Development of a utility feeder infrared thermography preventive maintenance program – with lessons learned

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ABSTRACT

In 2000, the ComEd Energy Delivery - Power Quality Department was given the task of performing infrared scans on the company's overhead distribution system in the City of Chicago. We were given the project time frame, a list of feeders, frequency of inspection, and prioritization of inspections. Preparation for the project included: benchmarking of other programs, vehicle design, obtaining maps, equipment, personnel, and training, and development of procedures, forms, spreadsheets and a data storage system. The process included: creation of map packages, recording of weather conditions, logging of potential problems and marking of feeder maps, recording the time required to perform the scans, and analysis and processing of data. Administrative duties included: updating the feeder list, entry of data into the work management system, tracking program progress, and generating program progress reports and graphs.

As the program progressed, modifications were made to the feeder list to include all relevant program information, vehicle layout, and vehicle equipment. The results of the program, (while successful), did show trends towards program modification.

Lessons learned from the initial year lead to several current and future modifications to vehicle design to help increase productivity and safety.

Keywords: Infrared thermography, preventive maintenance, utility feeder, overhead distribution system, electrical surveys

1. BACKGROUND

As utilities head into the new millennium and a deregulated environment, market share will become increasing more important to the survival of the organization. In order to achieve an acceptable piece of the market, utilities will either need to provide enhanced services and/or a superior product.

One way for a utility to deliver a superior product is for it to use infrared thermography (IR) as a preventative maintenance (PM) tool in its generating stations and on its transmission / distribution (T&D) system. Infrared thermography is a well-known and highly utilized tool in many applications from building envelope and roof surveys, to medical diagnoses. As utilities increase the use of this technology and its applications within the industry, many benefits can be achieved.

By using infrared thermography, utilities can perform fast and efficient PM on a large area and number of items. Routine IR scans of critical equipment can help avoid emergency restoration efforts by identifying anomalies prior to failure, and allow for the scheduling of maintenance during normal working hours. By identifying anomalies at an early stage of development, component deterioration can be minimized resulting in less expensive maintenance and increased life expectancy. Finally, IR scans can be used to verify the integrity of work performed and help identify poor work practices.

The results of performing such IR scanning in the delivery a superior product are:

- Reduced maintenance costs for the utility by reducing the amount of maintenance work and parts required, and reducing the number of emergency restoration calls.
- Increased utility system reliability.
- Reduced customer lost production and downtime due to fewer outages, resulting in increased production and revenues.
- Increased utility revenues through increased electricity sales.
- Increased utility customer retention and acquisition from higher customer satisfaction.

2. INITIAL PROGRAM

ComEd has recognized the usefulness of IR, and has had its substations scanned annually for quite a few years. Through 1998, a contractor performed this work, but starting in 1999, the Power Quality Department (PQ Dept.) has performed these inspections. Then in 2000, ComEd expanded its IR program to include the scanning of overhead feeders in the City of Chicago.

The project was to scan all of the 4kV feeders on a 2 year cycle, and all of the 12kV and higher feeders on a 3 year cycle. These scans were to include all of the exposed overhead main feeder stems, radial branches and associated equipment. The scans were not to include any underground or secondary equipment. Of course, any secondary problems that were identified while scanning the primary circuit would be imaged, recorded and reported, but no attempt would be made to purposely scan the service drops to each facility.

The temperature criteria selected for the project was the same as the one developed during the first several years of the substation program, and is based on other utilities, equipment manufacturers, and EPRI documentation. That criteria is as follows:

For line of sight items, (such as bolted connections, splices, and disconnect jaws and pivots):

- <18F Attention – no corrective action, but monitor equipment
- 18F to 63F Intermediate – corrective action as scheduling permits
- 64F to 135F Serious – corrective action as soon as possible
- >135F Critical – corrective action immediately

For non line of sight items, (such as transformer and capacitor cans, cable up feed and down feed pot heads, and lightning arrester bodies):

- 1F to 17F Intermediate – corrective action as scheduling permits
- 18F to 36F Serious – corrective action as soon as possible
- >36F Critical – corrective action immediately

All temperatures are temperature rises above an appropriately selected reference point. (Usually this reference point is a similar component on another phase that is assumed to be under similar load.)

3. PREPARATION

Once the PQ Dept. received the job, a lot of preparation was required before the scanning could actually begin. The first item to be addressed was obtaining the proper equipment. Several other utilities had already been performing this type of work for several years, so a trip was setup to visit one of them and benchmark their program. The results of the trip yielded a firmer idea of how the program should operate, as well as several modifications to the plans for the vehicles that would be specially built to perform the work.

