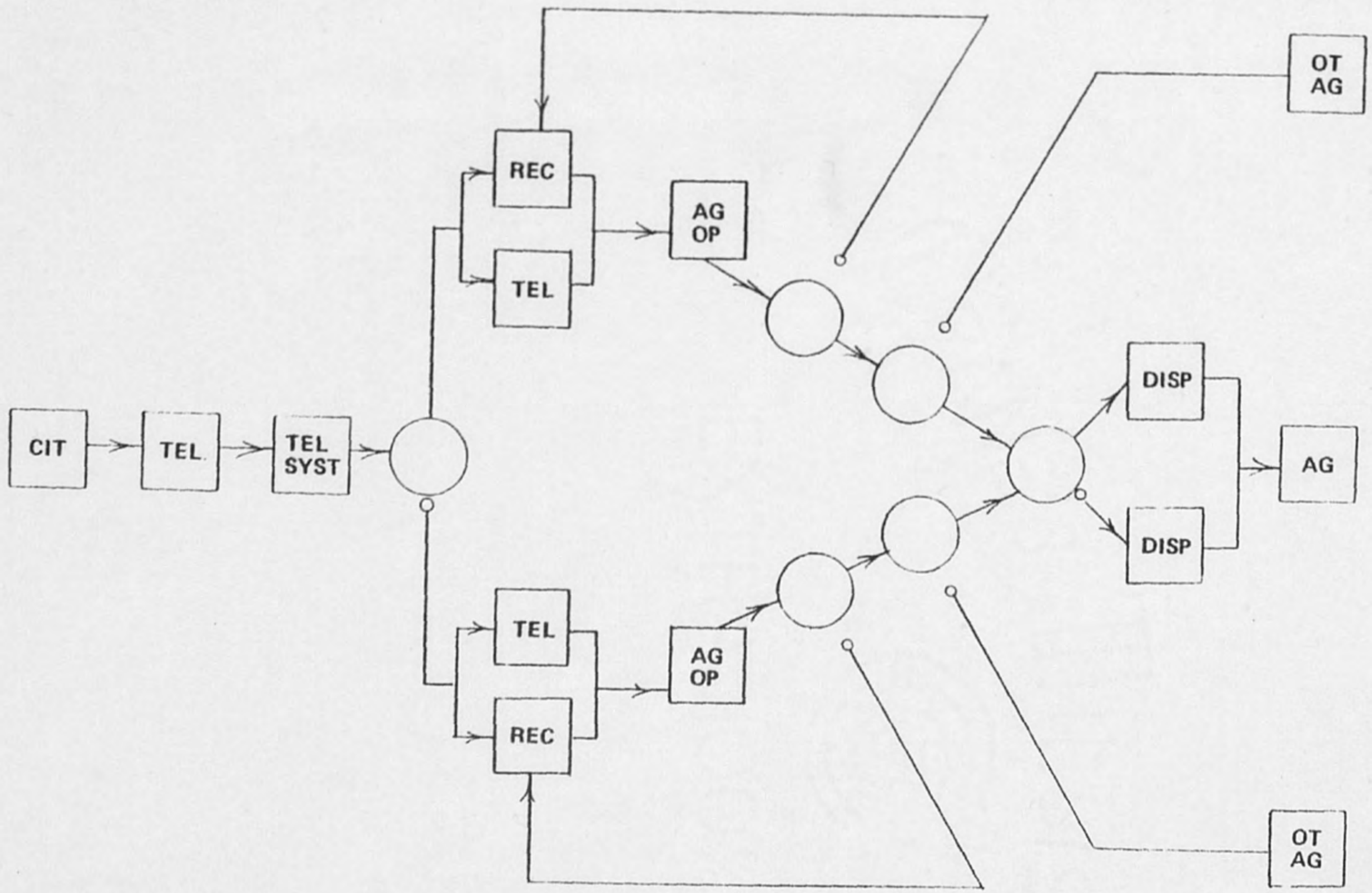

Figure 6. Citizen — Dialed Reliability Model

Call relay and call transfer routines are similar in structure. Because telephone company operators are more proficient than the general population when making communications connections (dialing, etc.), procedures where the citizen must do the least amount of dialing would be more efficient. Call relay and call transfer routines require the identical amount of dialing and operator connections. A central emergency operator must also extract the same information from the caller in each of two different schemes. If a call relay system is implemented, the central operator passes the given information to the safety agency operator. Because the original incident facts pass through another individual, the information becomes secondary and loses some of its reliability. However, response times should be low because the emergency operator is highly trained for extracting pertinent information in stress situations. In a call transfer system, the citizen reporting the emergency incident speaks directly to safety agency operator. His information is primary, but when repeating the incident information, he may forget which facts have been reported. Because the general population is not specifically trained for emergencies, citizens are not as efficient as the operators when they are in stress situations. Therefore, response times for emergencies requiring a singular response would tend to be high in the call transfer scheme. But, because the central operator remains free after the transfer of the citizen to the agency operator to contact other safety agencies, response times for emergencies requiring multiple responses are more favorable with the call transfer scheme.

The telephone company call relay configuration (Fig. 7) retains all the elements of Fig. 6. In addition, a telephone operator and telephone constructed with a standby telephone operator and telephone are interjected in series between the citizen and the responding agency. Another telephone system block is added to exhibit the re-use of the telephone system after the telephone operator is contacted.

The telephone company call transfer system is also demonstrated in Fig. 7. The block elements are identical to those of the telephone company call relay system. However, the path followed is not as direct as in the telephone company call relay system. The call feeds back from the telephone company operator to the citizen, then continues forward to the responding agency operator.

