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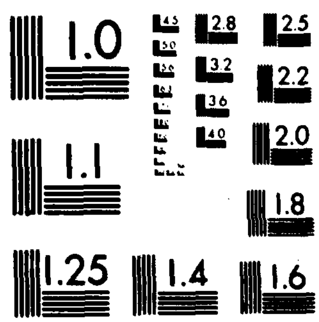

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REPORT NO. FAA-RD-80-109

VISUAL CONFIRMATION (VICON) OF TAKEOFF CLEARANCE SIGNAL SYSTEM IMPACT STUDY

C.L. Erdrich

INPUT OUTPUT COMPUTER SERVICES, INC.
400 Totten Pond Road
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NOVEMBER 1980
FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington DC 20590

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16. Abstract

A study was performed to evaluate the impact on airport capacity and voice communications of the Visual Confirmation of Takeoff Clearance (VICON) Signal System. Before-and-after test data collection and analysis were conducted at Bradley International Airport in Windsor Locks, CT. Detailed data were collected and time measurements were made for aircraft movements under various weather conditions and runway configurations. Pre- and post-VICON data were compared using a combination of statistical techniques (stratified sampling) and simulation (sequential sampling). Voice recordings were also analyzed to determine VICON's contribution to channel use.

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PREFACE

This report presents the findings of Input Output Computer Services, Inc. (IOCS) under contract to the Transportation Systems Center (TSC), Research and Special Programs Administration, U.S. Department of Transportation (Contract Number DOT-TSC-1514). The results and conclusions reported herein pertain to a before-and-after evaluation of the impact on airport operations of the Visual Confirmation of Takeoff Clearance (VICON) Signal System. The planning, data collection and analysis, and documentation were carried out by IOCS over a two-year span, with approximately sixteen months of intensive effort involved.

The progress of the study was monitored first by Franklin D. MacKenzie of TSC and then by Robert S. Yatsko and J.R. Coonan of the Office of Air/Marine Systems. Charles L. Erdrich was the IOCS project leader throughout the study; others at IOCS contributed to various parts of the analysis:

Joseph M. Morrissey - software for data reduction and analysis, supervision of pre-VICON data collection, other assistance as needed

George Hopper - supervision of post-VICON data collection

Steven Pozzi - statistical analyses of all data

Michael Smith - software for post-VICON data analysis

Daniel Mesnick and Robert Walker of IOCS also contributed to the study effort.

The author wishes to especially thank George Langdon and other Bradley Tower personnel for their outstanding assistance during all phases of the study.

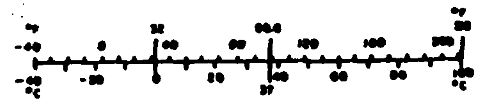
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

INTRODUCTION

In recent years there has been an increasing number of potentially serious incidents involving aircraft takeoff operations. In part, this may be due to a misunderstanding of voice instructions, leading to an increased hazard level in situations involving poor visibility, language differences at international airports, high traffic levels, or inexperienced aviators. The Visual Confirmation of Voice Takeoff Clearance (VICON) Signal System is one alternative that the Federal Aviation Administration (FAA) evaluated as part of the overall solution to airport surface traffic problems.

VICON consists of a cluster of three green lights located on the left side of the runway at each takeoff position on the airfield. Each light cluster is individually activated by a unique push-button switch on the control panel located at the local controller's position in the Air Traffic Control Tower. After being activated, the light will remain on until turned off by a timer or by passage of the departing aircraft through a microwave beam. This visual system provides an independent method of visually confirming the verbal takeoff clearance issued by the local controller.

OBJECTIVES

The FAA's overall objective in the VICON Signal System Evaluation was to determine the operational acceptability and technical feasibility of the system. This involved answering the following questions:

- Is visual confirmation of controller voice takeoff clearance feasible?

- Can VICON be integrated into the present Air Traffic Control (ATC) System?

- Does it provide an added measure of safety?

- What is VICON's impact on airport operations?

This study attempted to answer the last question by analyzing the system's impact on airport capacity and on voice communications.

METHODOLOGY

The general approach taken to achieve the study objectives was to perform before-and-after test data collection and analysis at Bradley International Airport (BDL) in Windsor Locks, Connecticut. Specifically:

- Data pertaining to aircraft operations in a variety of weather conditions, traffic levels, aircraft mixes, and runway configurations were collected before installation of VICON. This information was analyzed and related to capacity and communications via the detailed approach discussed in Section 2 of this report, and formed the baseline data for the study.

- Similar data were collected after installation of VICON under nearly identical operating conditions, analyzed in virtually the same manner, and statistically compared to pre-VICON data using a combination of sampling and simulation techniques.

- The results obtained at BDL were analyzed, and observations were made relating the measured impact to other airports.

FINDINGS

Impact on Aircraft Operations

VICON appeared to have increased runway occupancy time for departures, although the effect varied considerably by aircraft type. Based on the entire data sample, for departures cleared on the runway, the average increase in runway occupancy time was three seconds. For departures cleared on the taxiway, the effect was less consistent, with only certain aircraft types (large commercial jets and large props) showing significant increases. In addition to the measured increase being small, some of the difference may have been due to measurement error or differences in observers.

Comparisons of pre- and post-VICON data indicated an apparent drop in throughput (measure of capacity) after implementation of VICON. Based on the simulation approach (sequential sampling) applied to runway 33 in VFR conditions (Section 4.4.2), a decrease in operations per hour of approximately three percent was calculated at the 95 percent significance level (combined sample = 1,680 paired operations). Based on the weighted-average approach (stratified sampling) applied to runway configuration 6-33 in VFR conditions (Section 4.4.1), a decrease of 4.5 percent was seen at the 99 percent level (combined sample = 2,911 paired operations). These figures suggested an impact due to VICON. Since little data were available in IFR conditions, no definitive statements could be made although it is expected that the effects would be similar to VFR.

Further analysis and comparison of pre- and post-VICON data revealed some differences which may have contributed to these decreases. First, the aircraft type distributions were different. Post-VICON data contained a significantly higher percentage of heavy jets and smaller percentage of small props. Second, the post-VICON data base contained a significantly higher percentage of arrivals and lower percentage of departures. Finally, post-VICON data showed a significant increase in the frequency of both the Arrival-Arrival and Departure-Arrival pairs. These three factors in combination may have contributed to the apparent decrease in traffic flow after VICON implementation.

Impact on Voice Communications

No significant effects either on individual takeoff message strings or on local control channel use could be discovered. Cautions are advised due to lack of complete participation in the test by controllers and pilots, especially General Aviation pilots.

Impact at Other Airports

VICON's impact at other airports - particularly those with high, sustained traffic levels - would probably be more severe than at Bradley, at least initially. Those stations operating at near-saturation levels (constant queuing of arrivals and departures, frequent delays, high channel use, etc.) would be very sensitive to even small additions to the time and communication required for aircraft movements. It is probable, though, that over a longer period, experience with the system and its associated procedures would negate any short-term deleterious effects. Given the relatively simple nature of VICON signal activation by the controller and its receipt by the pilot, adoption of the signal into regular takeoff procedure should become automatic if the system is functioning reliably. Due to the low participation by system users in the test, it was difficult to assess the validity of the above statements although there were indications from controllers and pilots who participated enthusiastically in the test that VICON did become an almost automatic part of the takeoff routine.

CAUTIONS AND CONSIDERATIONS

Two major points should be made before drawing conclusions from this study.

- In a before-and-after, in-service, field evaluation of this nature, it was difficult to maintain identical operating conditions in both the before and after phases. Thus, when comparisons were made of pre- and post-VICON data, it was important to recognize and evaluate changes in other variables - aircraft mix, operations mix, procedures, etc. - that may have affected throughput, as well as effects due solely to VICON. Further, it could have been hypothesized that VICON contributed to some of these changes, and thus indirectly contributed to changes in throughput. The interactions among the factors were complex, and the decision maker should realize this in weighing the data and conclusions of this analysis.

- Use of VICON was not mandatory during the test period. If the VICON signal had been given on more than 60 percent of departures, and if pilots acknowledged receipt of the signal on a regular basis, then the conclusions of this study may have been significantly different. Since the intent of VICON was confirmation of takeoff clearance and not control, the system's impact under more stringent procedures may have been much different than the minor impact seen in this analysis.

1. INTRODUCTION

1.1 BACKGROUND

In recent years there has been an increasing number of potentially serious incidents involving aircraft takeoff operations. In part, this may be due to a misunderstanding of voice instructions, leading to an increased hazard level in situations involving poor visibility, language differences at international airports, high levels of traffic, or inexperienced aviators. The Visual Confirmation of Voice Takeoff Clearance (VICON) Signal System is one alternative that the Federal Aviation Administration (FAA) evaluated as part of the overall solution to airport surface traffic problems.

VICON consists of a cluster of three green lights located on the left side of the runway at each takeoff position on the airfield. Each light cluster is individually activated by a unique push-button switch on the control panel located at the local controller's position in the Air Traffic Control Tower. After being activated, the light will remain on until turned off by a timer or by passage of the departing aircraft through a microwave beam. The control panel also contains an override (turn off) switch. The light intensity is modulated by a rising and falling, bright-to-dim-to-bright pattern to provide identification. This visual system is intended to provide an independent method of visually confirming the verbal takeoff clearance issued by the local controller.

1.2 STUDY OBJECTIVES

The FAA's overall objective in the VICON Signal System Evaluation was to determine the operational acceptability and technical feasibility of the system. This involved answering the following questions:

- Is visual confirmation of controller voice takeoff clearance feasible?

- Can VICON be integrated into the present Air Traffic Control (ATC) System?

- Does it provide an added measure of safety?

- What is VICON's impact on airport operations?

This study attempted to answer the last question by analyzing the system's impact on airport capacity and on voice communications. (Measures of capacity and communications will be discussed later in this report as "airport throughput" and "channel use," respectively.)

1.3 STUDY APPROACH

The general approach taken to achieve the study objectives was to perform before-and-after test data collection and analysis at Bradlev International Airport (BDL) in Windsor Locks, Connecticut. Specifically:

- Data pertaining to aircraft operations in a variety of weather conditions, traffic levels, aircraft mixes, and runway configurations would be collected before installation of VICON. This information would be analyzed and related to capacity and communications via the detailed approach discussed in Section 2, and would form the baseline data for the study.

- Similar data would be collected after installation of VICON under nearly identical operating conditions, analyzed in virtually the same manner, and statistically compared to pre-VICON data.

- The results obtained at BDL would be analyzed, and observations would be made relating the measured impact to other airports.

1.4 TEST SITE

1.4.1 Test Period and Conditions

The pre-VICON data collection activity occurred during October 1978 and January 1979; the post-VICON activity took place during October/November 1979 and January/February 1980. Although planned as such, the two periods (pre- and post-) did not occur at exactly the same times of year for several reasons:

1. The VICON installation was not completed on schedule. The actual start-up did not occur until mid-October 1979.

2. The unusually consistent good weather during Fall/Winter 1979-1980 required that the post-VICON data collection periods be extended to optimize collection of bad weather data.

3. A companion study was being conducted for the National Aviation Facilities Experimental Center (NAFEC) during the post-VICON test. This limited the frequency with which tower data collection sessions could occur since the NAFEC study also required tower observers. In order to minimize intrusion into the controllers' workspace, a lengthier, overall data collection period was needed.

Further complicating the scheduling of the post-VICON test, approximately ten days before the start of the test, a tornado inflicted serious damage on the east side of the airport. Commercial power lines supplying eastern parts of two runway areas were destroyed; emergency power was used until commercial service was restored about three weeks later. General aviation aircraft parked on the east ramp were all severely damaged or destroyed. Also, the rotating beacon was torn loose.

1.4.2 Description of Bradley

1.4.2.1 The Airport - The overall arrangement of the airfield is shown in Figure 1-1. The primary runway is runway 06/24, which is 9,502' long by 220' wide. The control tower is located above the main passenger terminal building; it should be noted that the departure end of runway 06 is about 3/8 mile from the tower, and both ends of runway 15/33 are more than 1/2 mile away. This is shown graphically in Figure 1-1; the distance circles centered on the tower are in 1/4 mile increments. Thus, it is evident that when the visibility drops below 1/2 mile, the tower can see only limited portions of the runways.

1.4.2.2 The VICON Installation - The VICON System installed at Bradley consists of 21 light clusters, a control panel in the control tower, and the necessary relays, dimmers, timers, cables, and related components. The installation is shown schematically in Figure 1-2. One light cluster (Figure 1-3) is associated with each of the 21 takeoff locations. These are shown as X's in the figure. The lights are located on the left side of the runway in line with the runway edge lights, with the center of the light about nine inches above the ground.

