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## ECONOMICS OF IMAGE ACQUISITION ALTERNATIVES FOR DIGITAL PHOTOGRAMMETRIC PRODUCTION

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### ABSTRACT

Photogrammetric production based on softcopy technology requires digital imagery as the primary data input. Accordingly, a mapping company needs to secure a source of digital imagery that is both reliable and cost-effective. This paper presents a discussion on the economics of various imagery sources available for photogrammetric operations. A methodology is presented to evaluate three alternatives of imagery sources based solely on cost-effectiveness. These alternatives are high-resolution satellite imagery, in-house scanning of aerial photography, and outsourcing scanning needs. Specifically, this paper first examines the economic viability of digitally acquired imagery versus film-based photography for softcopy photogrammetric production. The paper further deals with the financial aspects associated with the decision whether to outsource scanning or to establish in-house capability. In addition, the initial capital required for in-house capability is evaluated based on projected workload. The analysis is applied with a specific set of variables, assumptions, and a forecasting risk that is within acceptable limits.

### 1 INTRODUCTION

The most evident technological advancement in photogrammetric mapping is the transition from film-based operations into all-digital, softcopy production. Photogrammetric production firms facing this transition have already invested considerable film-based resources, including stereoplotters, photographic laboratories, and operator training. It is thus understandable why the hesitance in making the decision to embrace the new technology, as it requires substantial capital investment in resources. However, the transition must not be evaluated in terms of the immediate cost effectiveness, but also in terms of the possibilities that it will bring about. These include airborne measurement systems, such as GPS, INS, and IMU; automated processes, such as interior orientation, point transfer, and surface generation; and digital orthorectification.

Another factor is that softcopy photogrammetric production requires digital imagery as the primary input data. The task ahead is to identify the most cost-effective source of input data. Digital imagery can be acquired directly in digital mode, such as in digital frame cameras and array scanners. The more common approach thus far, however, is through conversion from film photography using precision scanning systems. It is currently the most common source for imagery in photogrammetric mapping. While specialized commercial scanning services are now widely available, many mapping agencies opted to establish own in-house scanning capability.

In this paper, the economics of image acquisition alternatives for digital photogrammetric production is examined. This is achieved by, first, examining the viability of direct acquisition technologies including digital frame cameras and satellite scanners. The cost of directly acquired digital imagery is also compared with conventional aerial photography of similar ground resolution and coverage area. Then, assuming the selected source is scanned aerial photography, the paper then presents a methodology for estimating the cost required for various scanning workloads. Based on the resulting estimates, the economic potential of establishing in-house scanning capability is tested using typical cost and benefit analysis. Its profitability is tested against outsourcing of scanning needs, to determine whether scanning technology is a commercially viable alternative worthy of investment in terms of needed capital and future returns. The presented analyses are based on variables used from typical production requirements. However, the accuracy of future cash flows, and the cost of scanning systems, both are key to the validity of analysis recommendations.

## 2 DIRECT DIGITAL ACQUISITION

The two potential sources of direct digital acquisition for photogrammetric production are airborne digital frame cameras and satellite scanners. Airborne digital frame cameras must overcome specific technological challenges, such as resolution and array size, to become a cost effective source for acquisition. For instance, an array size that is in excess of 23K x 23K detectors is needed to cover the same area of a frame photograph. A currently available model from Airborne Data Systems, the SV1S7-12 has a 4096 x 7168 detector array (Airborne Data Systems, 2000). Another challenge is the rate of transfer of data captured by the detectors. Light (1996) listed 60 Mb per second for an 8 bit per pixel panchromatic image to satisfy specifications for the U.S. National Aerial Photography Program (NAPP). The rate would certainly need to be higher with larger scale photography (scale of NAPP is 1:40,000). Notwithstanding these challenges, airborne digital frame cameras are just entering the market of photogrammetric production (LH-Systems, 2000; Rosengarten, 2000). At this time, it is too early to produce an objective assessment of their economic viability.