Once the plans for the vehicles had been modified, the vehicles and associated equipment were ordered. In order to meet the time frame established for the program, it was estimated that two vehicles were required. One was ordered with a gas engine, and one with a diesel engine to compare the pros and cons of each for future orders. In addition, three infrared images were purchased. One would be permanently assigned to each vehicle. The third would act as a spare in case of equipment failure, during equipment calibrations, or used in the substation program when idle.

The next item to be addressed was to obtain a list of all the feeders included in the program and any prioritization of their scanning. Once this list was obtained, it indicated that there were 529 - 4kV feeders, 1525 - 12kV feeders, and 2 - 34kV feeders, broken up into 4 groups of priority. (But these numbers were soon to change, once the program had started.)

Now that the list of feeders was known, the corresponding feeder and 60 cycle maps needed to be obtained. The feeder maps indicated the approximate physical location of the feeder route, (See **figure 1** below), while the 60 cycle maps indicated all the poles and equipment on the feeder along with the corresponding pole and equipment numbers, (See **figure 2** below). This task was more difficult than it sounds because it took awhile to find a cooperative resource that could meet the time frame required. We originally wanted the feeder maps and corresponding 60 cycle maps assembled into map packages for us, but no one could accommodate our request. So we ended up obtaining two complete sets of feeder and 60 cycle maps that we would end up assembling later.

Based on our experience developing our substation program, we immediately requested that our training department put together a class for the thermographers and potential drivers on how to read the feeder and 60 cycle maps, and become familiar with overhead distribution design standards, equipment, and terminology. This class was then held prior to any scanning being performed.

The final part of the preparation involved developing a procedure, form, data storage system, data spreadsheet, work management system (WMS), and program handbook. Once again, our experience developing our substation program gave us an excellent head start on what needed to be done and how. The procedure addresses what steps are to be taken by both the thermographer and driver while scanning a feeder, what information is to be obtained, and how to process the data acquired. The form used for data collection was taken from the substation program with a few modifications to adapt it to feeder work. Some of the information included on the form is: the thermographer, type of scan, feeder number and voltage level, date, start time, stop time, scan time, weather conditions, image number, pole #, equipment #, equipment description, problem description, and a call in check box, (See **figure 3** below). The data storage system consists of a "Feeders" folder on the network drive for all feeder related information. Under that folder is a folder for each type of scan performed: "Scans in 2000", "Rescans in 2000", and "Special Scans in 2000". New folders would then be made for each year the work is performed, with the old data being archived onto CD. When a feeder is scanned and images taken, the thermographer would then create a folder with that feeder's number on it under the folder for the appropriate type of scan performed, along with a dated subfolder. All raw data, processed images, spreadsheets and Word documents related to that feeder's scan would then be placed under the dated subfolder, (See **figure 4** below). The data spreadsheet consists of the scan date, region, reporting office, feeder number and voltage level, pole #, equipment #, equipment description, temperature data, problem description, failure category, image #, and WMS #. A spreadsheet is made for each feeder that has problems identified on it, and is saved under the dated subfolder for that feeder. A copy of the data is also placed in a master spreadsheet that contains an entry for each feeder scanned, whether or not problems were found. This allows us to quickly sort through all the data that pertains to the program to determine different figures, statistics, and trends, (See **figure 5** below). The WMS that was eventually agreed upon is the Maximo system that much of the company presently uses. This is the same WMS that is used for the substation program. Problems are individually logged in the WMS against the appropriate feeder with the corresponding IR image(s) linked to the work ticket in a Word document. The program handbook was designed to supply the thermographer and driver with all of the information that they need to understand and administer the program. Information contained in and being created for the handbook includes: a program overview, detailed program procedure, training information on reading feeder and 60 cycle maps, overhead design standards and nomenclature, equipment photographs, thermographic component identification, feeder list, log sheet, problem contact list, and various data processing instructions.