The control panel is the only element of VICON located in the control tower. The panel is placed at the local controller's position adjacent to other control knobs and buttons regularly used by the controller. There is a specific

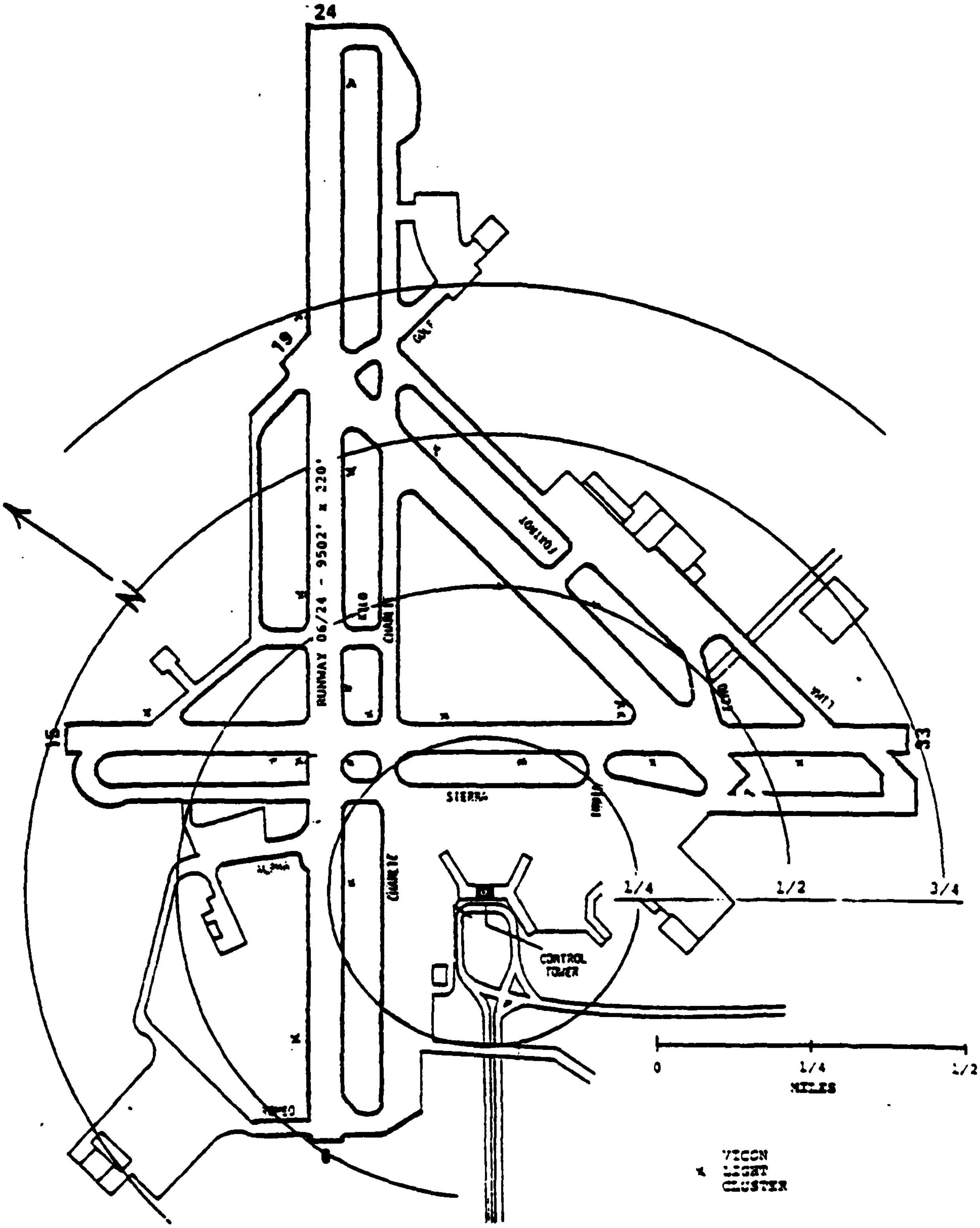

FIGURE 1-1. BRADLEY INTERNATIONAL AIRPORT

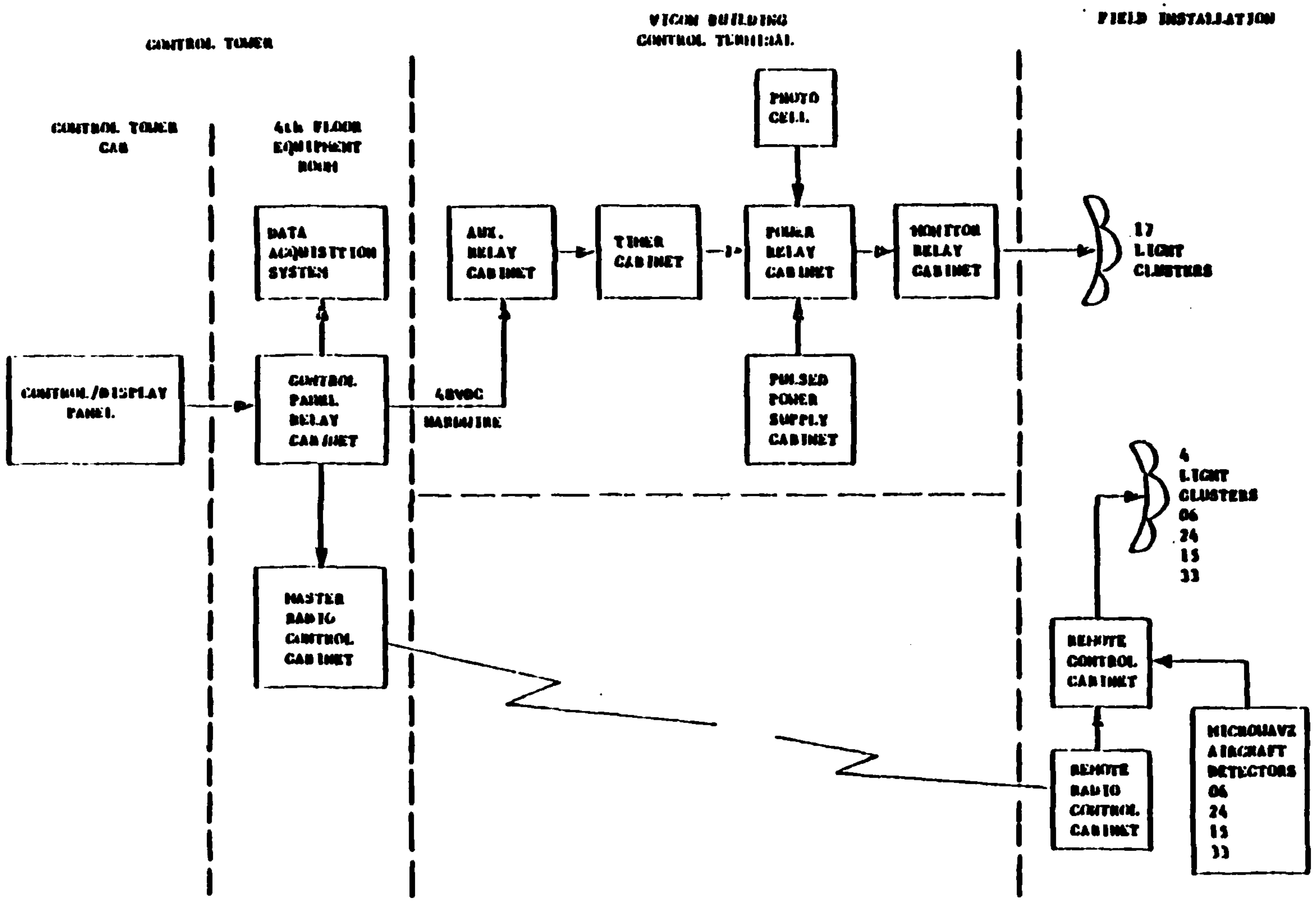

FIGURE 1-2. SCHEMATIC DIAGRAM OF VICON INSTALLATION AT BRADLEY

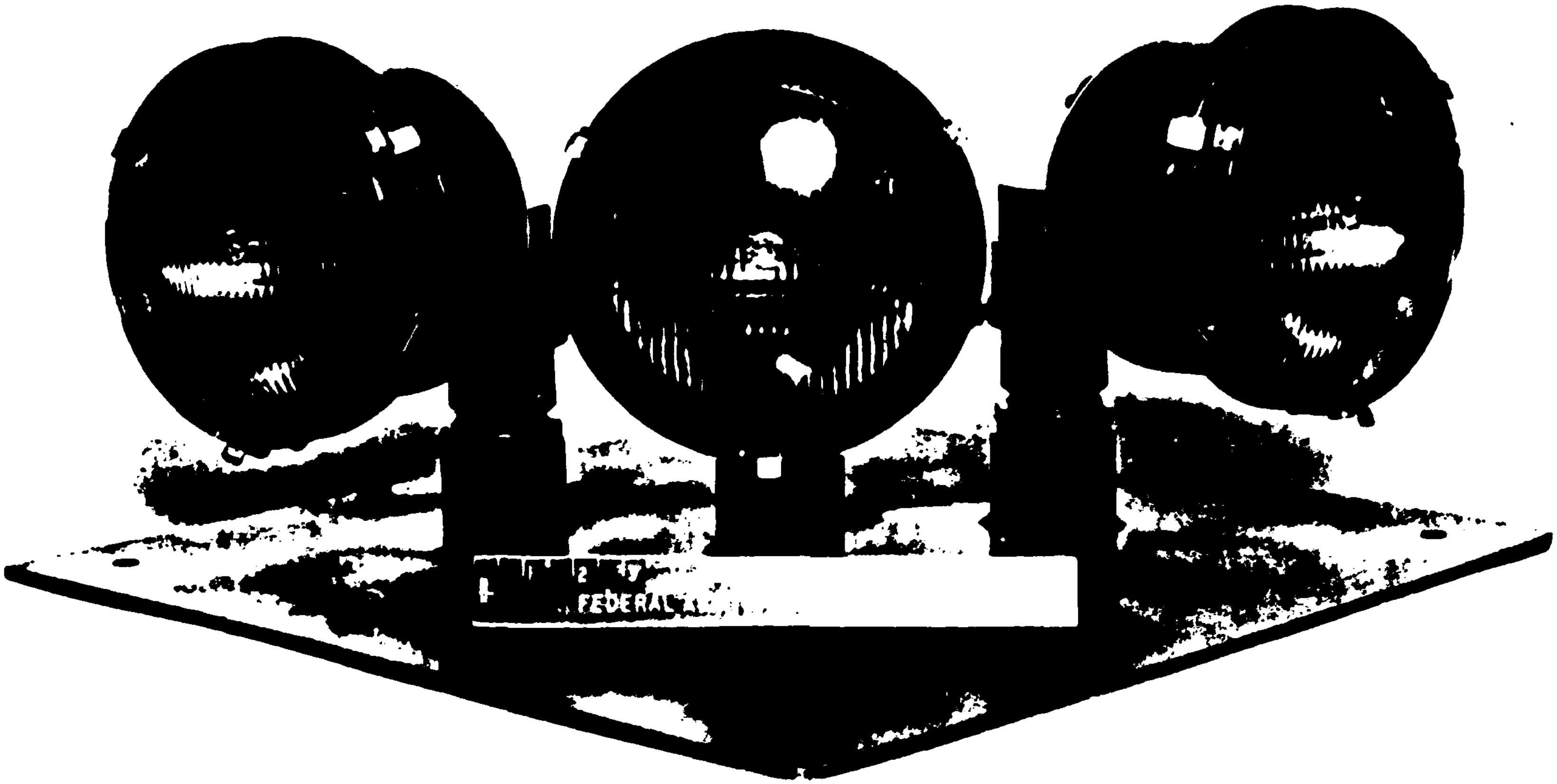

FIGURE 1-3. VICON LIGHT CLUSTER

button on the panel for each of the 21 takeoff/light cluster positions. A runway master button controls all of the individual buttons associated with a given runway. That is, the Runway 33 button controls the buttons for takeoff locations at the runway end and at intersections Lima, Echo, India and Charlie. When the Runway 33 button is pushed, amber lights are illuminated in the five activated location buttons. When one of these buttons is pushed, the amber light in that specific button changes to green and the light cluster is turned on. When the light cluster is turned off, the button light switches back to amber. The panel also contains an override (cancel) button and lights for night use.

The green cluster lights are turned off automatically. Microwave beams are installed 1,000 feet from the end of runways 06, 15, 24, and 33. When an aircraft breaks the beam on its takeoff roll, the green light is turned off. The other 17 takeoff position lights are turned off by timers. The remainder of the equipment is installed in a cement block building located near the center of the airfield.

1.5 REPORT ORGANIZATION

The remainder of this report is organized as follows:

- Section 2 - an overview of data analysis methods, and descriptions of the selected techniques
- Section 3 - data collection planning and results
- Section 4 - data reduction and analysis results for system's impact on airport capacity at BDL, including detailed statistical analysis; impact on communications; impacts at other airports

- Section 5 - overall study conclusions and other considerations.

2. DATA ANALYSIS METHODOLOGY

2.1 CONSIDERATIONS IN SELECTING AN ANALYSIS TECHNIQUE

A number of factors were taken into account in selecting the technique used to measure VICON's impact at Bradley.