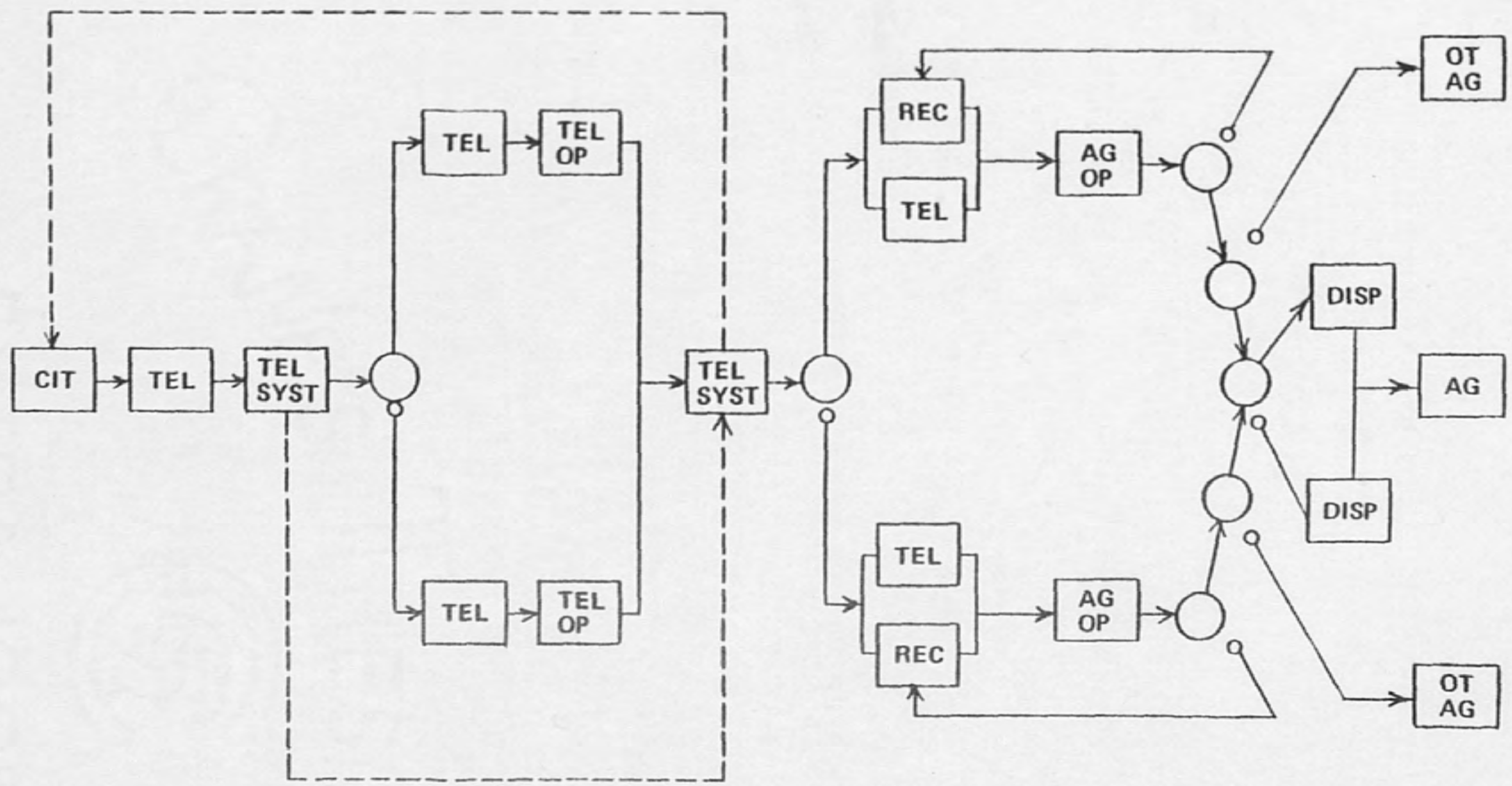

Figure 7. Telephone Company Operator Call Transfer and Call Relay Reliability Model

The central emergency (911) operator call relay and call transfer schemes (Fig. 8) replace the telephone company operator with the 911 emergency operator. The use of a digital computer in the emergency system introduces new elements. They are: two keypunches (standby); two keypunch operators (Standby); two video displays (standby); the lines from the keypunch to the computer and from the computer to the video display; and unit itself. A radio transmitter and receiver, and a hot line (dedicated to emergency calls only) are also added in a standby structure. The hot line and the digital computer are constructed in active parallel.

Numerous elements are added when a call relay or call transfer design is modified for use in a 911 emergency system. Since these supplemental blocks are linked in redundant configurations, their addition improves the system effectiveness by providing system checks and backups.