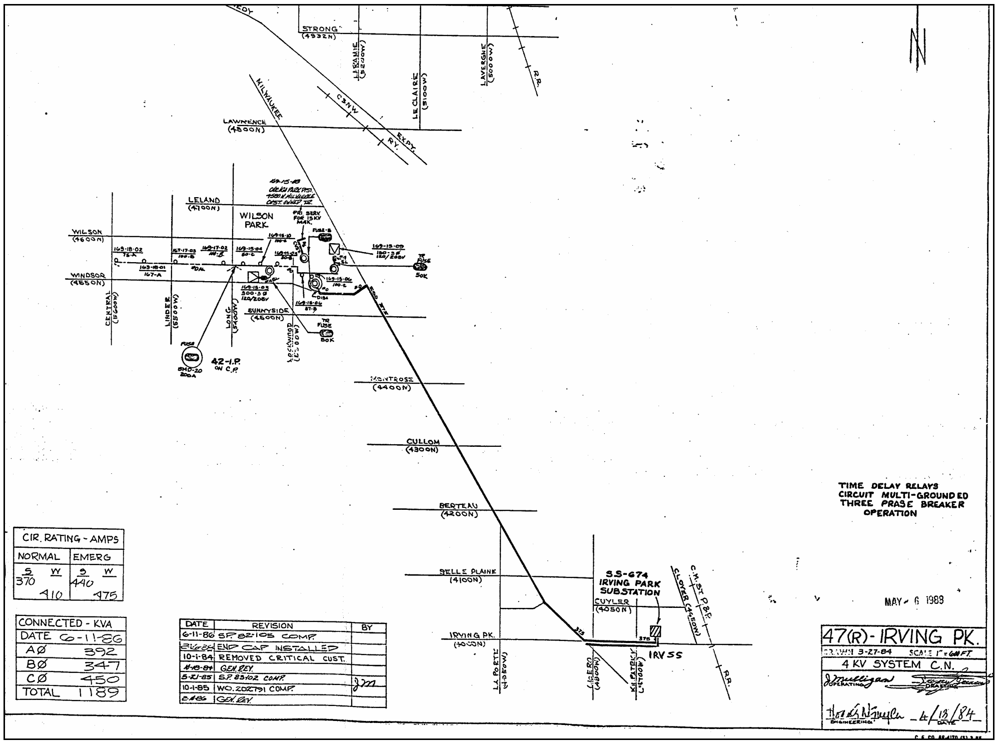


Figure 1 The feeder maps indicate the approximate physical location of the feeder route

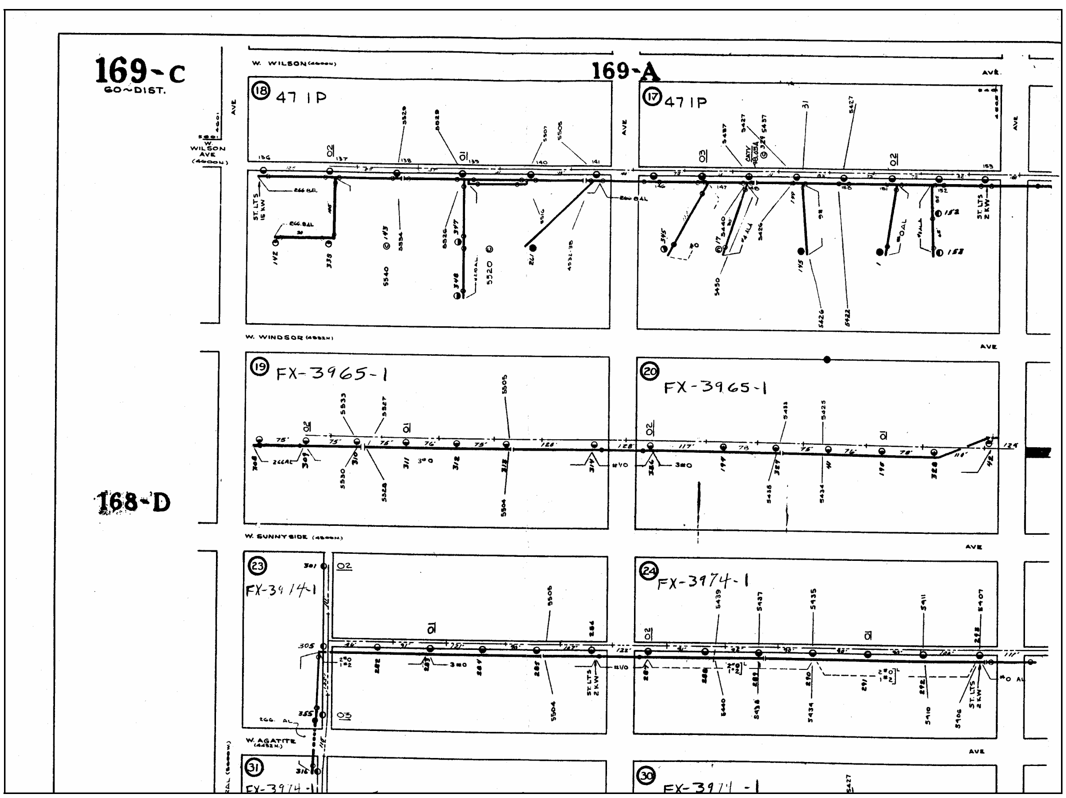


Figure 2 The 60 cycle maps indicate all the poles and equipment on the feeder along with the corresponding pole and equipment numbers