1. The method chosen should be sensitive to the random character of airport operations. In general, airport (aircraft) operations are random in nature; that is, those variables that may impact the operation of aircraft into and out of airports are subject to fluctuations which are not easily or accurately predicted. For instance, weather - wind direction and speed, visibility, and precipitation - directly affects runway configuration (runways in use at any given time), aircraft type mix, and traffic level which, in turn, affect traffic flow. In attempting to sift out the impact of VICON from among the many factors which can affect traffic flow, it was important to choose a method which would make it possible to compare "like" quantities before and after system implementation. Thus, if the method allowed comparison of pre- and post-VICON operations under nearly identical operating conditions (the same weather, runway configuration, aircraft type distribution, month, day of the week, etc.), the specific effect of VICON could be more readily calculated and the effects of random fluctuations more evenly smoothed out.

2. The method chosen should be applicable or adaptable to any airport, even those stations not normally operating at or near capacity (i.e., at traffic saturation such that queuing and delay occur).

Bradley Airport is a medium volume airfield with a mix of scheduled air carrier, air taxi, cargo, general aviation, and military aircraft. It is rare to experience delay or queuing of arrivals or departures due to high traffic levels or to other aspects of air or ground operations. Thus, in order to gauge VICON's impact on capacity, the technique should allow the creation (or simulation) of congested, or saturated, traffic conditions. In this way, the impact of the system can be determined for those critical situations in which its value to the National Airspace System is expected to be most beneficial.

3. The method chosen should be based on measurable quantities, be relatively easy to apply, and yield accurate comparisons of pre- and post-VICON data. In an experiment of this nature, a before-and-after study, data collection should be organized so as to minimize distortion and bias in the results and maximize the likelihood of collecting consistent data in both the before and after phases.

4. The method chosen should provide the ability to show statistical validity or confidence in the results. In the development of any model, whether it be a simulation, queuing, or deterministic technique, consideration should be given to being able to show that the results are valid with a specific degree of certainty. Data collection schedules and quantities should be developed with consideration to adequate sample sizes to meet this level of certainty.

2.2 SELECTED TECHNIQUE - IMPACT ON AIRPORT CAPACITY

From the above considerations, a technique was chosen which combined a comparative statistical analysis of pre- and post-installation data with a method to simulate the random character of airport operations. This technique consisted of the following general steps (defined in greater detail in Sections 3, 4 and 5):

1. Certain time segments associated with consecutive aircraft operations are observed and measured. Data are collected covering the scope of various runway use configurations and weather conditions. For arrivals, the aircraft's time over threshold and time exiting runway are required. For departures, time measurements for verbal clearance, entering runway, beginning roll, and lift-off are needed. For each operation, runway, aircraft type, departure queue length, and location at which the aircraft entered the runway are also recorded.

2. Distributions of runway events for specific sets of operating conditions are constructed as shown in the example given in Table 2-1. For this illustration, given the number of aircraft type classes (3) and the types of operations (2-arrival or departure), 36 different types of consecutive, paired operations are possible. Thus, in line 1, the paired operation is a heavy departing aircraft followed by a small departing aircraft. Line 6 represents a heavy departure followed by a large arrival, and so on. For a given set of operating conditions such as VFR weather, runway configuration 6-33, weekday-evening peak period, etc., a frequency of occurrence for each paired operation is calculated, based on the data sample collected for this set of conditions. Mean

TABLE 2-1. DISTRIBUTION OF RUNWAY EVENTS

Given: Weather Conditions, runway use configuration, time period of data collection, etc.

	TYPE OF AIRCRAFT		TYPE OF OPERATION		FREQUENCY OF OCCURRENCE	MEAN RUNWAY OCCUPANCY TIME		MINIMUM INTER-OPERATION TIME	PAIRED TOTAL OPERATION TIME
	LEAD	FOLLOW	LEAD	FOLLOW		LEAD (1)	FOLLOW (2)	(3)	(1) + (2) + (3)
1	H	S	D	D					
2	H	S	D	A					
3	H	S	A	D					
4	H	S	A	A					
5	H	L	D	D					
6	H	L	D	A					
7	H	L	A	D					
8	H	L	A	A					
9	H	H	D	D					
10	H	H	D	A					
↓	↓	↓	↓	↓					
35	S	H	A	D					
36	S	H	A	A					

H = Heavy
L = Large
S = Small

A = Arrival
D = Departure

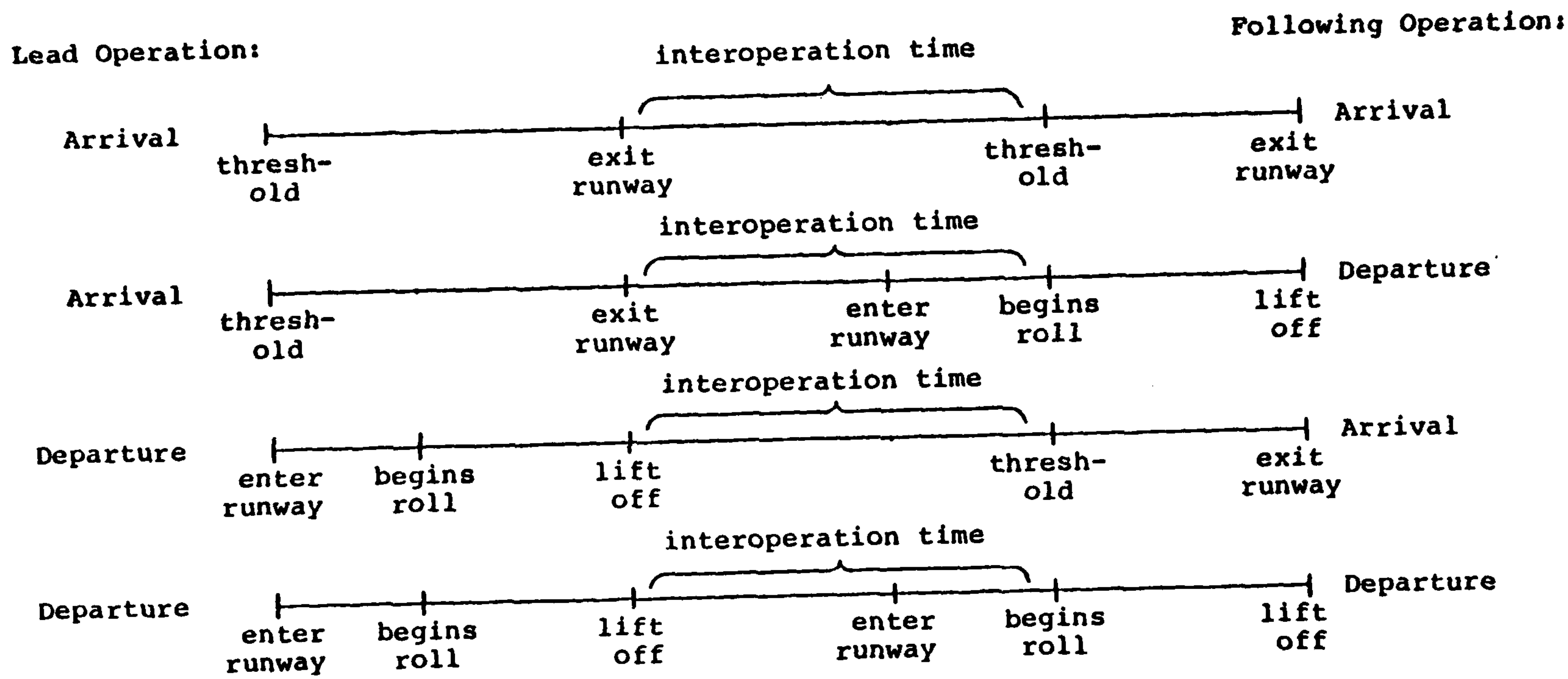

FIGURE 2-1. TIME SEGMENTS - PAIRED OPERATIONS

values of runway occupancy time are also calculated and inserted in the table. Given the type of paired operation, a minimum interoperation time which is based on actual observation or ATC rules and airport practices or an observed interoperation time is inserted in the table. The time segments of interest are diagrammed in Figure 2-1.

3. A random sample, based on the frequency of occurrence for each paired operation, is drawn from this "tabular" data base. As each paired operation is drawn, the paired total operation time is accumulated until a specified total time (such as five hours) is reached. Then, the theoretical capacity attainable for this set of operating conditions is the average number of single operations per hour over that five hour span. This number is called the "airport throughput." The simulation is repeated until the throughput (average value) can be stated with a specified level of certainty. This technique artificially creates a "saturated" condition at the airport by manufacturing a capacity measure.

4. By comparing measures of throughput before and after installation of VICON, under various sets of operating conditions, conclusions may be drawn as to the system's impact on traffic flow. Statistical tests are then performed to determine whether the before-and-after differences are significant.

To strengthen the validity of the analysis, other comparisons were made of the pre- and post-VICON data. Runway occupancy time, stratified by aircraft type and operation type, was compared to determine VICON's impact on this component of aircraft operations. Also, the distribution of paired operation types for various runway configurations was compared to determine if VICON altered the sequence of operations at the airport and, in this manner, contributed to delay. The distributions of aircraft type and operation type were also compared to test whether the pre- and post-VICON data bases represented similar operating conditions.

2.3 SELECTED TECHNIQUE - IMPACT ON VOICE COMMUNICATIONS

VICON was hypothesized to affect voice communications in the following ways:

- Controllers were expected to have to explain or clarify VICON use, at least until familiarity and acceptance among the users was achieved.
- Pilot acknowledgement of the signal might have added to local control channel use.
- The system might have confused inexperienced pilots, resulting in increased voice communications.

In order to measure the effect of VICON on channel use, recordings were made of all local controller-pilot communication during the test period. These recordings were analyzed to determine VICON's incremental effect on takeoff clearance messages and VICON's overall impact on channel use.

3. DATA COLLECTION

3.1 OBJECTIVES

The objectives of field data collection were:

- to measure certain time segments associated with runway operations and the issuing of takeoff clearances. These measurements would become the basis for calculating runway occupancy time, interoperation time, and other time segments which might be affected by VICON, and would form the inputs to the simulation of airport throughout.

- to record data which could be used to generate frequency distributions of important variables (e.g., aircraft mix, paired operation mix).

- to record changes in weather conditions, runway configuration, runway condition, and special events which might affect the determination of VICON's impact.

- to generate controller voice recordings of all data collection periods, to be used as back-up material to observed data and as a means of estimating VICON's impact on controller-pilot communications.

Similar data were to be collected in two phases: previous to the system's implementation at Bradley in order to establish a standard for airport operations from which the effects of VICON could be measured, and then again after the system was in place. The Fall/Winter seasons (1978-79 and 1979-80) were selected in order to maximize the probability of poor weather and snow.

3.2 DATA COLLECTION PLAN

3.2.1 Background

The initial plan called for three basic positions for data collection personnel: tower position, runway threshold, and reference position, near the lift-off point for most aircraft. Each was responsible for different time measurements, the separate observations having to be combined to resurrect the true sequence of operations. This method was chosen originally to maximize the accuracy of the measurements. For instance, it was felt that an observer stationed in a direct line with the runway threshold could obtain a more precise measurement of time over the runway end than an observer in the tower. For the first month of data collection (October 1978) these separate positions were used. Also during this period, comparisons were made of the same measurements taken from both the tower and from various positions on the airfield. These comparisons demonstrated that accurate measurements, within acceptable limits of error for this study, could be made from the tower and, subsequently, data collection was carried out entirely from the tower location.

3.2.2 Data Collection Shift Organization

The data collection team normally consisted of three people: a team supervisor and two data collectors (research assistants). Each was equipped with at least one digital stopwatch (as many as five were available to the team), a portable radio tuned to the local control frequency, hand-held binoculars, and a clipboard with a supply of data forms. Responsibilities were usually assigned according to traffic level. For instance, in the case of dual runway use (6 and 33), one person would be responsible for monitoring operations on 6, one for operations on 33, and the third for making additional time measurements and obtaining other data (aircraft identification or type, for example) as needed. In most cases, one observer made the actual written record of all measurements in order to minimize the need for later combining data from two or more separate forms.

Data collection shifts were six hours long, and started either at 7:00 A.M., 1:00 P.M., 2:00 P.M., or 3:00 P.M. This scheduling maximized the collection of peak traffic data and provided adequate night-time data collection. Occasional breaks were provided to tower observers by the team supervisor. At no time were there fewer than two observers in the tower.

Time measurements and recording of other pertinent data were carried out mainly from the rear portion of the BDL Tower Cab. This location afforded unobstructed views of all runway thresholds and allowed the research team to move freely about. As the controllers became familiar with the operation, the data collection team found it possible to station one observer near the local controller position. As a result, viewing of the radar BRITE display made it possible to keep more closely abreast of the sequence of operations. In addition, weather instrumentation could be scanned more easily.

3.2.3 Data Collected

As each data collection shift began, a cover sheet (Figure 3-1) was prepared. This summary of basic operations data was updated by the team supervisor as required during the course of a shift. In order to facilitate the eventual processing of a large data base, the basic data collection form was designed in the format of a computer coding sheet. A number of changes were made to the form as data collection experience grew; it is shown in Figure 3-2 in its final format.