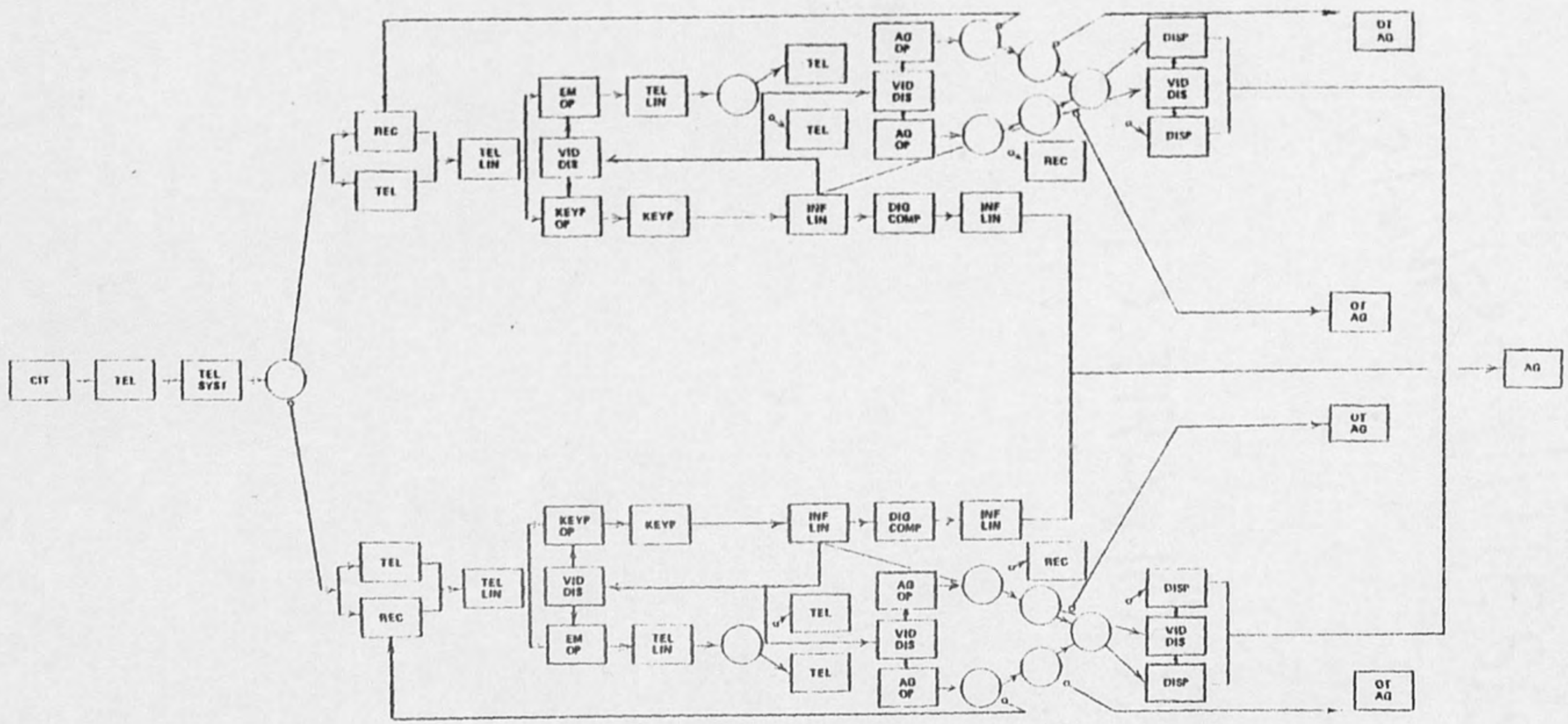

Figure 8. Emergency Operator Call Relay and Call Transfer Reliability Model

A call referral system using an information telephone number for emergencies only would be slightly more efficient than dialing a directory assistance operator because of the increased training of the emergency operator, but less efficient than dialing 0. The call referral emergency reporting method inherently possesses the slowest response time and greatest chance for error. The caller must dial the three digit emergency number to obtain the seven digit responding agency number. He may dial incorrectly, forget the referral number, misinterpret the operator, or request improper assistance. If he has lost contact with the operator, he must repeat the referral process. The only advantage of this system is the reduction of non-emergency calls that reach the emergency agencies.

The call referral system proposed in Fig. 9 does not eliminate any elements that are presently in use in Figures 6 and 7. The return path back to the citizen requiring him to re-dial a 7 digit number reduces the reliability because the new path is actually an added series link. Thus, the call referral option is not considered an improved system, but is included to display its ineffectiveness as a valid alternative.

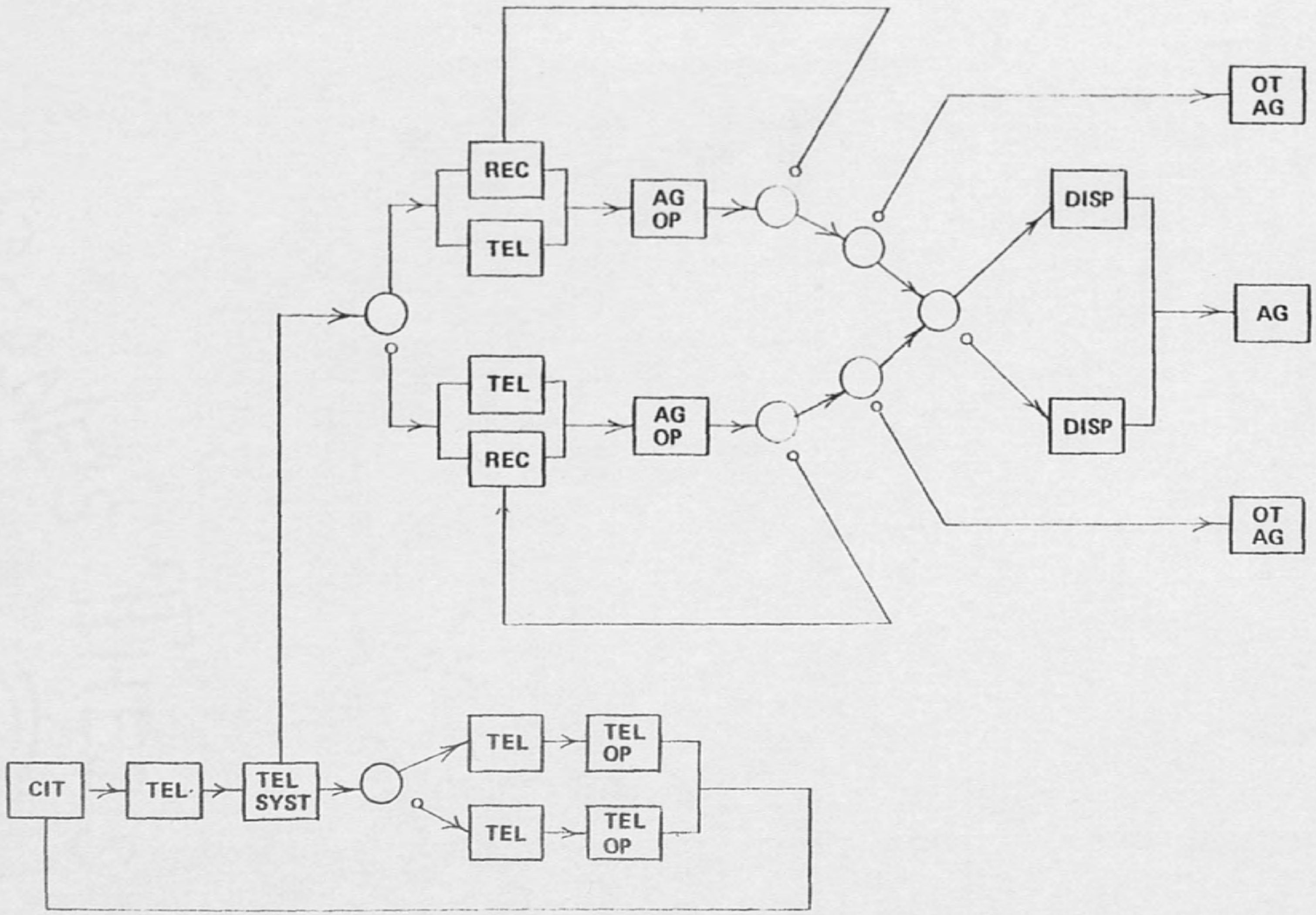

Figure 9. Call Referral Reliability Model

The central emergency telephone operator and the emergency agency operator become the same individual in a direct dispatch system. Since only a singular call is made and an operator is eleminated, the system efficiency is greater than a call relay or call transfer scheme the direct dispatch system (Fig. 10) possesses basically the same hardware as that of the present method where the citizen dials a seven digit emergency number. The difference is that the calling citizen must perform a minimum of tasks before he dials the emergency number in direct dispatch. He is not required to determine location, jurisdiction, or look up a telephone number. Thus, the direct dispatch system possesses the lowest response time and the highest reliability value. However, this scheme is not feasible in every location, and is politically difficult to implement. The area serviced by the emergency center cannot be excessively large, because the dispatchers will lose credibility in pinpointing emergency incident locations. Figure 10 demonstrates that the direct dispatch system is the least complicated of the systems (least number of elements in reliability diagram) and most reliable.