The other potential source is commercial satellite scanners. These have already demonstrated strong potential for photogrammetric mapping operations, such as with SPOT imagery. The potential is becoming even stronger as ground sampling distance has recently approached one meter, in addition to the stereo viewing and attitude stability available in these sensors. Table 1 shows a number of satellites of photogrammetric mapping potential, including operational, imminent, planned, as well as other expired programs of similar potential.

SATELLITE/ SYSTEM	AGENCY (Country)	SPECTRAL RANGE ( $\mu\text{m}$ )	GSD (m.)	STEREO Yes/No	LAUNCH DATE	SWATH (km.)
JERS	NASDA, MITI (Japan)	MS (7): 0.52 – 2.40	18	Yes	1992	75
IRS-1C	Indian Space Research Organization	Pan: 0.50 – 0.75	5.8	Yes	1995	70
MOMS-02	DARA, DLR (Germany)	Pan: 0.512 – 0.765 MS (4): 0.449 – 0.815	4.5-13.5	Yes No	1993	78/43
MOMS-2P	DARA, DLR (Germany)	Pan: 0.52 – 0.76 MS (4): 0.440 – 0.810	6-18	Yes No	1996	105/60
SPOT 4	CNES (France)	Pan: 0.61 – 0.68 MS (4): 0.50 – 1.75	10 20	Yes	1998	60
SPOT 5	CNES (France)	Pan: 0.51 – 0.73 MS (4): 0.50 – 1.75	2.5 – 5 10 – 20	Yes	2002	60
RADARSAT-1	RSI (Canada)	C-band SAR	8 – 100	Yes	1995	50 – 500
RADARSAT-2	RSI (Canada)	C-band SAR	3 – 100	Yes	2002	10 – 527
IKONOS	Space Imaging (USA)	Pan: 0.45 – 0.90 MS (4): 0.45 – 0.90	1 4	Yes	1999	11
OrbView-3	ORBIMAGE (USA)	Pan: 0.45 – 0.90 MS (4): 0.45 – 0.90	1 4	Yes	2000+	8
OrbView-4	ORBIMAGE (USA)	Pan: 0.45 – 0.90 MS (4): 0.45 – 0.90 HS (200): 0.45 – 2.5	1 4 8	Yes	2000+	8 8 5
Quick Bird	EarthWatch (USA)	Pan: 0.45 – 0.90 MS (4): 0.45 – 0.89	1 4	Yes	2000+	20

Table 1. Imaging Satellites and Systems with Photogrammetric Production Potential  
(Data are obtained from web sites and publications of respective companies; MOMS data are from Kramer, 1997)

In examining the economic potential of high-resolution satellite imagery, IKONOS imagery is used as a representative sample available at the time of writing this paper. The advertised starting price for IKONOS imagery is \$29 (\$ = U.S. Dollar) per square kilometer, or about \$75 per square mile (Space Imaging, 1999). The economic viability of this product is tested against the practical alternative, i.e., scanned aerial photography. The basis of comparison is the ground resolution. An equivalent one-meter ground distance can be obtained from scanning film photography by controlling the scale of photography and the scanning resolution. For example, scanning photographs with scale factors (SF) of 50K, 40K, and 25K will yield a one-meter ground distance when scanned with 20 $\mu$ m, 25 $\mu$ m, and 40 $\mu$ m, respectively. In turn, scale determines the coverage area, which corresponds to around 50, 32, and 10 square miles for the same SF's, respectively. As a result, using the \$75 per square mile as a unit price, the same coverage would cost between \$3783 and \$946. An aerial photograph and scanning it would probably cost between \$100 and \$200 per frame for a medium and large flight mission. The comparison is expressed by a cost ratio. This is a ratio between the cost of a satellite scene to the cost of a scanned photograph; provided that both have same coverage area and same ground resolution. Table 2 lists cost ratios for a range of scanning resolutions and their corresponding scales.