The following data elements were recorded for every operation observed:

DATE OF SURVEY: RECORDER:

DATA SET NUMBER: (assign consecutively)

BEGIN TIME:

END TIME:

WEATHER INFORMATION: (record time of observation and any major changes)

VISIBILITY:

CEILING:

TEMPERATURE:

WIND DIRECTION - SPEED:

RUNWAY USE: (record time of any changes)

ARRIVALS:

DEPARTURES:

RUNWAY CONDITION:

COMMENTS:

FIGURE 3-1. DATA COLLECTION COVER SHEET

DATE: ____________________ __________ WEATHER: __________ ______________

OBSERVATION PD: FROM: _____Z TO: _____Z RUNWAY: ________ TRAFFIC LEVEL: ______

OBSERVER(S): ______________________ TRAFFIC MIX: _________

	ACFT I.D.	ACFT TYPE	RWY	OPER	TIME OVER THRSHLD	TIME EXIT RWY	OPER	TIME T.O. CLRNCE ISSUED	LOC CLR ISS	TIME ENTERS RWY	LOC ENT RWY	TIME BEGIN ROLL	TIME LIFT OFF	COMMENTS
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														

FIGURE 3-2. OPERATIONS LOG

Item	Description	No. of Columns
Aircraft identification number (ACFT I.D.)	For commercial aircraft: airline code and flight number (e.g., TW155). For general aviation: identification used by pilot in first transmission with Local Control (e.g., B655G)	5
Aircraft type (ACFT TYPE)	Small prop = SPRP Medium/large prop = LPRP Small jet = SJET Medium jet = MJET Large jet = LJET Heavy jet = HJET	4
Runway (RWY)	01, 06, 15, 19, 24, or 33	2
Operation (OPER)	Arrival = A Departure = D Missed approach = M Low approach = L Touch-and-go = T Unknown = X	1
Time that aircraft is over threshold (TIME OVER THRSHOLD)	Time that aircraft nose passes over runway threshold marker (six digits recorded from digital stopwatch: 042754 is read as 4:27.54 - minutes, seconds, and hundredths)	
Time that aircraft exits runway (TIME EXIT RWY)	Time that the aircraft's tail is clear of the runway space	6
Departure queue length (QUE)	Number of aircraft awaiting departure clearance after each recorded operation	2
Time that takeoff clearance is issued (TIME T/O CLRNCE ISSUED)	Time that takeoff clearance is issued by Local Controller	6
Location clearance is issued (LOC CLR ISS)	Location at which clearance is issued (R = runway, T = taxiway)	1
Time that aircraft enters runway (TIME ENTERS RWY)	Time that aircraft's nose enters runway space	6

Item	Description	No. of Columns
Location aircraft enters runway (LOC ENT RWY)	Location, if not the runway threshold, that departing aircraft enters the runway, given as a letter designation of taxiway (S = SIERRA) or number designation of runway (01, 19)	2
Time that aircraft begins roll (TIME BEGIN ROLL)	Time that aircraft begins rolling after initial pause (full stop) after entering runway; if no pause, then TIME BEGIN ROLL = TIME ENTERS RWY	6
Time that aircraft lifts off (TIME LIFT OFF)	Time that all wheels lift off runway surface	6

The time measurements were made using digital stopwatches (CRONUS Model 3-S®) which recorded cumulative (elapsed) time up to 59 hours, 59 minutes, and 99/100 seconds (59:59.99), and then automatically recycled back to zero. Software developed for data reduction and analysis purposes inserted the appropriate hour to maintain the real-time nature of the data.

As can be seen from the Operations Log, the data gave a complete and detailed record of operations at Bradley from which any effects of VICON could be discerned.

3.2.4 Sampling Analysis and Scheduling

Sampling Analysis

In order to estimate the number of observations expected in each of the paired operation classes, the following approach was used:

1. Using Air Carrier Schedules and a sample of facility traffic counts at Bradley, the aircraft mix was

estimated as heavy (wide body jets) - 6.3 percent, large (other commercial jets such as 727 and DC9) - 29.6 percent, and small (propeller craft and smaller jets) - 64.1 percent. Also, it was assumed that arrivals and departures were evenly divided. Then, the expected frequency of a paired operation such as a large arrival followed by a small departing aircraft was estimated as follows: expected frequency of L-S-A-D = (.296) (.641) (.5) (.5) = .0474. Similarly, the frequencies of other paired operations were calculated.

2. From ceiling/visibility data, wind rose analysis, and discussions with Bradley ATC Personnel, the expected number of total observations for specific sets of operating conditions was estimated. The results of such an analysis were:

VFR Conditions			IFR Conditions		
Runway Use	Pct. of Total	Expected No.* of Observations	Runway Use	Pct. of Total	Expected No.* of Observations
6-33	43%	1591	6-33	65%	520
24-33	24%	888	15-24	30%	240
15-24	23%	851			
Other	10%	370	Other	5%	40
Total	100%	3700	Total	100%	800

*Based on 161 hours of data collection at 28 operations per hour in October and January and the following weather distribution:

October - 84.1% VFR, 15.9% IFR
January - 80.7% VFR, 19.3% IFR

3. By multiplying the expected frequency of occurrence by the expected number of observations, the expected sample size for a paired operation may be estimated; as an example, the results shown in Table 3-1 for VFR conditions and runway use 6-33 were obtained.

TABLE 3-1. EXPECTED SAMPLE SIZE - RUNWAY CONFIGURATION 6-33 AND VFR CONDITIONS

Lead Aircraft	Following Aircraft	Lead Operation	Following Operation	Expctd. Frqncy.	Expctd. Sample Size*
H	S	D	D	.0101	16
H	S	D	A	↓	↓
H	S	A	D	↓	↓
H	S	A	A	↓	↓
H	L			.0047	8
H	L	Same		↓	↓
H	L			↓	↓
H	L			↓	↓
H	H			.0010	2
H	H	Same		↓	↓
H	H			↓	↓
H	H			↓	↓
L	S			.0474	76
L	S	Same		↓	↓
L	S			↓	↓
L	S			↓	↓
L	L			.0219	35
L	L	Same		↓	↓
L	L			↓	↓
L	L			↓	↓
L	H			.0047	8
L	H	Same		↓	↓
L	H			↓	↓
L	H			↓	↓
S	S			.1027	164
S	S	Same		↓	↓
S	S			↓	↓
S	S			↓	↓
S	L			.0474	76
S	L	Same		↓	↓
S	L			↓	↓
S	L			↓	↓
S	H			.0101	16
S	H	Same		↓	↓
S	H			↓	↓
S	H			↓	↓

*Fractions of an observation are rounded upward

From these figures, it was apparent that sample size for paired operations involving heavy aircraft would be small, especially for the heavy-heavy pair. By using the simulation approach which is based on the frequency of observation, a larger sample could be created from a smaller amount of data. By performing the simulation repeatedly for a certain runway configuration and weather combination, the measures of throughput would be based on a larger data sample and, hence, more definitive statements could be made about VICON's impact. These ideas are expanded in Section 4.

Scheduling

The initial schedule called for 12-14 days of data collection, 5-3/4 hours per day, for October 1978 and January 1979. A similar schedule was developed for October/November 1979 and January/February 1980. Table 3-2 shows the final scheduling for all data collection periods. This scheduling gave the proper mix of weekday vs. weekend traffic over various time periods and traffic levels.

The 1979-80 schedule was extended to increase the IFR (bad weather) data base. At all times during the course of data collection, the team supervisor was prepared to reschedule a shift in order to obtain more IFR data. Unfortunately, the consistent good weather during both the pre- and post-VICON phases limited the size of the IFR data base.

TABLE 3-2. DATA COLLECTION SCHEDULE BY MONTH

October 1978	January 1979	Oct/Nov 1979	Jan/Feb 1980
10/6	1/10	10/25	1/3
10/7	1/11	10/26	1/4
10/11	1/12	10/30	1/5
10/12	1/16	10/31	1/9
10/13	1/17	11/4	1/10
10/15	1/18	11/7	1/11
10/16	1/19	11/8	1/13
10/17	1/22	11/14	1/14
10/18	1/23	11/15	1/21
10/24	1/24	11/19	1/23
10/25	1/25	11/20	1/25
10/26	1/26	11/26	1/28
10/27		11/27	1/29
			1/31
			2/16
			2/22

3.2.5 Results of Data Collection

Aircraft Movements

Table 3-3 shows the number of observations (of raw data) for both the pre- and post-VICON phases, by weather condition and runway configuration. As can be seen from this table, IFR data accounted for 12 percent and 9.4 percent of the total observations in the pre- and post-VICON phases, respectively. Runway configuration 6-33 accounted for the highest percentage of operations in each phase, an average of 46 percent of the total operations. Operation on 33 alone was the next highest, an average of 25 percent of the total data collected. Because of the adequate sample obtained in each case, these two

TABLE 3-3. SUMMARY OF PRE- AND POST-VICON DATA BY RUNWAY CONFIGURATION AND WEATHER

RUNWAY CONFIG-URATION	NUMBER OF VFR OBSERVATIONS		NUMBER OF IFR OBSERVATIONS		TOTAL OBSERVATIONS		PERCENTAGE OF TOTAL	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST
6	31	108	62	217	93	325	2.5	8.5
6-33	1,460	1,670	264	44	1,724	1,714	47.2	44.7
33	1,071	723	4	24	1,075	747	29.5	19.5
33-24	283	311	-	-	283	311	7.8	8.1
24-15	365	599	109	76	474	675	13.0	17.6
other	-	61	-	-	-	61	-	1.6
Totals	3,210	3,472	439	361	3,649	3,833	100.0	100.0

configurations would become the basis for conclusions drawn about VICON's impact on traffic flow in VFR conditions. Due to lack of sufficient IFR data, general conclusions about VICON's effect on runway occupancy time and traffic flow would be made based on the entire data base (all runways).

<u>Weather Data</u>

Hourly weather observations for each data collection period were obtained from the National Weather Service office at Bradley. An example of this data is shown in Table 3-4. For those days with IFR conditions, these hourly observations were used to estimate when bad weather conditions started and ended.

Facility Traffic Forms

Hourly traffic counts, on Form 7230-12, were collected at the end of a month's data collection. These counts were used to monitor the traffic level at BDL as a cross-check to the operations log.

Communications Tapes

Voice-actuated tape recordings were made of local controller-pilot communications during all data collection periods.

TABLE 3-4. EXAMPLES OF HOURLY WEATHER DATA

Date	Condition(s)	Hour of Observation (GMT)	Ceiling	Visibility
10/6/78	IFR/VFR	1654	M7 BKN,10 OVC	10
		1755	M7 BKN, 9 OVC	10
		1854	M7 OVC	8
		1954	M7 OVC	7
		2055	M8 BKN,13 OVC	7
		2155	M8 BKN,11 OVC	5 F
		2255	8 SCT,M11 OVC	5 F
10/12/78	IFR	1055	M7 BKN,45 OVC	1-1/2 F
		1155	M6 BKN, 9 OVC	1-1/2 F
		1255	M6 BKN, 9 OVC	1-1/2 F
		1355	M6 OVC	1-1/2 F
		1455	M5 OVC	1-1/2 F
		1555	M7 OVC	1-1/2 F
		1655	8 SCT,M11 OVC	3 F
10/13/78	IFR/VFR	1055	W3X	1/8 F
		1155	W4X	3/8 F
		1223	M3 OVC	5/8 F
		1255	M4 OVC	5/8 F
		1330	M6 OVC	5/8 F
		1355	M6 BKN,8 OVC	2 F
		1455	M10 BKN,14 OVC	3 F
		1555	M13 BKN,19 OVC	7
		1655	25 SCT,110 SCT	8
1/25/79	IFR/VFR	1556	5 SCT,M15 OVC	5 RF
		1654	5 SCT,M16 OVC	5 R-F
		1755	7 SCT,M16 OVC	5 R-F
		1853	7 SCT,M15 OVC	7 S-
	(Special report)	1936	5 SCT,M15 OVC	3 R-S-
		1953	5 SCT,M15 OVC	2-1/2 R-S
	(Special report)	2030	M5 BKN,15 OVC	2-1/2 R-S
		2053	M5 BKN,15 OVC	2-1/2 R-S
		2154	5 SCT,M15 OVC	2-1/2 L-F

Key: M7 BKN = measured 700' broken
10 OVC = 1,000' overcast
8 SCT = 800' scattered
W3X = 300' ceiling (obscured)
1/8 F = 1/8 mile in fog
2-1/2 R-S = 2-1/2 mile, light rain & snow

4. DATA REDUCTION AND ANALYSIS

4.1 METHOD OF DATA REDUCTION

At end of each month's data collection, the completed Operations Logs for each data collection period were reviewed by IOCS analysts for completeness, accuracy, legibility, and special comments and occurrences. The data records were then submitted to TSC, keypunched to cards, verified, and read into a disk file. The DEC-10 computer at TSC was used to create the data base and perform certain analyses. All software was written in FORTRAN. (In some of the pre-VICON analyses, the Statistical Package for the Social Sciences (SPSS) was used.)

4.2 CREATION OF PRE- AND POST-VICON DATA FILES

The basic steps taken to create the data files of aircraft operations observed at BDL were:

1. Assemble raw data files of pre- and post-VICON observations in a format identical to the Operations Log.

2. Translate all time measurements to cumulative, elapsed seconds and sequence records appropriately, if not already in sequence. Assign an observation number to each record.

3. Scan data file for "bad" records (missing data, duplicates, incorrect format, etc.). This was done both manually and via computer program, if appropriate.