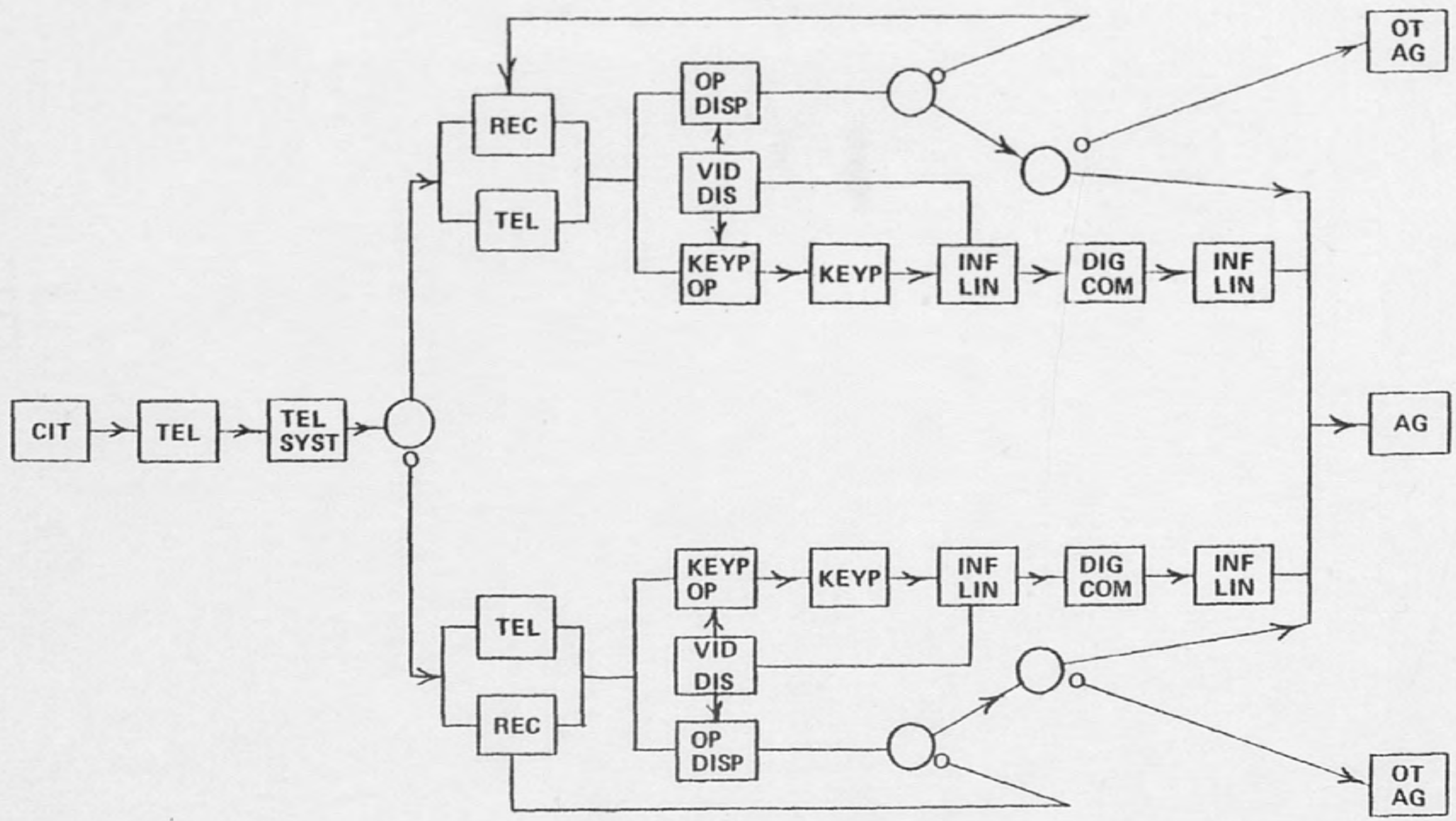

Figure 10. Direct Dispatch Reliability Model

V. SYSTEM MODEL ANALYSIS

Model Validation

Table 2 lists the elements used in the reliability models, the symbols representing them in the resulting reliability equations, and the numerical values assigned to them. The reliability values assigned to physical equipment were estimated from military standard values rates for a five minute period of similar equipment. (U.S. Department of Defense 1967).

TABLE 2

RELIABILITY SYMBOLS AND VALUES

Symbol	Reliability Element	Assigned Value
RTP	Telephone	.99
RTS	Telephone System	.99
RRC	Recorder	.99
RC1	Citizen (dial agency)	.96
RC2	Citizen (dial operator)	.99
RC3	Citizen (dial operator)	.99
RC4	Citizen (dial operator)	.99
RC5	Citizen (dial operator)	.99
RTO	Telephone Operator	.98
REO	Emergency Operator	.99
RAO	Agency Operator	.99
RKO	Keypunch Operator	.99
RDO	Dispatcher-Operator	.99
RDS	Dispatcher	.99
RVD	Video Display	.99
RKP	Keypunch	.99
RDC	Digital Computer	.99
RTL	Telephone Line	.99
RIL	Information Line	.99
ROA	Other Agency (internal)	.99
RAG	Agency (internal)	--

The mathematical combination of two sets of independent elements simplifies the schematic and reliability equation of Figure 6. The formula for the probability of success of "either or" of two elements in an active parallel arrangement is used.

$R_{1,2} = R_1 + R_2 - R_1 R_2$ (ARINC Research Corp., 1964)

substituting

$$R_{TRC} = R_{TP} + R_{RC} - R_{TP} R_{RC} \quad (1)$$

$$= .99 + .99 - .99\ (.99)$$

$$= .9999$$

When combining several independent elements in a series, the formula for the probability of success of all elements is used.