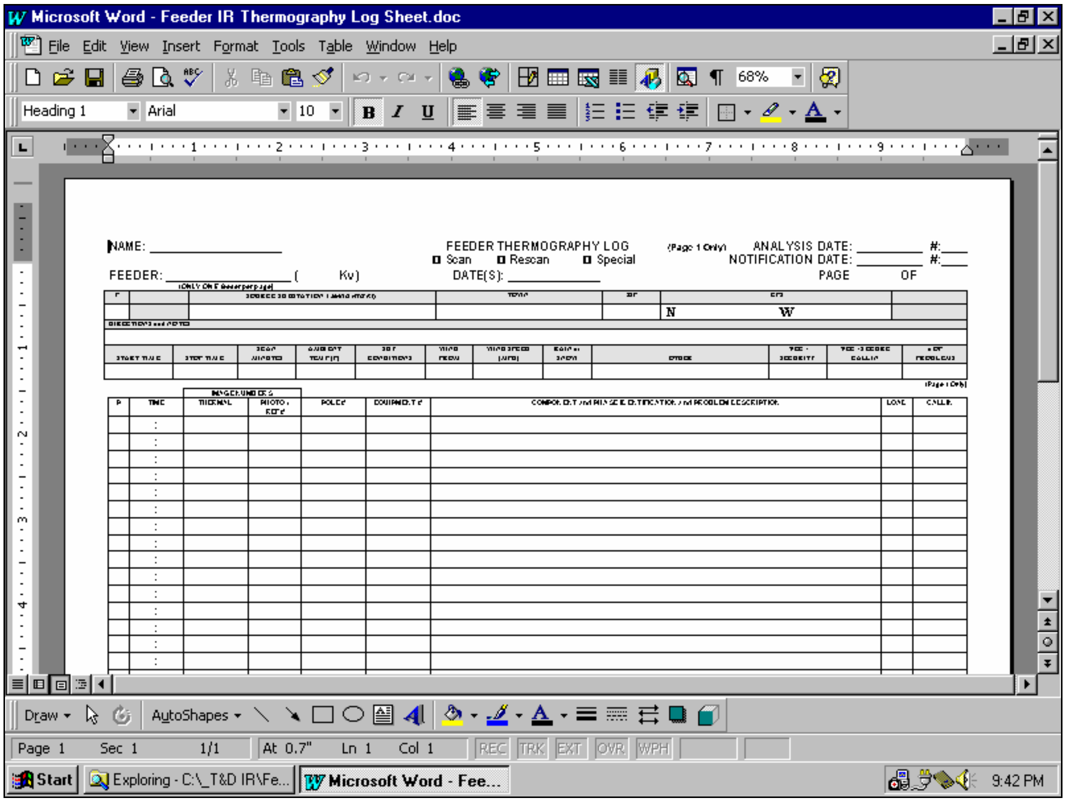


Figure 3 The form used for data collection