4. Assemble clean, sequenced data file and insert, for each record, weather and runway configuration identifiers.

5. Again, and periodically throughout this procedure, manually scan data file for bad or out-of-sequence records.

6. Compute runway occupancy time, in seconds, for each record. Insert -99.99 if any computation could not be made due to partial missing data.

7. Create paired operation data base. Each record represented two consecutive operations (leading and following aircraft) and included those time measurements needed to compute both runway occupancy times and the interoperation time. The format of this data base is shown in Figure 4-1.

8. Again, manually scan data file for bad records.

9. Disaggregate paired operation data base by runway configuration and weather condition. In other words, create separate data sets for 33-VFR, 33-IFR, 6-33-VFR, 6-33-IFR, etc.

10. Further disaggregate data sets according to paired operation types (A-A, A-DR, A-DT, DR-A, etc.) and calculate statistics necessary to perform simulation of airport throughput. "A" represented an arrival; "DR", a departure cleared on the runway; and "DT", a departure cleared on the taxiway. An example of the output from this step is shown in Figure 4-2.

These steps resulted in nine separate paired operation data sets for each runway configuration-weather combination, for both pre- and post-VICON data. These data sets became the basic input to the simulation of airport throughput, explained in Section 4.4.

field number	description		field number	description	
1	runway	lead operation	11	exit runway time - lead	
2	operation		12	lift-off time - lead	
3	aircraft type		13	over threshold - follow	
4	loc. of clearance		14	enter runway - follow	
5	record no.		15	begin roll - follow	
6	record no.	following operation	16-17	runway occupancy time - lead + follow	
7	runway		18	interoperation time	
8	operation		19-20	runway configuration	lead + follow
9	aircraft type		21-22	queue length	
10	loc. of clearance		23-24	weather conditions	

1-5	6-10	11	12	13	14	15	16-17		18	19-20		21-22	23-24
33A1 3536	-3537 33D2A	5148.76	0.00	0.00	5123.75	5158.63	55.62	62.27	9.87	633-	633	0-	0V-V
33D2R3537	-3538 6A6	0.00	5106.02	5099.51	0.00	0.00	62.27	43.60	308.49	633-	633	0-	0V-V
6AF 3538	-3539 6AF	5538.11	0.00	5612.52	0.00	0.00	43.60	61.38	74.41	633-	633	0-	0V-V
6A6 3539	-3540 33D8R	5573.90	0.00	0.00	5509.87	5640.22	61.38	66.06	-33.69	633-	633	0-	0V-V
33D8R3540	-3541 6AF	0.00	5655.03	5732.04	0.00	0.00	66.06	63.58	76.11	633-	633	0-	0V-V
6A6 3541	-3542 33D1R	5795.62	0.00	0.00	5709.55	5786.37	63.59	94.47	-9.25	633-	633	0-	0V-V
33D1R3542	-3543 33D6T	0.00	5804.02	0.00	5856.74	5856.74	94.47	59.29	52.72	633-	633	0-	0V-V
33D6T3543	-3544 6A[illegible]	0.00	5903.73	6353.60	0.00	0.00	59.29	52.09	450.87	633-	633	0-	0V-V
6A5 3544	-3545 33D1T	6405.69	0.00	0.00	6456.53	6456.53	52.09	51.03	50.84	633-	633	0-	0V-V
33D1T3545	-3546 33A1	0.00	6406.93	6527.20	0.00	0.00	51.03	51.24	40.27	633-	633	0-	0V-V
33A1 3546	-3547 33A1	6578.44	0.00	6969.20	0.00	0.00	51.24	45.60	390.76	633-	633	0-	0V-V
33A1 3547	-3548 6D1R	7019.80	0.00	0.00	6944.89	6997.16	45.60	64.60	-17.64	633-	633	0-	0V-V
6D1R3548	-3549 33A1	0.00	7009.49	7100.57	0.00	0.00	64.60	39.45	91.08	633-	633	0-	0V-V
33A1 3549	-3550 6D5T	7190.02	0.00	0.00	7438.32	7438.32	39.45	78.56	298.30	633-	633	0-	0V-V
6D5T3550	-3551 33D5T	0.00	7470.06	0.00	7558.17	7559.17	78.56	65.90	80.11	633-	633	0-	1V-V
33D5T3551	-3552 33D1T	0.00	7602.93	0.00	7711.41	7711.41	65.90	33.23	108.98	633-	633	1-	0V-V
33D1T3552	-3553 33A1	0.01	7732.32	7708.11	0.00	0.00	33.23	60.04	55.81	633-	633	0-	0V-V
33A1 3553	-3554 33A1	7899.17	0.00	7936.59	0.00	0.00	60.04	21.32	80.91	633-	633	0-	0V-V
33A1 3554	-3555 33A2	7957.90	0.00	8028.55	0.00	0.00	21.32	-99.90	70.65	633-	633	0-	0V-V
33A1 3556	-3557 33A5	99.99	0.00	8174.50	0.00	0.00	-99.90	61.58	-99.90	633-	633	0-	0V-V
33A5 3557	-3558 33A1	8236.08	0.00	8366.11	0.00	0.00	61.58	38.45	130.03	633-	633	0-	0V-V
33A1 3558	-3559 33A0	8404.56	0.00	8470.45	0.00	0.00	38.45	32.50	65.89	633-	633	0-	0V-V
33A0 3559	-3560 6D5T	8502.55	0.00	0.00	8491.20	8491.20	32.50	42.02	-11.67	633-	633	0-	0V-V
6D5T3560	-3561 33D1T	0.00	8525.87	0.00	8586.57	8586.57	42.02	26.11	59.70	633-	633	0-	0V-V
33D1T3561	-3562 33A1	0.00	8602.71	8601.20	0.00	0.00	26.11	-99.90	80.49	633-	633	0-	0V-V
33A1 3562	-3563 6D1T	99.99	0.00	0.00	8730.75	8730.75	-99.90	32.18	-99.90	633-	633	0-	0V-V
6D1T3563	-3564 33A1	0.00	8756.30	8795.65	0.00	0.00	32.18	-99.90	38.35	633-	633	0-	0V-V
33A4 3565	-3566 33D1R	8845.17	0.00	0.00	8824.04	8840.09	45.49	45.90	1.67	633-	633	0-	0V-V
33D1R3566	-3567 33A4	0.00	8870.03	8887.41	0.00	0.00	45.90	43.31	16.58	633-	633	0-	0V-V
33A4 3567	-3568 33A1	8910.72	0.00	8991.37	0.00	0.00	43.31	53.73	60.65	633-	633	0-	0V-V
33A4 3568	-3569 33A1	9045.10	0.00	9068.30	0.00	0.00	53.73	40.05	23.20	633-	633	0-	0V-V
33A1 3569	-3570 6DC4	9108.25	0.00	0.00	9007.72	9126.06	40.05	147.39	17.71	633-	633	0-	0V-V

FIGURE 4-1. EXCERPT FROM PAIRED OPERATION DATA BASE

(index=lead and follow aircraft types)

IN-DEX	TOTL OBS	TOTL MSNG	TOTL VALID	SUM-TIO	SUM OF SQUARES	MINIMUM	MAXIMUM	MEAN	VARIANCE	STD DEV	PRQCT	MEAN-ID	MEAN-FOI	paired tot. oper. time TTL BY MIN	TTL BY MEAN
11	26.	0.	26.	4070.55	1671096.70	-10.68	664.68	156.56	41352.52	203.35	.0543	46.79	46.44	82.55	249.79
12	4.	0.	4.	588.38	102123.60	75.01	231.00	147.10	5195.28	72.08	.0084	43.28	48.53	166.82	238.91
13	11.	1.	10.	542.74	41557.24	24.12	141.92	54.27	1344.51	36.67	.0210	59.73	52.88	136.73	166.89
15	18.	1.	17.	1514.40	221773.21	13.28	319.67	89.08	5429.18	73.68	.0376	50.75	53.81	117.04	193.64
16	1.	0.	1.	79.53	6325.02	79.53	79.53	79.53	0.00	0.00	.0021	57.45	41.18	178.16	178.16
21	2.	0.	2.	561.19	277718.10	35.39	525.80	280.60	120250.99	346.77	.0042	46.24	54.63	136.25	391.46
23	1.	0.	1.	80.62	6499.58	80.62	80.62	80.62	0.00	0.00	.0021	36.09	47.53	164.24	164.24
25	4.	0.	4.	557.46	95473.80	43.35	226.32	139.36	5927.79	76.99	.0084	55.62	56.50	155.47	251.89
31	10.	0.	10.	806.96	97126.05	19.49	183.91	80.70	3557.51	59.64	.0209	50.34	46.95	116.78	177.99
33	11.	0.	11.	106.80	29234.34	-41.81	125.25	9.71	2819.74	53.10	.0230	48.52	46.72	53.83	105.35
35	2.	0.	2.	351.78	97684.82	42.08	309.70	175.89	35810.23	189.24	.0042	49.07	68.81	159.96	293.77
51	22.	0.	22.	3015.16	735932.40	23.28	448.22	137.05	15366.50	123.96	.0459	54.68	49.77	127.73	241.50
52	5.	0.	5.	520.35	106961.69	13.79	284.73	104.07	13202.22	114.90	.0104	52.58	55.05	121.42	211.78
53	2.	0.	2.	122.26	7584.16	53.70	68.56	61.13	110.41	10.51	.0042	44.72	58.28	148.70	156.13
55	13.	0.	13.	2081.81	871477.82	-0.15	626.88	160.14	44841.53	211.76	.0271	54.18	57.41	111.44	271.72
56	1.	0.	1.	162.67	26461.51	162.67	162.67	162.67	0.00	0.00	.0021	42.88	50.76	256.31	256.31
61	2.	0.	2.	251.89	32159.12	111.20	140.69	125.95	434.83	20.85	.0042	97.48	49.12	257.80	272.55
63	1.	0.	1.	63.86	4078.10	63.86	63.86	63.86	0.00	0.00	.0021	61.55	45.23	170.64	170.64
65	4.	0.	4.	253.70	24506.36	7.04	134.83	63.43	2831.81	53.21	.0084	65.93	55.38	128.35	184.74

FIGURE 4-2. EXAMPLE OF SIMULATION STATISTICS - 33-VFR, A-A PAIR

4.3 COMPARATIVE STATISTICAL ANALYSIS OF RUNWAY OCCUPANCY TIME

As a first examination of VICON's effect on traffic flow, a comparative analysis was made of runway occupancy time. Using the data files created as of step 6 above, a statistical breakdown of mean runway occupancy time (by type of operation and aircraft type) was generated. For this comparison, runway occupancy times (RWOCC) were calculated as follows for each type of operation:

- Arrivals - RWOCC = exit runway time minus time over threshold.
- Departures cleared on runway - RWOCC = lift-off time minus clearance time.
- Departures cleared on taxiway - RWOCC = lift-off time minus enter runway time.

Table 4-1 shows the results of the statistical breakdown for both pre- and post-VICON data. T-tests comparing the pre- and post- mean values were performed. Comparisons of aircraft type and operation type were also made. The results were as follows:

1. Aircraft type - data extracted from Table 4-1 yielded the following comparison: (to page 4-7)

TABLE 4-1. RUNWAY OCCUPANCY TIME COMPARISON

PRE-VICON

ACFT TYPE	ARRIVALS TOTAL OBS.	ARRIVALS VALID OBS.*	ARRIVALS MEAN	ARRIVALS STD. DEV.	DEPARTURES - CLRD. ON R/W TOTAL OBS.	DEPARTURES - CLRD. ON R/W VALID OBS.	DEPARTURES - CLRD. ON R/W MEAN	DEPARTURES - CLRD. ON R/W STD. DEV.	DEPARTURES - CLRD. ON T/W TOTAL OBS.	DEPARTURES - CLRD. ON T/W VALID OBS.	DEPARTURES - CLRD. ON T/W MEAN	DEPARTURES - CLRD. ON T/W STD. DEV.
1	768	692	49.49	18.73	394	373	29.22	13.51	406	293	32.12	13.76
2	96	91	54.94	21.01	46	46	37.26	9.16	37	33	36.23	10.17
3	129	113	59.95	17.88	85	82	30.24	10.26	35	32	43.77	18.80
5	547	522	57.93	23.88	335	328	41.40	8.45	262	245	42.21	10.06
6	81	74	69.21	25.72	55	52	43.71	7.77	58	50	46.76	10.41
	1,621	1,492			915	881			798	653		

POST-VICON

ACFT TYPE	ARRIVALS TOTAL OBS.	ARRIVALS VALID OBS.*	ARRIVALS MEAN	ARRIVALS STD. DEV.	DEPARTURES - CLRD. ON R/W TOTAL OBS.	DEPARTURES - CLRD. ON R/W VALID OBS.	DEPARTURES - CLRD. ON R/W MEAN	DEPARTURES - CLRD. ON R/W STD. DEV.	DEPARTURES - CLRD. ON T/W TOTAL OBS.	DEPARTURES - CLRD. ON T/W VALID OBS.	DEPARTURES - CLRD. ON T/W MEAN	DEPARTURES - CLRD. ON T/W STD. DEV.
1	795	718	52.50	23.80	342	328	29.93	9.20	399	382	31.19	11.23
2	124	117	55.40	18.44	64	60	38.27	6.59	51	50	41.99	13.68
3	198	184	60.22	18.24	88	85	39.78	15.76	70	68	38.51	14.42
5	577	535	60.36	18.63	296	289	43.50	10.53	329	322	44.29	11.13
6	109	103	68.31	19.51	91	87	45.14	9.04	73	71	46.50	12.45
	1,803	1,657			881	849			922	893		

*Those observations for which r/w occupancy time could be calculated.