$R_{1,n} = R_{1}, R_{2}, \ldots R_{n}$ (ARINC Research Corp., 1964)

substituting

$$R_{CPS} = R_{Cn}\ R_{TP}\ R_{TS} \quad (2)$$

$$= R_{C1}\ R_{TP}\ R_{TS}$$

$$= .96\ (.99)\ (.99)$$

$$= .941$$

$$R_{TRA} = R_{TRC}\ R_{AO} \quad (3)$$

$$= .999\ (.99)$$

$$= .9899$$

Figure number 6 reduces to:

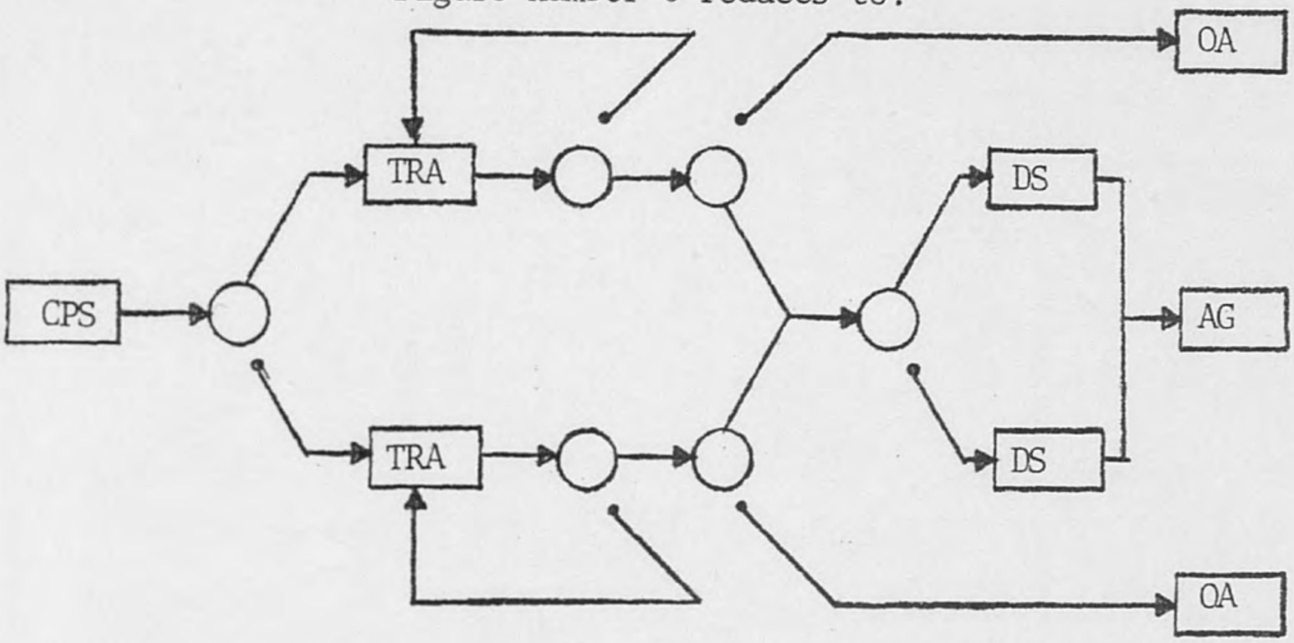

Figure 11. Figure 6 - Simplification

The mathematical combinating of several sets of parallel redundant switching elements further simplifies the equation. The formula for the standby redundancy value of two switching elements is implemented.

R_C = Switch contact probability = .9999

R_Y = Probability of switching when not required

R_N = Probability of not switching when required

$R_Y = R_N = .99$

$R_{1,2} = R_1\ R_2\ R_C\ TR_1(1-R_2)\ R_C\ R_Y + (1-R_1)R_2R_CR_N$ (Arinc Research Corp., 1964)

substituting

$$R_{SWD} = R_{DS}\ R_{DS}\ R_C + R_{DS}\ (1-R_{DS})\ R_C\ R_Y + (1-R_{DS})\ R_{DS}\ R_C\ R_Y$$

$$= R_{DS}\ R_C(R_{DS} + R_Y - R_{DS}\ R_Y + R_Y - R_{DS}\ R_Y)$$

$$= R_{DS}\, R_C\, (R_{DS} + 2R_Y - 2\, R_{DS}\, R_Y) \qquad (4)$$

$$= .99\ (.9999)\ [.99 + 2(.99) - 2\ (.99(.99))]$$

$$= .9996$$

$$R_{SWJ} = R_C\ [R_{SWD}\, R_{OA} + R_{SWD}(1-R_{OA})\, R_Y + R_{OA}(1-R_{SWD})R_Y] \qquad (5)$$

$$= .9999[.9996(.99)+.9996(1-.99).99+.99(1-.9996).99]$$

$$= .9998$$

$$R_{SWQ} = R_C\ [R_{SWJ}\, R_{RC} + R_{SWJ}(1-R_{RC})\, R_Y + R_{RC}\ (1-R_{SWJ})R_Y] \qquad (6)$$

$$= .999[.9998(.99) + .9998(1-.99).99+.99(1-.9998).99]$$

$$= .9999$$

The product of the series of elements, is given by:

$$R_{SQJ} = R_{TRA}\, R_{SWJ}\, R_{SWQ} \qquad (7)$$

$$= .9899\ (.9998).9999$$

$$= .9896$$

The schematic reduces to:

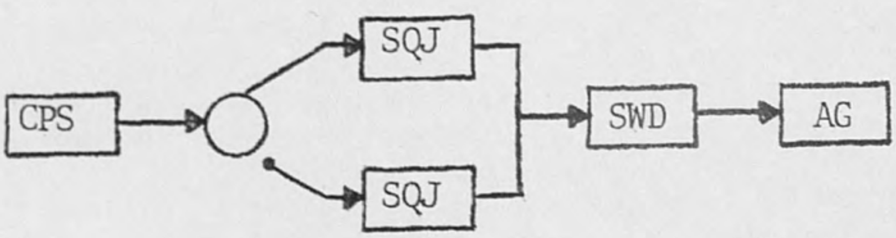

Figure 12, Figure 11 - Simplification

The combination at the remaining parallel standby switch results in the form.

$$R_{SWAO} = R_C\ [(R_{SQJ})^2 + R_{SQJ}(1 - R_{SQJ})R_Y + R_{SQJ}(1 - R_{SQJ})R_Y] \qquad (8)$$

$$= R_C\ [R_{SQJ}{}^2 + 2(R_{SQJ} - R_{SQJ}{}^2)R_Y]$$

$$= .999\ [(.9896)^2(.9896 - (.9896)^2\ .99]$$

$$= .9996$$

which yields the schematic

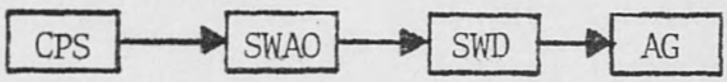

Figure 13. Figure 12 - Simplification

The resulting equation when solving the final series schematic is

$$R_1 = R_{CRS}\ R_{SWAO}\ R_{SWD}\ R_{A}.$$

The element values expressed for the humans in the system represent the probability of obtaining their services. The actual reliability of an individual service is the product of his probability of service and his probability of success when in service.