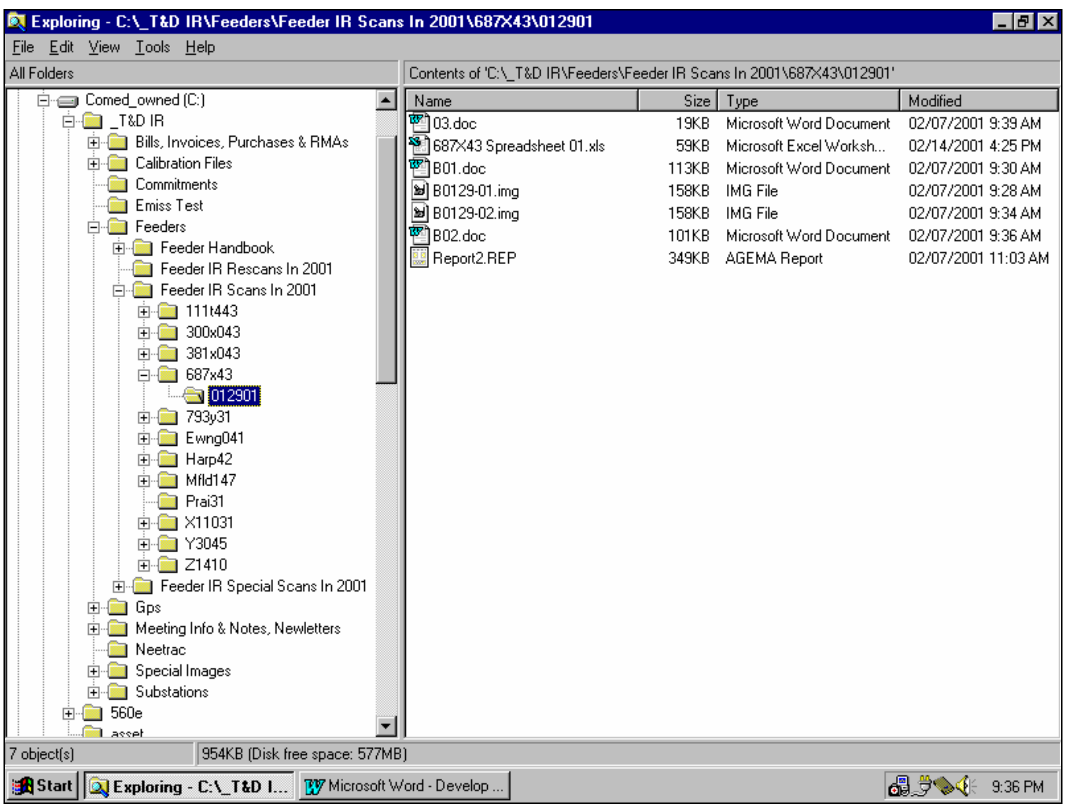
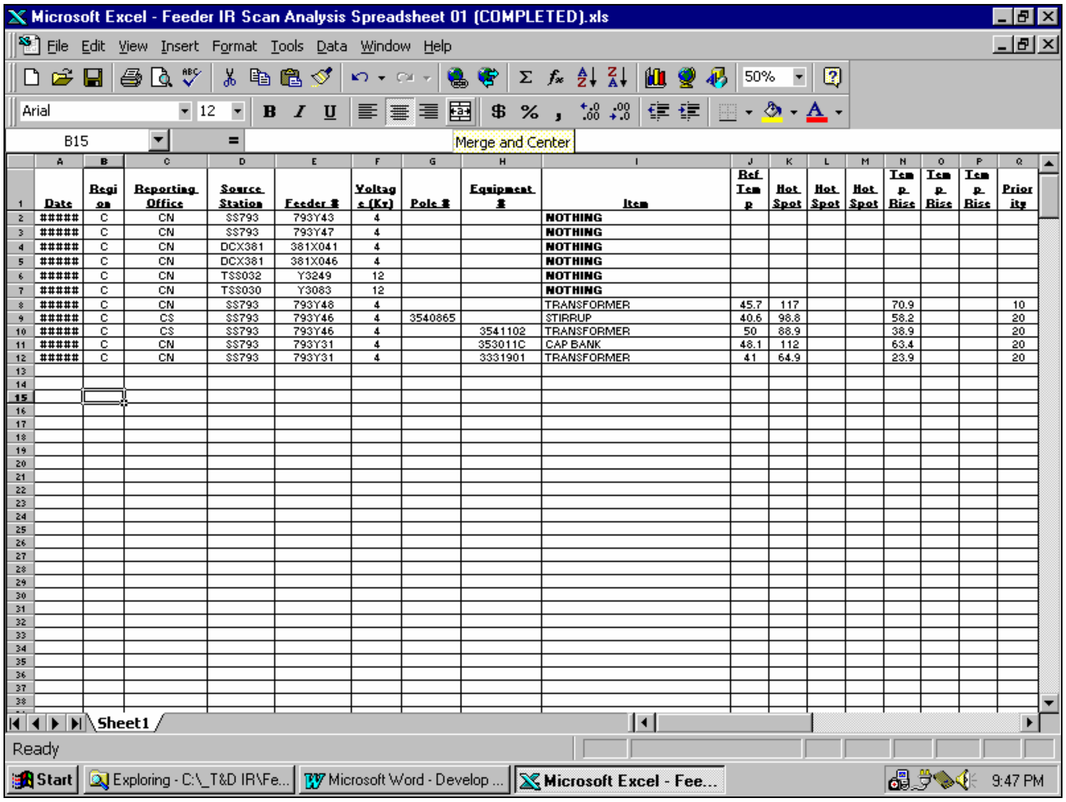