NUMBER OF OBSERVATIONS

ACFT TYPE	PRE-	%	POST-	%	TOTAL
1	1,568	47.0	1,536	42.6	3,104
2	179	5.4	239	6.6	418
3	249	7.5	356	9.9	605
5	1,144	34.3	1,202	33.3	2,346
6	194	5.8	273	7.6	467
	3,606		3,334		6,940

1 = small prop
2 = large prop
3 = medium/small jet
5 = large commercial jet
6 = heavy jet

Using the chi-square test, the hypothesis that the distributions were similar was tested against dissimilarity. The chi-statistic was calculated to be 32.07 which implied, with extreme certainty, that the distributions were not similar. Two nonparametric tests, Wilcoxon and Kolmogorov-Smirnov, were also applied; they also indicated dissimilarity with fairly high confidence levels.

2. Operation type - data extracted from Table 4-1 yielded the following comparison:

NUMBER OF OBSERVATIONS

OPER. TYPE	PRE-	%	POST-	%	TOTAL
Arrival	1,621	48.6	1,803	50.0	3,424
Dep R/W	915	27.5	881	24.4	1,796
Dep T/W	798	23.9	922	25.6	1,720
	3,606		3,334		6,940

In this case, the chi-square test indicated that the distributions were not similar, at about the 97% confidence level (chi-statistic = 8.63). On the other hand, both the Wilcoxon and Kolmogorov-Smirnov tests indicated that no differences could be detected. Thus, it cannot be stated with confidence that the distribution of operation types are dissimilar for the pre- and post-VICON data bases. This was to be expected. In Section 4.4.2, the question of similarity between the paired operation distributions is discussed.

3. Runway Occupancy Time - this part of the analysis attempted to answer whether VICON increased runway occupancy time. Also, comparisons of pre- and post-VICON data might reveal differences which could be related to inconsistencies in measurement technique. The following data were extracted from Table 4-1:

(Runway Occupancy Time in Seconds)

ARRIVALS

ACFT TYPE	PRE-	POST-	T VALUE	
1	44.49	52.50	2.64	reject H_o
2	54.94	55.40	.17	
3	59.95	60.22	.13	
5	57.73	60.36	1.99	reject H_o
6	69.21	68.31	- .25	

DEPARTURES CLEARED ON RUNWAY

ACFT TYPE	PRE-	POST-	T VALUE	
1	29.22	29.93	.82	
2	37.26	38.27	.63	
3	30.24	39.78	4.65	reject H_o
5	41.40	43.50	2.71	reject H_o
6	43.47	45.14	1.15	

DEPARTURES CLEARED ON TAXIWAY

1	32.12	31.19	- .94	
2	36.23	41.99	2.20	reject H_o
3	43.77	38.51	-1.40	
5	42.21	44.29	2.33	reject H_o
6	46.76	46.50	- .12	

The t-statistic was calculated as:

$$t = \frac{\overline{X}_{post} - \overline{X}_{pre}}{\text{std. error of difference}}$$

$$\text{where std. error} = \sqrt{\frac{s^2_{pre}}{n_{pre}} + \frac{s^2_{post}}{n_{post}}}$$

The hypothesis H_o: $\overline{X}_{post} = \overline{X}_{pre}$ was tested against H_a:$\overline{X}_{post}$ $\overline{X}_{pre}$ at the 95% significance level. The decision rule was: reject H_o if t 1.645. At the 99% level, H_o was rejected if t 2.326. For both departures cleared on the runway and on the taxiway, there were increases in runway occupancy time for various aircraft types. Large commercial jets, (type "5") showed a consistent increase at the 99% significance level, for both departure types. All other aircraft types showed positive t-values for departures cleared on the runway, indicating that there were statistically significant differences at varying significance levels. The data appeared to support the hypothesis that VICON increased runway occupancy time, although the average increase for the five aircraft types was only three seconds.

4.4 SIMULATION OF AIRPORT THROUGHPUT

4.4.1 Preliminary Estimates

Before applying the procedure discussed in Section 2.2, an estimation of VICON's impact was developed. Using the individual data sets created in step 10 above, a weighted-average, paired total operation time (PTOT) was calculated for each runway configuration-weather combination. (PTOT is equal to the sum of the runway occupancy times for the leading and following aircraft plus the interoperation time.) The weighted average was calculated by multiplying the frequency of occurrence of each paired operation type (1-1-A-A, 1-2-A-A, etc.) times PTOT associated with that pair, and then summing to obtain a weighted average. Since the minimum observed interoperation time represented only one observation, it was felt that using the PTOT value calculated with the minimum was not a true expected value. Therefore, PTOT using the mean interoperation time, based on all observations in a particular paired operation category, was used.

First, the mean and and standard deviation of PTOT were calculated for each paired operation category. The results for 6-33-VFR and 33-VFR are shown in Tables 4-2 and 4-3. From these statistics, a weighted average mean and variance were calculated using the following formulae (stratified sampling approach):

$$\bar{y}_{st} = \frac{\sum n_h \bar{y}_h}{n}$$

$$V(\bar{y}_{st}) = \sum \frac{wh^2 sh^2}{n_h}$$

h = subscript referring to each paired operation category (1 through 9)

n_h = number of observations in each category

w_h = weight assigned to each category (n_h/n)

TABLE 4-2. PAIRED TOTAL OPERATION TIME STATISTICS - 6-33-VFR

PAIRED OPER. TYPE	PRE-VICON MEAN ($\bar{y}_h$)	PRE-VICON S.D. (S_h)	PRE-VICON n_h	POST-VICON MEAN ($\bar{y}_h$)	POST-VICON S.D. (S_h)	POST-VICON n_h
A-A	202.39	28.22	278	220.92	46.21	386
A-DT	210.63	55.29	124	221.14	44.75	177
A-DR	88.48	25.01	200	91.08	12.17	217
DT-A	266.75	51.96	147	272.51	78.89	204
DR-A	242.73	52.27	179	236.03	50.23	191
DT-DT	209.59	49.45	98	213.80	53.75	131
DT-DR	147.21	46.65	63	137.95	32.10	84
DR-DT	243.12	85.96	85	232.45	75.20	107
DR-DR	109.46	39.76	123	103.08	25.44	117

TABLE 4-3. PAIRED TOTAL OPERATION TIME STATISTICS - 33-VFR

PAIRED OPER. TYPE	PRE-VICON MEAN ($\bar{y}_h$)	PRE-VICON S.D. (S_h)	PRE-VICON n_h	POST-VICON MEAN ($\bar{y}_h$)	POST-VICON S.D. (S_h)	POST-VICON n_h
A-A	186.62	24.08	186	216.69	51.47	140
A-DT	184.18	67.54	91	167.21	41.57	53
A-DR	93.09	9.81	133	92.36	12.18	60
DT-A	221.94	62.74	106	216.93	53.93	56
DR-A	205.79	38.40	117	213.21	55.07	57
DT-DT	205.81	60.04	47	214.42	54.26	36
DT-DR	98.07	25.57	30	139.85	44.25	14
DR-DT	180.62	50.08	46	165.37	58.68	24
DR-DR	112.37	20.80	62	98.20	39.96	31

The results for 6-33-VFR were:

	PRE	POST	% INCREASE
$\bar{y}_{st}$	190.20	199.15	4.7
$V(\bar{y}_{st})$	1.67	1.58	

and for 33-VFR:

	PRE	POST	% INCREASE
$\bar{y}_{st}$	170.35	182.02	6.9
$V(\bar{y}_{st})$	2.18	4.84	

In order to answer the question of whether PTOT increases with VICON in operation, the following hypotheses were tested:

Ho: $\bar{y}_{POST} = \bar{y}_{PRE}$ against

Ha: $\bar{y}_{POST} > \bar{y}_{PRE}$

The t-statistic was calculated as follows:

$$t = \frac{\bar{y}_{POST} - \bar{y}_{PRE}}{\bar{V}_{POST} + \bar{V}_{PRE}} = \begin{cases} 4.97 \text{ (6-33-VFR)} \\ 4.41 \text{ (33-VFR)} \end{cases}$$

A one-sided t-test performed at the 99% significance level ($t > 2.58$) appeared to support the hypothesis that $\bar{y}_{POST} > \bar{y}_{PRE}$, since the calculated t-statistics were greater than 2.58. To strengthen this result, 99% confidence intervals around the mean PTOT values for pre- and post- were calculated as follows:

a. Mean difference between pre- and post- PTOT

values = 8.95 (6-33-VFR)
11.67 (33 -FR)

b. Standard error of the difference

$$= \sqrt{1.67 + 1.58}$$

$$= 1.80 \text{ (6-33-VFR)}$$

$$= \sqrt{2.18 + 4.84}$$

$$= 2.65 \text{ (33-VFR)}$$

c. Ninety-nine percent confidence interval of the difference =

$$8.95 \pm 1.80\ (2.58) = 8.95 \pm 4.64 \text{ (6-33-VFR)}$$

$$11.67 \pm 2.65\ (2.58) = 11.67 \pm 6.84 \text{ (33-VFR)}$$

d. Similarly calculated, 99% confidence intervals on the individual PTOT values were:

6-33-VFR	pre-	190.20 ± 3.33
	post-	199.15 ± 3.24
33-VFR	pre-	170.35 ± 3.81
	post-	182.02 ± 5.68

Since the confidence intervals on the individual PTOT values did not overlap each other, the hypothesis that VICON did increase PTOT (and thus decreased traffic flow) was strengthened. At the 99% level (as shown in item C above), the magnitude of the difference in PTOT values was calculated to be between 4.31 and 13.59 seconds, for 6-33 VFR; and between 4.83 and 18.51 seconds, for 33 VFR. As seen below, these preliminary results were not rejected by the simulation approach which is based on a larger sample.

4.4.2 Simulation Application and Results

Application of the simulation procedure discussed in Section 2.2 showed that a slightly modified approach could yield accurate results with an optimum number of repeated simulation runs. (In this case, "optimum" means smallest number of simulation runs while still maintaining an adequate sample size.) The following method was used:

1. Forty paired operations were drawn randomly from a particular data set (runway configuration 33 in VFR conditions, for example).

2. An average PTOT value was calculated and tabulated as shown in Table 4-4. This value became the first observation, or first sample.

3. An additional 40 paired operations were chosen randomly. Again, an average PTOT was calculated ($\bar{X}$), as well as a running mean ($\bar{X}_n$) and variance (S_n^2) based on the samples.

4. Two rules were applied to determine when to stop sampling (i.e., when to stop drawing groups of 40 paired operations). One rule, based on sequential sampling, was:

   $$\text{when } S_n^2 \leq \frac{nd^2}{t^2_{n-1,\,\alpha/2}}, \text{ stop sampling,}$$

   where n = number of samples
   d = acceptable interval width around $\bar{X}_n$
   $t_{n-1,\,\alpha/2}$ = t-statistic at certain significance level

In this case, "d" was chosen to be five ($\bar{X}_n \pm 2.5$) and α was .05 (95% confidence level). The other rule involved the standard error based on the entire sample of paired operations, calculated as S/n_T. When this value became less than half the interval width, sampling was stopped. Either rule could be the governing factor.