Scanning Res. ( $\mu$ m)	Photo Scale	Coverage (Sq. Miles)	Imagery Cost of Equivalent Coverage	Ratio
10	1:100000	201.8	\$15132.7	76
15	1:66667	89.7	\$6725.6	34
20	1:50000	50.4	\$3783.2	19
25	1:40000	32.3	\$2421.2	12
30	1:33333	22.4	\$1681.4	8
35	1:28571	16.5	\$1235.3	6
40	1:25000	12.6	\$945.8	5
45	1:22222	10.0	\$747.3	4
50	1:20000	8.1	\$605.3	3

Table 2. Ratios between the costs of a satellite scene to the costs of a scanned photograph, while both have the same coverage area. The listed ratios are for various scanning resolutions and photo scales that maintain the same ground resolution of one meter. The unit cost of a scanned photograph is assumed to be \$200.

The cost per scanned frame can be very subjective and depends on multitudes of factors. These include timeliness, frequency, and access. Especially the latter, it even may not be at all possible to obtain access to some areas. The cost ratios can therefore be drastically different under such conditions. High-resolution satellite imagery would undoubtedly be very valuable and justified. However, until cost effectiveness of satellite imagery is clearly demonstrated as a viable alternative, scanned aerial photography remains the primary source for mapping projects of medium and large coverage areas. A reliable scanning capability is therefore a prerequisite for any commercial softcopy operation.

### 3 ESTIMATING SCANNING COST

A decision has to be made on whether to develop in-house capabilities or subcontract all scanning needs, i.e., outsourcing. Developing in-house capability involves committing significant capital that must be clearly justified. This may be achieved either by net savings against outsourcing, or by net profit generated from scanning services. In either case, the capital must be weighed against the potential savings or cash inflow. The capital consists of an upfront cost of equipment, as well as an annual working capital to support in-house operations. The annual working capital supports maintenance, staffing, and overhead; it is incurred so long as in-house scanning is operational.

As a result, a criterion can be put forward as follows: in-house scanning would be justified if it generates sufficient, consistent cash inflow that is higher than the total of both the initial capital and the annual working capital. To determine if a proposal adheres to this criterion, the required capital and the cash inflow (or savings) must be estimated. We defer estimating the initial capital (cost of equipment) to a later section. Cash inflow depends on the rate per a scan, anticipated volume, and the working capital.

Commercial scanning services charge rates according to the desired resolution, volume, and bands, i.e., B/W or color. For the purpose of this analysis, we select an average of \$35.00 per photograph, which also covers media and shipping. The annual cost for scanning varies as a function of frames processed per day. A production facility is expected to process thousands of frames annually. This translates into a number of performed each working day. The resulting amount, i.e., annual cost for scanning, can be viewed in two ways. If it is subcontracted to a scanning firm, then establishing an in-house capability is treated as cost saving. On the other hand, if the company intends to use the in-house capability to offer commercial scanning services, then the generated revenue is treated as cash-inflow. In either case, working capital, depreciation and tax consequences must be factored in estimating the net cash flow. For the purpose of this paper, we assume a five years depreciation, 34% tax, and \$10,000 annual working capital required for maintenance, media, and overhead. Table 3 illustrates the approach used in estimating the net annual cash flow. A specific set of variables is used in this table, such as a volume of 6 scans per day, and \$100K equipment cost.

Scanning cost per photograph:			\$35
Working days per year:			240
Scans per day:			10
Number of frames processed annually:	$240 * 10$	=	\$2,400
Annual revenue from scanning:	$2400 * 35$	=	\$84,000
Annual working capital (maintenance, media, etc.):			\$10,000
Annual cash flow (revenue – working capital):	$84,000 - 10,000$	=	\$74,000
Depreciation (based on 5 year and 100K):	$100,000 / 5$	=	\$20,000
Taxable cash flow (cash flow – depreciation):	$74,000 - 20,000$	=	\$54,000
Tax:	$34% * 54,000$	=	\$18,360
Net cash flow or cost savings:	$74,000 - 18,360$	=	\$55,640

Table 3. Estimating Procedures of Annual Cash Flow/Savings Using Specific Variables

A net cash flow of \$55,640 is expected annually throughout the lifetime of the scanner, based on 10 scans per day. Although the scanning workload may vary from one day to another, a realistic workload can be estimated from previous years and from forthcoming mapping projects. The real workload is controlled by the overall softcopy operations the company would undertake. The annual cash flows resulting from volumes ranging from 4 through 14 scans are listed in Table 4. These annual cash flows will occur throughout the lifetime of the systems. In this case, five years is used which is consistent with the tax law in the United States.