Figure 4 Location and contents of the data folder



	Date	Region	Reporting Office	Source Station	Feeder #	Voltage (Kv)	Pole #	Equipment #	Item	Ref Temp	Hot Spot	Hot Spot	Hot Spot	Temp Rise	Temp Rise	Temp Rise	Priority
2	#####	C	CN	SS793	793Y43	4			NOTHING								
3	#####	C	CN	SS793	793Y47	4			NOTHING								
4	#####	C	CN	DCX381	381X041	4			NOTHING								
5	#####	C	CN	DCX381	381X046	4			NOTHING								
6	#####	C	CN	TSS032	Y3249	12			NOTHING								
7	#####	C	CN	TSS030	Y3083	12			NOTHING								
8	#####	C	CN	SS793	793Y48	4			TRANSFORMER	45.7	117			70.9			10
9	#####	C	CS	SS793	793Y46	4	3540865		STIRRUP	40.6	98.8			58.2			20
10	#####	C	CS	SS793	793Y46	4		3541102	TRANSFORMER	50	88.9			38.9			20
11	#####	C	CN	SS793	793Y31	4		353011C	CAP BANK	48.1	112			63.4			20
12	#####	C	CN	SS793	793Y31	4		3331901	TRANSFORMER	41	64.9			23.9			20

Figure 5 Feeder scan IR analysis spreadsheet

As much as possible, the feeder program was designed to parallel the established substation program. This would allow the thermographers to quickly learn the new program, and allow them to move back and forth between the two programs with minimal adaptation.

4. THE VEHICLES

The vehicles are specially modified extended vans that accommodate the infrared scanning of an overhead distribution system. The outside of the vehicle has a front bumper winch, front and rear warning lights, roof hatch, roof deck with a camera pan & tilt unit mounted to it, left, right and rear quartz lights for illuminating potential work areas, rear arrow bar, and rear door ladder to the roof deck, (See **figures 6 and 7** below).

Figure 6 Left side view of vehicle

Figure 7 Right side view of vehicle

The driver's area has a GPS unit, controls for operating the warning lights and arrow bar, and a map compartment with fold up map table between the seats for storing and highlighting the map packages. All of the necessary office supplies for performing the driver's duties are stored in the engine cover console, (See **figure 8** below).

Figure 8 Driver's working console

The thermographer's area has swivel chair, wrap around counter top, equipment racks (with TV, VCR, computer monitor, and keyboard), interior and exterior electrical system control panel, 12VDC lighting system, and a variety of compartments, cabinets and drawers for equipment and supply storage. All of the necessary office supplies for performing the thermographer's duties are stored in a drawer organizer that has been Velcroed onto the counter top. Operation of the infrared and visual cameras on the roof deck are performed by remote control and positioned by a joystick controller, (See **figures 9 and 10** below).

Figure 9 Visual and IR monitors in thermographer's area

Figure 10 Thermographer's position

Inside the rear doors of the vehicle are selves for equipment storage, as well as the vehicles special 12VDC charging system and 110VAC inverter system, (See **figure 11** below).

Figure 11 Storage area , charger and inverter

5. THE PROCESS

Finally, on July 12th, 2000, our first vehicle was ready to roll out and perform the first official scan of the program. The second van was not received and ready for use until late August.

During the first cycle through all of the feeders, the initial stage in the process is to create the map package. This consists of pulling the feeder map(s) and identifying all of the corresponding 60 cycle maps associated with that feeder. Then those 60 cycle maps need to be pulled, copied, and the originals returned to their original location. The package, now consisting of the feeder and 60 cycle maps, is copied again in its entirety. One set of maps will act as the master set for all future scans, while the second set act as the working copy to be marked up by the thermographer and driver. These completed packages were then placed in a rack for retrieval by the scan team prior to departure for the day's work. Due to the prioritization of the feeders, the first two groups of feeders did not allow for optimization of travel time between scans. But once the third group of feeders was started on, all feeders originating from a particular location had their packages created and grouped together in the rack. That way, the scan team could grab a group of packages for the day and work in a small geographical location, saving time between the end of one scan and the beginning of another.