$$R_1 = R_{CPS}\ R_{SWAO}\ R_{AO}\ R_{SWD}\ R_{DS}\ R_A$$

Thus;

$$= .941\ (.9996)\ (.99)\ (.9996)\ .99\ R_A$$

$$= .9215\ R_A$$

The two sets of active parallel elements in Figure number 7 are combined as they were in Figure number 6. Using equation 1.

$$R_{TRC} = R_{TP} + R_{RC} - R_{TP}\ R_{RC}$$

$$= .9999$$

The interior sets of series elements are also combined using equation 2.

$$R_{CPS} = R_{C2}\ R_{TP}\ R_{TS}$$

$$= .99\ (.99)\ (.99)$$

$$= .9703$$

The use of equation 3 yields,

$$R_{TRA} = R_{TRC}\ R_{AO}$$

$$= .9999\ (.99)$$

$$= .9899$$

Another series set is combined using the series equation.

$$R_{TOP} = R_{TP}\ R_{TO} \qquad (9)$$

$$= .99(.98)$$

$$= .9702$$

The schematic of Figure number 7 reduces to:

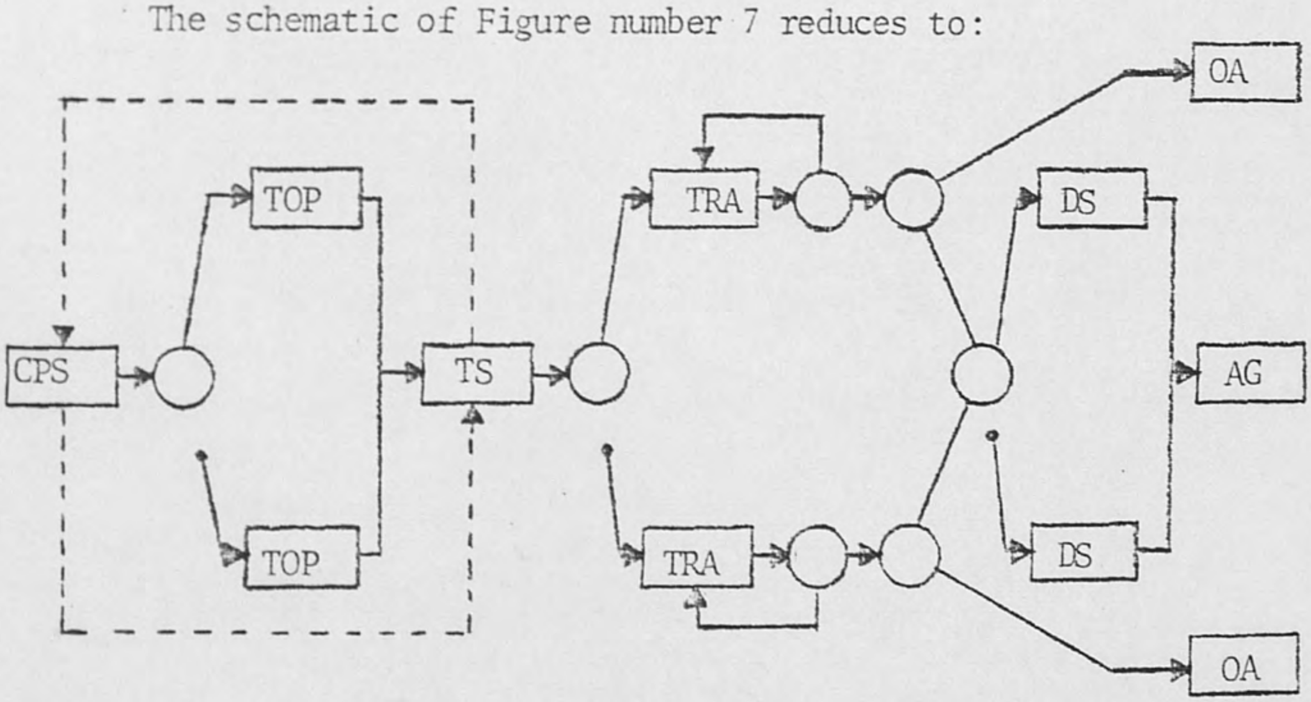

Figure 14. Figure 7 - Simplification

The standby redundant switching elements can be combined as in Figure number 6, using equation's 4,5,6,7, and 8.

$$R_{SWD} = R_C R_{DS} (R_{DS} + 2R_Y - 2R_{DS} R_Y)$$

$$= .9996$$

$$R_{SWJ} = R_C [R_{SWD} R_{OA} + R_{SWD} (1-R_{AO})R_Y + R_{OA} (1-R_{SWD})R_Y]$$

$$= .9998$$

$$R_{SWQ} = R_C [R_{SWJ} R_{RC} + R_{SWJ} (1-R_{RC}) + R_{RC}(1-R_{SWJ})R_Y]$$

$$= .9999$$

$$R_{SQJ} = R_{TRA} R_{SWJ} R_{SWQ}$$

$$= .9896$$

$$R_{SWAO} = R_C [R_{SQJ}{}^2 + 2(R_{SQJ} - R_{SQJ}{}^2) R_Y]$$

$$= .9996$$

Similarly the redundant switching equation and equation number 9 yields;

$$R_{SWTO} = R_C [R_{TOP}{}^2 + 2(R_{TOP} - R_{TOP}{}^2) R_Y]$$

$$= .9999[(.9702)^2 + 2(.9702 - (.9702)^2).99]$$

$$= .9984$$

The schematic of Figure number 7 is;

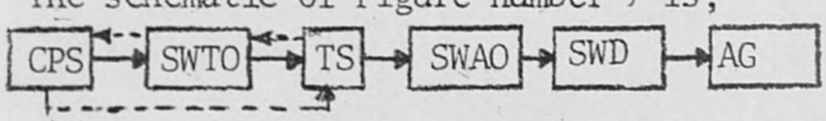

Figure 15. Figure 14 - Simplification

Combining the remaining series element groupings the call relay option yields;

$$R_{2A} = R_{CPS}\, R_{SWTO}\, R_{TO}\, R_{TA}\, R_{SWAO}\, R_{AO}\, R_{SWD}\, R_{DS}\, R_{AG}$$

$$= .9703(.9984)(.98)(.99)(.9996)(.99)(.9996)(.99)R_{AG}$$

$$= .9204\, R_{AG}$$

The call transfer option yields;

$$R_{2B} = R_{CPS}\, R_{SWTO}\, R_{TD}\, R_{TS}\, R_{C2}\, R_{SWAO}\, R_{AO}\, R_{SWD}\, R_{DS}\, R_{AG}$$

$$= .9703(.9984).99(.99).99(.9996).99(.9996).99\, R_{AG}$$

$$= .9205\, R_{AG}$$

Simplifying Figure number 8, several interior sets of elements can be combined as in the previous systems. Equation number 1 yields;