Scans Required per Day	4	6	8	10	12	14
Annual Cash Flow (\$1000)	22.4	33.5	44.6	55.6	66.7	77.8

Table 4. Annual Cash Flow for Various Scanning Volumes

The annual cash flow is in fact a future return, generated as a direct result of the capital investment that is made now in acquiring the in-house scanning capability. The future return must then be compared to the invested capital to find out if the investment is profitable. The future cash flow is thus converted into the corresponding present value based on a specific discount rate, hence the *discounted present value*. The discount rate is the target rate of return the investment must achieve. For the purpose of this analysis, a 20 percent annual rate of return is used. The relation between daily scanning activity and discounted cash flow of future cash flows is depicted in Figure 1. This figure shows the present value of scanning cost (or savings) for a range of scans per day based on a 20% discount rate. In examining the figure, we find the discounted cash flows are progressively smaller than the cumulative annual cash flow for a particular year. For example, in the 6 scans category, the discounted cash flow from 5 years is \$100K. This is smaller than \$167K, which corresponds to an identical period (i.e., 5 years) accumulation of cash flow of the \$33.5K listed in Table 4.

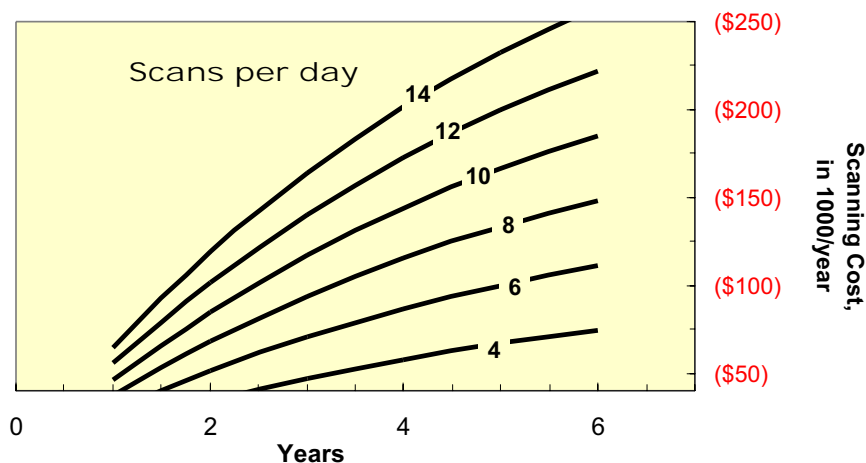


Figure 1. Discounted Cash Flow of Future Scanning Cost/Savings based on Variable Scanning Volume and 20% Discount Rate

The discounted present value of net cash flow is hence weighed against the initial capital. Establishing in-house capability would be favorable if the discounted present value is larger than the initial capital. This difference between the discounted cash flow and the total initial capital is a primary profitability measure called the **net present value** and abbreviated as NPV. It not only indicates whether investment in in-house capability is favorable, but also differentiates among different levels of initial investment. To calculate the NPV, the cost of equipment must be known. A range of equipment costs is discussed in the next section.