5. When sampling was stopped, the final $\bar{X}_n$ value became the PTOT value for that data set. A 95% confidence interval was then constructed around this value according to:

$$\bar{X}_n \pm t_{\alpha/2,n-1}(S/\sqrt{n_T}) = \bar{X}_n \pm 1.96\ (S/\sqrt{n_T})$$

6. The confidence interval and mean PTOT value were then translated to throughput measures (operations per hour):

$$\text{Throughput} = [3{,}600/\bar{X}_n] \times 2$$

Table 4-4 depicts this method as it was applied to the 33-VFR post-VICON data set. In this case, the rule regarding the standard error was applied. The comparative results for 33-VFR are shown in Table 4-5. On the surface, these figures indicated that throughput, after implementation of VICON, decreased by 3.1 percent. From Table 4-5, though, it can be seen that the 95 percent confidence intervals around the pre- and post-VICON PTOT and throughput values overlapped. Thus,

TABLE 4-4. 33-VFR POST-VICON SIMULATION RESULTS

CUMULATIVE NO. OF PAIRED OPERATIONS	$\bar{X}$	n	$\bar{X}_n$	S_n^2	nd^2/t^2
40	190.65	1	190.65	-	-
80	179.54	2	185.10	61.72	.31
120	165.23	3	178.47	162.40	4.05
160	176.06	4	177.87	109.72	9.88
200	181.33	5	178.56	84.69	16.22
240	184.53	6	179.56	73.68	22.69
280	176.48	7	179.12	62.76	29.23
320	187.79	8	180.20	63.19	35.76
360	175.98	9	179.73	57.27	42.31
400	163.69	10	178.13	76.65	48.86
440	185.15	11	178.77	73.46	55.40
480	149.39	12	176.32	138.70	61.93
520	168.30	13	175.70	132.09	68.45
560	159.96	14	174.58	139.63	75.02
600	154.45	15	173.24	156.66	81.50
640	188.61	16	174.20	160.99	88.08
680	161.25	17	173.43	160.79	94.56
720	191.35	18	174.43	169.16	101.08
760	182.68	19	174.86	163.34	107.61
800	172.97	20	174.77	154.93	114.14

n_T = 800

S = 66.10 (standard deviation of all paired operations)

$S_{\bar{X}}$ = 2.337 (standard error of the mean)

95% confidence interval = 174.77 ± 1.96(2.34) = (170.18, 179.36)

= 41.2 operations/hour (42.3, 40.1)

TABLE 4-5. RESULTS OF 33-VFR SIMULATION OF AIRPORT THROUGHPUT

	PRE-	POST-	PERCENT CHANGE (±)
TOTAL NUMBER OF OBSERVATIONS	880	800	
$\bar{X}$ (AVERAGE PTOT VALUE)	169.42	174.77	+3.2
AVERAGE THROUGHPUT VALUE	42.5 oper./hr.	41.2 oper/hr.	-3.1
$\bar{S}$ STD. DEVIATION OF ALL PAIRED OPERATIONS)	64.76	66.10	
$S_{\bar{X}}$ STD. ERROR OF THE MEAN	2.18	2.34	
95% CONFIDENCE INTERVAL AROUND $\bar{X}$	(165.15, 173,69)	(170.18, 179.36)	
95% CONFIDENCE INTERVAL AROUND THROUGHPUT	(43.6, 41.5)	(42.3, 40.1)	

although there was an indication that $\overline{X}_{POST} > \overline{X}_{PRE}$, the sample size was not large enough to state that the difference was significant with more than 95 percent confidence. Nevertheless, it is probable that a somewhat larger sample would yield a difference of the same magnitude (three to four percent).

Throughput values calculated for 6-33-VFR from the results shown in Section 4.4.1 indicated a decrease of 4.5 percent (37.9 to 36.2 operations per hour). This was the same order of magnitude as the decrease shown above for 33-VFR.

In order to further verify these results, a comparison of the pre- and post-VICON distributions of aircraft type and paired operation type were made for each data set. (Traffic flow is, to a large extent, dependent on the aircraft mix and the nature of the paired operation distribution). If these distributions proved to statistically similar at the 95% significance level, then it was felt that the test results would be strengthened.

As shown in Section 4.3, it appeared that the pre- and post-VICON data bases yielded different aircraft type distributions. This was confirmed using the chi-square, Wilcoxon, and Kolmogorov-Smirnov tests. The important differences seem to be in aircraft types 1 (small prop) and 6 (heavy jet). The post-VICON data contains a higher percentage of heavy jets and a lower percentage of small propeller aircraft. This difference may have contributed to the decreased throughput values calculated via the weighted-average and simulation techniques. A higher percentage of heavy jets would mean increased separations, higher paired operation times, and decreased traffic flow.

The distributions of paired operation types also showed significant differences between pre- and post-VICON data. Based on the simulation data, Table 4-6 shows a comparison at two levels: for the nine paired operation categories based on three operation types and for four categories based on combining DR and DT into a single departure category. At very high significance levels, the chi-square test rejected the hypothesis of similar distributions. These differences in pre- and post-VICON data were interpreted in several ways:

- The A-A and D-A pairs showed a significant increase in frequency in the post-VICON data. Since these pairs had large paired operation times compared to other pairs (see Table 4-3), their increased frequency in the post-VICON phase contributed to a decreased throughput value.

- It is possible that VICON influenced the paired operation distribution. Although this was impossible to test accurately, the great dissimilarity of the pre- and post-VICON distributions suggested that a change in controller procedures to accommodate the added workload imposed by VICON might have led to the differences.

4.5 VOICE TAPES ANALYSIS

4.5.1 Data Collection and Reduction

During the pre-VICON data collection phase, voice-actuated recordings of local controller-pilot communications were made for all data collection periods. Recordings were made from a motel near Bradley, using a high-quality receiver and OMNICRON CTR-8LP recorders equipped with a talking clock. At one minute intervals, the Greenwich Mean Time was recorded (electronically-produced voice) over the controller-pilot communication. This

TABLE 4-6. COMPARISON OF PAIRED OPERATION DISTRIBUTIONS - 33-VFR

PAIRED OPERATION TYPE	NUMBER OF OBSERVATIONS PRE-	POST-	TOTAL
A-A	201 (-1.42)	223 (1.48)	424
A-DT	97 (.28)	83 (- .29	180
A-DR	157 (1.26)	114 (-1.32)	271
DT-A	96 (- .46)	96 (.48)	192
DR-A	59 (-2.00)	87 (2.10)	146
DT-DT	50 (-1.26)	64 (1.32)	114
DT-DR	84 (3.56)	25 (-3.73)	109
DR-DT	61 (.24)	52 (- .25)	113
DR-DR	75 (.77)	56 (- .81)	131
	880	800	1,680
A-A	201 (-1.42)	223 (1.48)	424
A-D	254 (1.16)	197 (-1.21)	451
D-A	155 (-1.66)	183 (1.74)	338
D-D	270 (1.62)	197 (-1.71)	467
	880	800	1,680

[Numbers in parentheses represent standardized values: (observed frequency minus expected frequency) divided by square root of expected frequency, where the expected frequency of any pair is the row total times the column total divided by the total number of observations. As an example, for A-A, pre-VICON:

$$\text{expected frequency} = \frac{424 \times 880}{1{,}680} = 222.1$$

$$\text{standardized value} = \frac{201 - 222.1}{\sqrt{222.1}} = -1.42$$

The standardized value is a measure of the relative differences in the distribution.]

Ho: Similar distributions is tested against
Ha: Different distributions

At the 95% significance level, reject Ho if chi-square statistic is greater than 15.51. Since chi-square statistic = 47.84 for the nine category distribution, reject Ho at the 99-plus percent significance level. Since chi-square statistic = 17.914 for the four category distribution, again reject Ho at the 99-plus percent significance level.

enabled an analyst to locate specific points on the tape.

During the post-VICON phase, equipment designed and constructed by the FAA was used. The data acquisition system consisted of a specialized HP3964A® Instrumental Recorder, a Syston Donner® Time Gen-Reader, and special circuitry. This recording equipment, which was voice-actuated, was housed in the Bradley Tower. Information, recorded 24-hours a day during the course of the VICON test, consisted of:

- Local Control - pilot communications
- Ground Control - pilot communications
- VICON signal activities tone by location
- Continuous digital time readout

The time was recorded to the nearest second in Greenwich Mean Time. Due to significant differences in the types of equipment used in the pre- and post-VICON phases, it was difficult to construct a consistent before-and-after analysis. Therefore, the conclusions drawn below depend primarily on post-VICON data.

4.5.2 Pre-VICON Analyses

Two hours of data collected during the pre-VICON phase were reduced to determine the nature of communications at BDL and to develop an estimate of the fraction of communication time and channel use allocated to takeoff clearance messages. This preliminary data was in the form of message strings - several transmissions pieced together to form an exchange between controller and pilot.

The data shown in Table 4-7 translate to an 11 percent channel use without VICON. Since VICON would be expected to affect only those message strings related to departures, and since the time involved with those message strings accounted for about 20-25 percent of all messages, VICON was not expected to significantly affect channel loading. For instance, if VICON added three seconds to the average duration of a takeoff clearance message string, then overall channel use would increase, for these two hours, to 12.1 percent - an 11 percent increase. This might be significant at airports operating at or near capacity.

4.5.3 Cautions

Use of VICON was not mandatory during the evaluation period. Examination of 132 hours of local control-pilot communications revealed that VICON was used on 60 percent of takeoff operations. For the data reduced, Table 4-8 shows the pattern of VICON use by month. Table 4-9 reveals the pattern of decreasing pilot response to VICON (in the form of signal acknowledgement) over the test period.

Thus, the analysis presented below is based on an incomplete sample in that the system user (pilots and controllers) did not fully participate in the test. If VICON were to be implemented, and if its use was mandated, the resulting impact on voice communications might be different.

TABLE 4-7. PRELIMINARY ANALYSIS OF PILOT-CONTROLLER COMMUNICATIONS

TYPES OF MESSAGE STRINGS*				AVG. DURATION (seconds)	STD DEVIATION (seconds)	NO. OF OBSERVATIONS
CONTROLLER	PILOT	CONTROLLER	PILOT			
	ARRIVALS -					
	aircraft position	clear to land	response	9.3	2.0	12
	aircraft position	clear to land	no response	6.2	-	2
		clear to land	response	5.7	1.9	4
	aircraft position	position in queue	response	6.8	1.2	3
	aircraft position	position in queue	no response	-	-	-
		position in queue	response	-	-	-
		hand-off to ground	response	5.5	2.1	5
		hand-off to ground	no response	3.3	1.0	7
	pilot call-in	hand-off to ground	response	8.6	0.9	2
	by the marker	short response		1.8	-	1
	short 180°?	approved	response	10.2	-	1
	I see VASI	thank you		4.0	-	1
	report arrival position	short response		5.6	-	1
	DEPARTURES -					
	ready for t.o.	clear to t.o	response	9.0	2.6	10
		clear to t.o.	response	5.0	1.7	15
		clear to t.o.	no response	3.2	0.4	4
	ready for t.o.	position and hold	response	8.0	2.3	7
		position and hold	response	5.1	1.4	11
		position and hold	no response	4.8	-	1
	ready for t.o.	hold short-landing traffic	response	6.5	1.4	3
		contact dep. control	response	3.5	0.9	27
		course approved	response	3.5	-	1
		freq. change approved	response	3.1	0.7	2
	freq. change approved?	confirmation	response	5.0	-	1
	freq. change approved?	confirmation	no response	6.7	-	1
		squawk code	response	10.9	-	1
		clear thru airport traffic area	response	8.4	-	1
get around a/c?	confirmation	clear to t.o.	response	17.8	-	1
	release approved?	confirmation		5.6	-	1
		time until release	response	4.7	-	1
(Unintelligible transmissions with *helicopter*)				39.9	-	1
(unknown transmissions - *pieces of messages*, bad transmission, etc).				2.1	0.8	5

*Based on two hour data sample, 1230-1330 GMT period, 1/19 and 1/26/79. Total message duration = 784.5 seconds.

TABLE 4-8. VICON USE BY MONTH

MONTH	NO. OF TAKEOFFS	NO. OF VICON ACTIVATIONS	PERCENT VICON USE
October	57	48	84.2
November	252	137	54.4
December	318	212	66.7
January	316	197	62.3
February	219	153	69.9
March	464	236	50.9
TOTAL	1626	983	60.5

TABLE 4-9. FREQUENCY OF PILOT RESPONSE TO VICON

MONTH OF OBSERVATION	NO. OF PILOT VICON RESPONSES	NO. OF VICON CLEARANCES	PERCENT OF VICON RESPONSES
October	7	48	14.6
November	17	137	12.4
December	13	212	6.1
January	9	197	4.6
February	9	153	5.9
March	7	236	2.9
TOTAL	62	983	6.3

4.5.4 Channel Use

Two approaches were used to measure the impact of VICON on channel use. First, a specific hour was selected which contained a significant amount of local control communications pertaining to VICON. The period selected was the November 9, 1979 (1500-1600Z) data containing about 27 seconds of VICON communications. This hour was used to determine, at the micro-level, the additional channel use per message due to VICON, on a message by message basis.

The second approach was to measure VICON's impact at the overall level. This was accomplished by timing all VICON-related messages for every period reduced and by determining its contribution to the sum of all messages (including VICON).

The results of the first approach are presented in Table 4-10 and Table 4-11. It is evident from these tables that the contribution of VICON to channel use was small.

This conclusion was supported by the results of the second approach (Table 4-12, cols. 6-7). In only seven instances (Obs. Nos. 3, 4, 35, 62, 79, 112, and 114) did VICON's contribution to message duration surpass one percent, and in most cases it was zero. The average VICON contribution to the total channel use for the 132 hours analyzed was 0.1 percent. The total channel use was 13.8 percent. If VICON had been used and acknowledged 100 percent of the time, the effect on channel loading would still be minor. Moreover, in routine operation, acknowledgement would not be required or would be included in the mandatory takeoff clearance acknowledgement and additional channel loading would be minimal.

TABLE 4-10. BREAKDOWN OF MESSAGE DURATION (SECONDS) FOR TRANSMISSIONS CONTAINING VICON MESSAGES

COMMUNICATION STREAM NUMBER	DURATION OF STREAM (SECONDS)	DURATION OF VICON MESSAGE (SECONDS)	PERCENT VICON
1	5	4	80.0
2	11	2	18.1
3	19	4	21.1
4	6	1	16.7
5	5	1	20.0
6	21	12	57.1
7	7	3	42.9
TOTAL	74	27	36.5

Source: November 9, 1979 Tape, Observation No. 3.