$$R_{TRC} = R_{TP} + R_{RC} - R_{TP}\, R_{RC}$$

$$= .9999$$

Similarly solving the active parrallel dual set yields;

$$R_{TVD} = R_{TP} + R_{VD} - R_{TP}\, R_{VD} \qquad (11)$$

$$= .99 + .99 - .99\,(.99)$$

$$= .9999$$

The results of the use of equation 2 are;

$$R_{CPS} = R_{C3}\, R_{TP}\, R_{TS}$$

$$= .99\,(.99)\,.99$$

$$= .9703$$

$$R_{TRL} = R_{TRC} R_{TL}$$

$$= .9999 (.99)$$

$$= .9899$$

$$R_{TVA} = R_{TVD} R_{AO}$$

$$= .9999(.99)$$

$$= .9899$$

$$R_{EOL} = R_{EO} R_{TL}$$

$$= .99(.99)$$

$$= .9801$$

$$R_{KOL} = R_{KO} R_{KP} R_{JL} R_{DC} R_{JL} R_{VD} \quad (12)$$

$$= .99(.99).9999(.99).9999(.99)$$

$$= .9604$$

Three sets of standby redundant switching elements can be combined using equations 4,5, and 6.

$$R_{SWD} = R_C R_{DS} (R_{DS} + 2R_Y - R_{DS} R_Y$$

$$= .9996$$

$$R_{SWJ} = R_C[R_{SWD} R_{OA} + R_{SWD} (1-R_{OA})R_Y + R_{OA} (1-R_{SWD})R_Y]$$

$$= .9998$$

$$R_{SWQ} = R_C[R_{SWJ} R_{AC} +R_{SWJ} (1-R_{RC})R_Y + R_{RC}(1-R_{SWJ})R_Y]$$

$$= .9999$$

The combination of series of elements is

$$R_{VAQJ} = R_{TVA} R_{SWJ} R_{SWQ}$$

$= .9899(.9998).9999$

$= .9896$

A modification of equation number 8 can be used since $R_{VAQJ} = R_{SQJ}$.

$$R_{SWAO} = R_C\ [R_{VAQJ}^2 + 2(R_{VAQJ} = R_{VAQJ}^2) R_Y]$$

$= .9996$

Additional simplification yields;

$$R_{SOL} = R_{EOL}\ R_{SWAO}\ R_{SWD}$$

$= .9801\ (.9996)\ .9996$

$= .9793$

$$R_{SKOL} = R_{SOL} + R_{KOL} - R_{SOL}\ R_{KOL}$$

$= .9793 + .9604 - .9793\ (.9604)$

$= .9992$

$$R_{STOL} = R_{TRL}\ R_{SKOL}$$

$= .9899\ (.9992)$

$= .9891$

The schematic of Figure number 8 now exhibits the following:

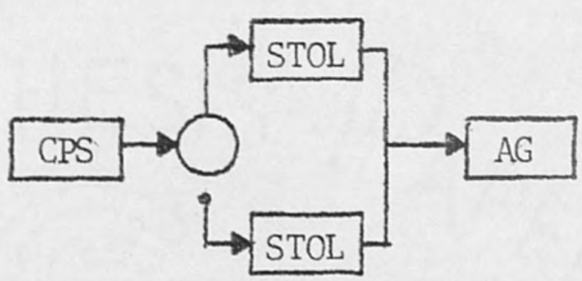

Figure 16. Figure 8 - Simplification

Reducing the remaining redundant switch results in,

$$R_{SWTOL} = R_C\ [R_{STOL}{}^2 + 2(R_{STOL} - R_{STOL}{}^2)R_Y]$$

$$= .9999\ [(.9891)^2 + 2(.9891 - (.9891)^2).99]$$

$$= .9997$$

The (transfer option) reliability equation for Figure number 8 is:

$$R_{3A} = R_{CPS}\ R_{SWTOL}\ R_{EO}\ R_{AO}\ R_{DS}\ R_{AG}$$

$$= .9703\ (.9997)\ .99(.99).99\ R_{AG}$$

$$= .9411\ R_{AG}$$

Again in the relay option the citizen R_{C3} is reintroduced but the operator's reliability slightly increases,

$$R_{3B} = R_{CPS}\ R_{SWTOL}\ R_{EO}\ R_{AO}\ R_{DS}\ R_{C3}\ R_{AG}$$

$$= .9703(.9997)(.999)(.99)(.99)(.99)\ R_{AG}$$

$$= .9402$$

Several sets of series, active parallel, and standby redundant elements can be combined in Figure number 9 using equations 1,2,3,4,5,6,7,8,9 and 10.

$$R_{TRC} = R_{TP} + R_{RC} - R_{TP}\ R_{RC}$$

$$= .9999$$

$$R_{CPS} = R_{CH}\ R_{TP}\ R_{TS}$$

$$= .98(.99)(.99)$$

$$= .9605$$

$$R_{TRA} = R_{TRC}\, R_{AO}$$

$$= .9899$$

$$R_{SWD} = R_{DS}\, R_C (R_{DS} + 2R_Y - 2\, R_{DS}\, R_Y$$

$$= .9996$$

$$R_{SWJ} = R_C [R_{SWD}\, R_{OA} + R_{SWD}\, (1-R_{OA}) R_Y + R_{OA} (1-R_{SWD}) R_Y]$$

$$= .9998$$

$$R_{SWQ} = R_C [R_{SWJ}\, R_{RC} + R_{SWJ}\, (1-R_{RC}) R_Y + R_{RC} (1-R_{SWJ}) R_Y]$$

$$= .9999$$

$$R_{SQJ} = R_{TRA}\, R_{SWJ}\, R_{SWQ}$$

$$= .9896$$

$$R_{SWAO} = R_C [R_{SQJ}^{\ 2} + R_{SQJ} (1-R_{SQJ}) R_Y + R_{SQJ} (1-R_{SQJ}) R_Y]$$

$$= .9996$$

$$R_{TOP} = R_{TP}\, R_{TD}$$

$$= .9801$$

$$R_{SWTO} = R_C [R_{TOP}^{\ 2} + 2(R_{TOP} - R_{TOP}^{\ 2}) R_Y]$$

$$= .9992$$

The schematic of Figure number 9 is now

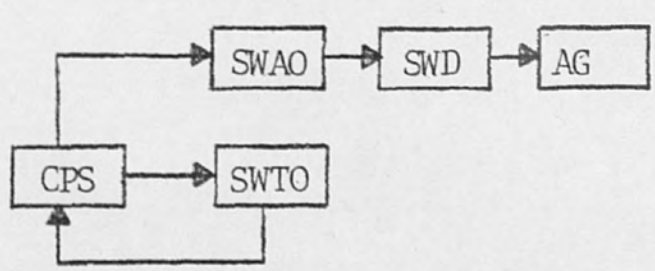

Figure 17. Figure 9 - Simplification

To solve for the reliability of the schematic which has a feedback loop, the chain is treated as a series of elements.