Each day, (weather permitting), the scan team of thermographer and driver would select a group of map packages from the rack and head out to perform the scans. Once at the location, the team would identify where the overhead section of the feeder started. If the feeder started out overhead at the substation, then the scan would begin at the substation. If the feeder left the substation underground, the scan began at the first upfeed out of the substation. (Any equipment associated with the feeder that is located at the substation is scanned yearly under the substation program.) Once the starting point of the feeder is identified, the vehicle is driven to that location. The thermographer then starts filling out a feeder log sheet indicating who the thermographer is, the type of scan being performed, the feeder number and voltage level, the date, the source substation, the start time, and the weather conditions. The driver then follows the feeder while the thermographer scans the conductors and equipment. The driver visually follows the line, performing a minor visual inspection, while appropriately operating the vehicles warning lights. The driver also communicates with the thermographer about any upcoming feeder equipment while highlighting in **GREEN** all sections of the feeder map that have been scanned. If there are any sections of the feeder which are not accessible for scanning by the vehicle, the driver will highlight those sections of the feeder map in **PINK**. Whenever the thermographer or driver identify a potential problem, the vehicle is stopped, the problem imaged and logged, and the feeder map marked with the corresponding image number at the location of the problem. The scanning is then resumed until another problem is found or the feeder completed. Once the feeder is completed, the thermographer logs the finish time, calculates and records the scan time, and notes the number of perceived problems. If no problems were found, the word "NOTHING" is written on the log sheet. The team then moves on to the next feeder and repeats the process until the day is over and it's time to return to the office.

Then, approximately every week, (based on the amount of problems identified), the thermographers would process their data and fill in their spreadsheets so that the information could be passed on for entry into the WMS. In this way, the problems are forwarded to the work crews in a timely manner so that they can be addressed appropriately.

6. ADMINISTRATION

Administrative duties for the project are numerous. First, the feeder list that was supplied to us needed to be updated with any corrections or changes that were identified. In addition, the list was modified to become a master spreadsheet of all pertinent data pertaining to the project. Additional information now included in the spreadsheet includes: the feeders region, reporting office, source substation, feeder and 60 cycle map names, frequency of inspection, and yearly grouping. Next, the thermographers' information had to be managed so that it got entered into the WMS for tracking, repair and reporting purposes. Finally, reports and graphs of the program's progress had to be created and generated to update supervisors and managers on the current status of the program.

7. MODIFICATIONS

Even though any process may be well thought out and many options considered, there is almost always room for improvement. By obtaining feedback from many of the parties associated with or affected by the project, modifications to the process have been made to better serve those involved.

As the map packages were being created, it was discovered that many of the feeders on the list could be omitted. This was due to the fact that some of the feeders had no overhead portions to them, or that the feeder was designated using two different numbers, (one for the underground portion, and one for the overhead portion). Once these references were made on the original list, it now appears, (at this moment), that there are 525 - 4kV feeders, 1213 - 12kV feeders, and 2 - 34kV feeders that need to be scanned. (This update eliminated 316 feeders from the original workload. The new workload represents 263 4kV and 405 12kV feeders per year for a total of 668 inspections per year.)

Next, upon working with the vehicle, it became obvious that the placement of the light bar off the rear of the roof deck put the light bar in jeopardy of being broken. The light bar was therefore moved to under the roof deck for protection.

The next situation that arose in the program was several inefficiencies or problems with the camera pan & tilt units on the vehicles. The first issue was the speed with which the unit could pan and tilt. A lot of time was being lost waiting for the thermographer to pan around to look at the back side of a pole, and then pan back to continue driving down the feeder. Conversations with the manufacturer of the unit revealed that the gearing in the unit could be changed out to speed up the unit. This modification was done to each unit, (one at a time), to increase the efficiency of the scans, and keep one vehicle out scanning at all times. The second issue involved the joystick control for the pan & tilt unit. The original joystick supplied with the vehicles could only pan or tilt at one time. Again the manufacturer was contacted and new joysticks were obtained that would allow the thermographer to both pan and tilt the cameras simultaneously, again increasing the efficiency of the scan. Finally, it was discovered that as winter set in, the pan & tilt units would bog down. Once again the manufacture helped solve the problem by supplying a heater kit accessory for each unit.

Other minor vehicle modifications included: installation of 3" convex mirrors on the side mirrors, installation of an 8" backup mirror on the roof deck, installation of strain relieves on the cables at the camera box on the pan & tilt unit, and installation of a variable speed fan for the thermographer.