TABLE 4-11. EFFECT OF VICON ON LOCAL CHANNEL LOADING

Duration of Study Period	475,200 seconds
Duration of All Messages	65,402 seconds
Duration of VICON Messages	174 seconds
Percent Channel Use With VICON	13.8 percent
Percent Channel Use Without Vicon	13.7 percent

TABLE 4-12. STATISTICAL SUMMARY

OBSERVATION NUMBER (1)	NUMBER OF VICON ACTIVATIONS (2)	NUMBER OF ERRONEOUS LIGHT SELECTIONS (3)	NUMBER OF MULTIPLE VICON CLEARANCES (4)	NUMBER OF MULTIPLE VERBAL CLEARANCES (5)	OVERALL MESSAGE DURATION (SEC) (6)	VICON MESSAGE DURATION (SEC) (7)	NUMBER OF PILOT VICON RESPONSES (8)
1	9	0	1	1	330	0	1
2	21	0	1	2	1,260	12	2
3	8	2	8	0	374	27	8
4	16	0	1	2	404	8	2
5	0	0	0	0	598	0	0
6	11	0	2	2	308	1/2	1
7	10	0	0	1	390	2	2
8	7	0	0	0	858	0	0
9	14	0	0	0	349	2	2
10	9	0	1	0	624	3-1/2	1
11	3	0	0	0	786	0	0
12	6	1	0	0	368	0	0
13	12	0	0	0	696	4	3
14	12	0	0	0	759	1	1
15	15	0	0	0	330	1-1/2	1
16	7	0	0	0	293	0	0
17	3	0	0	0	226	0	0
18	11	0	0	0	364	0	0
19	0	0	0	1	290	0	0
20	0	0	0	0	244	0	0

TABLE 4-12. (Cont.)

OBSERVATION NUMBER (1)	NUMBER OF VICON ACTIVATIONS (2)	NUMBER OF ERRONEOUS LIGHT SELECTIONS (3)	NUMBER OF MULTIPLE VICON CLEARANCES (4)	NUMBER OF MULTIPLE VERBAL CLEARANCES (5)	OVERALL MESSAGE DURATION (SEC) (6)	VICON MESSAGE DURATION (SEC) (7)	NUMBER OF PILOT VICON RESPONSES (8)
21	3	0	0	0	229	1	1
22	15	0	0	0	360	1	1
23	0	0	0	0	306	0	0
24	1	0	0	0	301	0	0
25	14	0	0	0	411	0	3
26	5	0	0	1	359	0	0
27	15	0	0	0	744	0	0
28	16	0	0	0	739	0	1
29	4	0	0	0	381	0	0
30	4	0	0	0	105	0	0
31	3	0	0	0	140	0	0
32	9	0	0	0	394	1	1
33	9	0	1	0	420	0	0
34	8	0	0	0	578	1	1
35	15	0	0	1	797	17	1
36	2	0	0	0	230	1	1
37	5	0	0	0	456	2	1
38	0	0	0	0	370	0	0
39	12	0	0	0	483	1	1
40	17	0	0	0	547	0	0

TABLE 4-12. (Cont.)

OBSERVATION NUMBER (1)	NUMBER OF VICON ACTIVATIONS (2)	NUMBER OF ERRONEOUS LIGHT SELECTIONS (3)	NUMBER OF MULTIPLE VICON CLEARANCES (4)	NUMBER OF MULTIPLE VERBAL CLEARANCES (5)	OVERALL MESSAGE DURATION (SEC) (6)	VICON MESSAGE DURATION (SEC) (7)	NUMBER OF PILOT VICON RESPONSES (8)
41	7	0	0	0	584	3	2
42	16	0	0	0	516	1	1
43	15	0	0	0	677	0	0
44	11	0	0	0	728	0	1
45	15	0	0	0	320	0	0
46	10	0	0	0	330	0	0
47	14	0	0	1	416	0	0
48	12	0	0	0	404	0	0
49	1	0	0	0	486	0	0
50	8	0	1	0	456	0	0
51	8	0	0	0	655	2	2
52	11	0	0	0	666	0	0
53	3	0	0	0	626	0	0
54	16	0	0	0	557	0	0
55	5	0	0	0	554	0	0
56	7	0	1	1	653	1	1
57	12	0	0	0	542	0	0
58	13	0	0	0	1,246	0	0
59	1	0	0	0	550	0	0
60	9	0	0	0	526	0	0

TABLE 4-12. (Cont.)

OBSERVATION NUMBER (1)	NUMBER OF VICON ACTIVATIONS (2)	NUMBER OF ERRONEOUS LIGHT SELECTIONS (3)	NUMBER OF MULTIPLE VICON CLEARANCES (4)	NUMBER OF MULTIPLE VERBAL CLEARANCES (5)	OVERALL MESSAGE DURATION (SEC) (6)	VICON MESSAGE DURATION (SEC) (7)	NUMBER OF PILOT VICON RESPONSES (8)
61	3	0	0	0	358	0	0
62	8	0	0	0	244	10	1
63	10	0	0	1	332	2	1
64	9	0	0	0	315	0	0
65	0	0	0	0	422	0	0
66	1	0	0	0	170	0	0
67	0	0	0	0	210	0	0
68	8	0	0	1	508	0	0
69	11	1	0	0	414	0	0
70	4	0	0	0	213	0	0
71	6	0	0	0	339	0	0
72	4	0	0	0	235	0	0
73	7	0	0	0	358	0	0
74	12	0	0	0	282	2	1
75	10	0	0	1	294	0	0
76	3	0	0	0	105	0	0
77	8	0	0	1	206	0	0
78	0	0	0	0	283	0	0
79	13	0	0	0	334	8	1
80	10	0	0	0	467	0	0

TABLE 4-12. (Cont.)

OBSERVATION NUMBER (1)	NUMBER OF VICON ACTIVATIONS (2)	NUMBER OF ERRONEOUS LIGHT SELECTIONS (3)	NUMBER OF MULTIPLE VICON CLEARANCES (4)	NUMBER OF MULTIPLE VERBAL CLEARANCES (5)	OVERALL MESSAGE DURATION (SEC) (6)	VICON MESSAGE DURATION (SEC) (7)	NUMBER OF PILOT VICON RESPONSES (8)
81	10	0	0	0	549	2	1
82	0	0	0	0	572	0	0
83	15	0	0	0	548	1	1
84	8	0	0	0	202	1	1
85	0	0	0	0	316	2	1
86	14	0	0	0	498	3	2
87	8	0	0	0	300	3	1
88	12	0	0	1	625	0	0
89	0	0	0	0	367	3	1
90	8	0	0	0	840	0	0
91	11	0	0	1	440	0	0
92	4	0	0	0	788	5	1
93	3	0	0	0	480	0	0
94	5	0	0	1	749	1	1
95	5	0	0	0	178	0	0
96	9	0	0	0	384	0	0
97	0	0	0	0	492	0	0
98	8	0	0	0	488	0	0
99	0	0	0	0	324	0	0
100	0	0	0	0	833	0	0

TABLE 4-12. (Cont.)

OBSERVATION NUMBER (1)	NUMBER OF VICON ACTIVATIONS (2)	NUMBER OF ERRONEOUS LIGHT SELECTIONS (3)	NUMBER OF MULTIPLE VICON CLEARANCES (4)	NUMBER OF MULTIPLE VERBAL CLEARANCES (5)	OVERALL MESSAGE DURATION (SEC) (6)	VICON MESSAGE DURATION (SEC) (7)	NUMBER OF PILOT VICON RESPONSES (8)
101	8	0	0	0	598	0	0
102	10	0	0	0	323	0	0
103	13	0	0	0	458	1	1
104	4	0	0	0	185	0	0
105	10	8	0	0	613	0	0
106	1	0	0	0	56	0	0
107	9	0	0	0	482	1	1
108	0	0	0	0	603	0	0
109	11	0	0	0	516	0	0
110	10	0	0	0	523	0	0
111	13	0	0	0	501	1	1
112	6	0	0	0	402	10	1
113	8	0	0	0	640	0	0
114	9	0	1	1	530	11	2
115	8	0	0	0	112	2	2
116	7	0	0	1	384	2	1
117	11	0	0	0	512	0	0
118	10	0	0	0	719	0	0
119	7	0	0	0	513	0	0
120	6	0	0	0	675	0	0
121	0	0	0	0	672	0	0

TABLE 4-12. (Cont.)

OBSERVATION NUMBER (1)	NUMBER OF VICON ACTIVATIONS (2)	NUMBER OF ERRONEOUS LIGHT SELECTIONS (3)	NUMBER OF MULTIPLE VICON CLEARANCES (4)	NUMBER OF MULTIPLE VERBAL CLEARANCES (5)	OVERALL MESSAGE DURATION (SEC) (6)	VICON MESSAGE DURATION (SEC) (7)	NUMBER OF PILOT VICON RESPONSES (8)
122	0	0	0	0	512	0	0
123	10	0	0	0	470	0	0
124	6	0	0	0	1088	0	0
125	0	0	0	0	1600	3	1
126	0	0	0	0	550	0	0
127	7	0	0	0	770	0	0
128	8	0	0	0	1244	10	1
129	11	0	0	0	1378	0	0
130	14	0	0	0	650	0	0
131	9	1	1	0	540	0	0
132	17	0	0	0	838	1	1

4.6 ESTIMATED IMPACT AT OTHER AIRPORTS

Based on the results of this analysis, the following scenario seems possible regarding VICON's impact at other airports, particularly those with high, sustained traffic levels. If the results generated at Bradley - a three second average increase in runway occupancy time for departures and a three to four percent drop in throughput - are accurate, higher trafficked airports will probably experience more severe impacts, at least initially. Those stations operating at near-saturation levels (constant queuing of arrivals and departures, frequent delays, high channel use, etc.) would be very sensitive to even small additions to the time and communication required for aircraft movements. It is probable, though, that over a longer period, experience with the system and its associated procedures would negate any short-term deleterious effects. Given the relatively simple nature of VICON signal activation by the controller and its receipt by the pilot, adoption of the signal into regular takeoff procedure should become automatic if the system is functioning reliably. Due to the low participation by system users in the test, it was difficult to assess the validity of the above statements. There were indications from controllers and pilots who participated enthusiastically in the test that VICON did become an almost automatic part of the takeoff routine.

5. CONCLUSIONS

5.1 CAUTIONS AND CONSIDERATIONS

Two major points should be made before drawing conclusions from this study.

- In a before-and-after, in-service, field evaluation of this nature, it was difficult to maintain identical operating conditions in both the before and after phases. Thus, when comparisons were made of pre- and post-VICON data, it was important to recognize and evaluate changes in other variables - aircraft mix, operations mix, procedures, etc. - that may have affected throughput, as well as effects due solely to VICON. Further, it could have been hypothesized that VICON contributed to some of these changes, and thus indirectly contributed to changes in throughput. The interactions among the factors were complex, and the decision maker should realize this in weighing the data and conclusions of this analysis.

- Use of VICON was not mandatory during the test period. If the VICON signal had been given on more than 60 percent of departures, and if pilots acknowledged receipt of the signal on a regular basis, then the conclusions of this study may have been significantly different. Since the intent of VICON was confirmation of takeoff clearance and not control, the system's impact under more stringent procedures may have been much different than the minor impact seen in this analysis.

5.2 IMPACTS OF VICON ON AIRCRAFT OPERATIONS

5.2.1 Runway Occupancy Time

VICON appeared to have increased runway occupancy time for departures, although the effect varied considerably by aircraft type. Based on the entire data sample, for departures cleared on the runway, the average increase in runway occupancy time was three seconds. For departures cleared on the taxiway, the effect was less consistent, with only certain aircraft types (large commercial jets and large props) showing significant increases. In addition to the measured increase being small, some of the difference may have been due to measurement error or differences in observers.

In a dual runway configuration with a capacity of 80 operations per hour, a three second increase in runway occupancy time for departures would translate to approximately a three to four percent decrease in capacity, depending on arrival-departure mix and the sequence of operations.

5.2.2 Airport Throughput

Comparisons of pre- and post-VICON data indicated an apparent drop in the throughput measure after implementation of VICON. Based on the simulation approach (sequential sampling) applied to 33-VFR (Section 4.4.2), a decrease in operations per hour of approximately three percent was calculated at the 95 percent significance level (combined sample = 1,680 paired operations). Based on the weighted-average approach (stratified sampling) applied to 6-33-VFR (Section 4.4.1), a decrease of 4.5 percent was seen at the 99 percent level (combined sample = 2,911 paired operations). These figures suggested an impact due to VICON.

Further analysis and comparison of pre- and post-VICON data revealed some differences which may have contributed to these decreases. First, the aircraft type distributions were different. Post-VICON data contained a significantly higher percentage of heavy jets and smaller percentage of small props. Second, the post-VICON data base contained a significantly higher percentage of arrivals and lower percentage of departures. Finally, post-VICON data showed a significant increase in the frequency of both the A-A and D-A pairs. These three factors in combination may have contributed to the apparent decrease in traffic flow after VICON implementation.

5.2.3 Voice Communications

No significant effects either on individual takeoff message strings or on local control channel use could be discovered. Again, cautions are advised due to lack of complete participation in the test by controllers and pilots, especially General Aviation pilots.

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