$$R_4 = R_{CPS}\ R_{SWTO}\ R_{TO}\ R_{CPS}\ R_{SWAO}\ R_{AO}\ R_{SWD}\ R_{DS}\ R_{AG}$$

$$= .9605(.9992).99(.9605).9996(.99).9996(.99)R_{AG}$$

$$= .8937\ R_{AG}$$

Figure number 10 can be simplified by combining the interior sets of independent elements using equations 1,2,5, and 6

$$R_{TRC} = R_{TP} + R_{RC} - R_{TP}\ R_{RC}$$

$$= .9999$$

$$R_{CPS} = R_{C5}\ R_{TP}\ R_{TS}$$

$$= .99(.99)(.99)$$

$$= .9703$$

When combining the redundant switching elements the results are:

$$R_{SWJ} = R_{OA}\ R_C\ (R_{OA} + 2R_Y - 2\ R_{OA}\ R_Y$$

$$= .99(.9999)[.99 + 2(.99) - 2(.99)(.99)]$$

$$= .9998$$

$$R_{SWQ} = R_C[R_{SWJ}\ R_{RC} + R_{SWJ}\ (1-R_{RC})R_Y]$$

$$= .9999$$

Using equations 11, and 12

$$R_{TVD} = R_{TP} + R_{VD} - R_{TP}\ R_{VD}$$

$$= .9999$$

$R_{KUL} = R_{KO} R_{KP} R_{IL} R_{DC} R_{JL} R_{VD}$

$= .9604$

$R_{PUL} = R_{DS} R_{SWQ} R_{SWJ}$

$= .99 (.9999).9998$

$= .99 (.9999).9998$

$= .9897$

Further simplification yields;

$R_{DKOL} = R_{DOL} + R_{KOL} - R_{DOL}R_{KOL}$

$= .9897 + .9604 - .9897(.9604)$

$= .9996$

$R_{DTOL} = R_{TRC} R_{DKOL}$

$= .9999 (.9996)$

$= .9995$

The schematic of Figure number 10 is simply

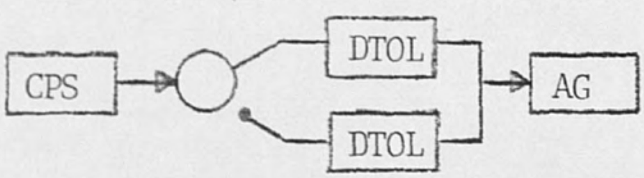

Figure 18. Figure 10 - Simplification

Simplifying,

$R_{SWTOL} = R_{DTOL} R_C [R_{DTOL} + 2R_Y - 2 R_{DTOL} R_Y]$

$= .9995(.9999)[.9995+2(.99)-2(.9995(.99)]$

$= .9998$

Finally, the combining of the resultant series is

$$R_5 = R_{CPS} R_{SWTOL} R_{OD} R_A$$

$$= .9703(.9998).99 R_A$$

$$= .9604 R_A$$

Model Results

TABLE 3

RELIABILITY MODEL RESULTS

Reliability Model Symbol	Acting Personnel	Personnel Function	Relative Reliability	Per Cent Improvement
R_1	Citizen	Dial	.9215	0
R_{2A}	Telephone Company Operator	Transfer Call	.9204	-.12
R_{2B}	Telephone Company Operator	Relay Call	.9205	-.11
R_{3A}	Emergency Operator	Transfer Call	.9411	2.13
R_{3B}	Emergency Operator	Relay Call	.9402	2.03
R_4	Emergency Operator	Refer Call	.8937	-3.02
R_5	Emergency Operator Dispatcher	Dispatch	.9604	4.22

Conclusions

Because the constant reliability elements contained in the responding agency are common to all the reliability equations, they can be factored from the reliability equations. The relative reliability values are employed for comparison purposes. Thus, although not correct on an absolute reliability basis, the relative comparison is valid. The resultant relative reliability values are compared to the most reliable present system value as a percentage of improvement. The resultant relative reliability values are lowest for the present use schemes of equations R_1, R_{2A}, and R_{2B} and the call referral scheme of equation R_4. This is expected because these configurations were included to demonstrate possible improvement of the proposed systems. It is apparent that the estimated reliability values of multiple components in parallel configurations do not significantly affect the system reliability because their reliability values approach 1.0 as the number of parallel structures increases.

The Telephone Company operator call transfer (R_{2A}) and call relay (R_{2B}) schemes show no improvement when compared to the citizen dialed scheme R_1. Because the relative reliability value of the call relay scheme (R_4) shows even less improvement (more negative improvement shown in Table 3), the inclusion of this system is not considered. The emergency operator call transfer plan relative reliability (R_{3A}) has positive results which is shown in Table 3. The emergency operator call relay scheme also has positive results when compared with R_{1A} (Table 3) but the system relative reliability is lower than that of the emergency operator call transfer plan. However, the response time is lower for the emergency operator relay call transfer scheme due to the relaying operator's emergency training. The costs involved are similar but may be slightly higher when the call relay scheme is instituted. This is due to the more detailed relaying policies that the emergency operator must learn.

The direct dispatch scheme exhibits the highest relative reliability R7. Since the number of elements and thus, the necessary functions to perform in this system are small, the response time is also the most advantageous. However, since the direct dispatch system is the least adaptable and may be the most expensive to implement, the call relay or call transfer is suggested as an integrating system until the communicating system is modified to properly accept the direct dispatch system.

Suggestions and Further Work

Extended capabilities can be realized through the installation of additional communications features. Some presently available are forced disconnect, tone application, and hold and ringback. Automatic number identification and selective call routing are the ultimate improvements for emergency communications systems, but are presently unavailable for use. The availability of these options would alter the system models and demonstrate an easily noticable solution to the emerging communications problem. The future examination of the progress of these improvements and their practicality could be instrumental in increasing the system effectiveness. A full scale simulation would also add greater insight into the calculation of the expected response time values.

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