8. RESULTS

After 5½ months of scanning, (along with down time for modifications), the following statistics were produced:

120 4kV and 167 12kV feeders were scanned for a total of 287 feeders.

250 images were taken and processed.

244 anomalies were identified.

The 244 anomalies identified fell into the priority categories as follows:

	0 - Critical	10 - Serious	20 - Intermediate	30 – Attention
4kV	6	26	21	1
12kV	34	71	83	2
Total	40	97	104	3

The 244 anomalies identified were distributed between the following types of equipment:

	Arresters	Cap Banks	Connections	Fuses	Disconnects	Transformers	Splices	Other
4kV	0	8	22	2	6	12	4	4
12kV	2	14	75	4	12	44	16	32
Total	2	22	97	6	18	56	20	36

Finally, the average number of anomalies found per feeder were 0.45 for the 4kV system, 1.14 for the 12kV system, and 0.85 overall.

9. LESSONS LEARNED AND IMPROVEMENTS IMPLEMENTED

As the project progresses, the thermographers, associated project personnel, and affected work groups are constantly poled for ideas on how to improve the program. The following ideas have been presented, and are being considered or are in the process of being implemented. (Because most of the logistical problems were worked out in the development of the substation program, most of the improvements pertain to the operation of the vehicle.)

While the extended van version of the vehicle would work well in the suburbs and rural areas around Chicago, the vehicle sometimes proved difficult to maneuver in the alleys and tight spaces of downtown Chicago. Therefore, it is planned that if any new vehicles are built, some would be of a shorter variety for city work, while the extended models would perform suburb and rural work. In addition, a 4-wheel drive version is being considered for possible off road work on transmission lines.

A safety issue that was expressed was the performance of lap belt on the rear seat. It was felt that this belt was not adequate for preventing the thermographer from coming in contact with the equipment racks in case of a collision. Therefore, we are pursuing developing a 4 or 5 point harness system for the rear seat that would greatly reduce the thermographer's movement during a crash.

Work is currently being done with the manufacturer of the pan & tilt unit to produce a product more applicable to this application. Proposed changes include: DC pan and tilt motors for more torque, faster pan and tilt speeds, variable pan and tilt speeds based on joystick positioning, simultaneous pan and tilt functions, pan and tilt positioning readouts, built-in heater units, and a remote joystick unit.

An ergonomic issue that was brought up was the placement of the current joystick control for the pan & tilt unit. The joystick is presently located on a flexible arm that is attached to the equipment rack and extends towards the thermographer. This requires that the thermographer reach out to operate the pan & tilt unit which becomes tiring after 8 hours of operation. Therefore, flip up arm rests with an attached bracket will be installed on the rear swivel chair. Once the thermographer is seated, he will be able to fold down the arm rests and Velcro the remote joystick to the bracket. This will allow him to operate the pan & tilt unit while resting his arm on the arm rest, reducing fatigue.

Another modification being worked on is the reorganization of the equipment racks. After having used the equipment for awhile, it was determined that some of the equipment is not utilized often and can be remotely located within the vehicle. Also, the use of flat screen monitors is being explored. The goal would be to have a pair of flat screen monitors vertically mounted behind the driver, with a very short and shallow equipment rack in front of the thermographer. This would help to improve the communications between the driver and thermographer, while possibly helping to alleviate some of the nausea experienced by many of the thermographers. (This modification would be accompanied by a rework of some of the vehicles electrical system.)

Other minor possible modifications to the present vehicles, and definite changes to all additional vehicles built have been suggested. These include: installation of strobe type warning lights, installation of LED type light bars, new placement of the cable hole in the roof deck to prevent damage from the pan & tilt of the camera box, and installation of cargo nets in the rear storage area to prevent the movement of equipment.

10. CONCLUSION: PROGRAM EXPANSION

Where can the program go from here? The next phase of the program is to start scanning the overhead distribution system outside the City of Chicago. After that, possibilities include network vaults, customer transformer locations, underground manholes, and building risers.

Regardless of what facet of the program is developed next, it is important that each phase be thought out and developed carefully, and allowed to change, improve and mature with experience so that the program becomes an efficient, cost saving, and irreplaceable tool for the company. This will help to insure the highest reliability on the transmission and distribution system, while minimizing repair costs to the company. In this way, the company will be able to deliver a superior product to its customers and increase its share of the market place.