#### 4 IN-HOUSE CAPABILITY: COST AND BENEFITS

There are several commercial precision scanners that vary in functionality, performance, as well as cost. Many manufacturers consider their primary competitive advantage as their barrier to entry against competition. This is directly dependent either on overall value, or on innovation and automation. A low-end system can provide a balance between price range and performance, hence an overall value. The price for a complete system in this category is about \$50,000. High-end systems, on the other hand, offer automation in labor-intensive tasks, such as automatic film rolling, and on-the-fly interior orientation. The price for a high-end precision scanner is about \$150,000. A mid-range cost of about \$100,000 is also selected. These three categories represent a realistic range of cost in the market at the time of writing this paper. The initial cost of these systems is summarized in Table 5. The total initial capital consists of the cost of equipment and the net working capital at the time of initial investment. This has been already estimated at a \$10,000. Further, the actual implication of initial cost is influenced by the depreciation period. As mentioned in the previous section, relevant tax laws dealing with depreciation of computer hardware dictate 5 year. Cost effectiveness can therefore be expressed in terms of the equivalent annual cost (EAC) for each investment, as shown in Table 5.

Investment	Initial Cost	EAC
Low-Cost Scanner	50	20.06
Mid-Range Scanner	100	36.78
High-End Scanner	150	53.50

Table 5: Initial Cost and Equivalent Annual Cost, EAC, in \$1000

The EAC determines present value of initial cost calculated on annual basis throughout the system's lifetime, based on a specific rate of return. This is the same rate used earlier, which is 20%. This rate is used in view of the alternative options available in the investment market. EAC for each system is the initial cost spread over the system's theoretical lifetime. The resulting values are consistent with the initial cost, as one would expect. The decision of which system to select, and consequently the initial capital, will have consequences on future cash flow and net profit. These factors are key to profitability of various investment options. The task at hand thus becomes estimating the annual net cash flow for each of the three options based on the above assumptions, as well as on the corresponding annual net working

capital. The annual net cash flow values, listed in Table 6, are calculated using commonly known finance procedures. Table 6 shows starting year's net return with a negative value, simply because this is an outflow, not inflow. This outflow consists of the cost of equipment plus net working capital for start-up year, \$10,000. These figures are sufficient to determine whether the investment yields a favorable NPV. Under the above assumptions, acquiring in-house scanning capability will result in net profit ranging from \$21K to \$100K. The difference is clearly the result of the initial capital invested. The resulting NPV must be used, exclusively, to determine whether the investment is at all favorable against outsourcing. A positive NPV indicates the investment is favorable against outsourcing. A negative NPV means that the present value of estimated future return is less than the total initial capital. In general, this indicates the investment is undesirable.

Investment	Years						NPV
	0	1	2	3	4	5	
Low-Cost Scanner	-50	52.2	52.2	52.2	52.2	62.2	100
Mid-Range Scanner	-100	55.6	55.6	55.6	55.6	65.6	60
High-End Scanner	-150	59.0	59.0	59.0	59.0	69.0	21

Table 6. Estimated Annual Cash flow And The NPV, In \$1000.

It has been shown that the NPV helps deciding whether establishing in-house scanning capability is a favorable investment when compared with outsourcing. It must not be viewed, however, as the primary tool to decide between scanners. For instance, in Table 6 the investment in the low cost scanner yields the highest NPV. Does this mean that this capital would yield the most profitable investment? To answer this question, multiple criteria are used decide which one is most profitable among proposed capital investments.

One measure that is closely related to NPV is the internal rate of return, abbreviated as the IRR. This measure is defined as the discount rate that generates a present value of future net cash flow that is equal to the initial capital. Consequently, the IRR is a rate of return that results in a zero NPV of an investment. Another measure is the discounted pay back period - the duration at which the sum of the discounted cash flows becomes equal to the future value of initial capital. A proposed investment in a scanner is deemed acceptable only if its discounted payback is realized within predefined time. The investment will breakeven at the discounted pay back period then continue to generate net cash flow thereafter. Such positive net cash flow beyond the payback period is profit. Furthermore, the discounted pay back period itself depends largely on future net profit from scanning workload, as shown in Figure 2. For example, a \$100,000 initial investment will have a payback period of less than three years if there is a need for 10 scans per day. If there is higher work volume of 14 scans per day, the payback period will be shortened to less than two years. The scanner, however, must sustain heavier workload, which means highly automated, higher cost scanner.

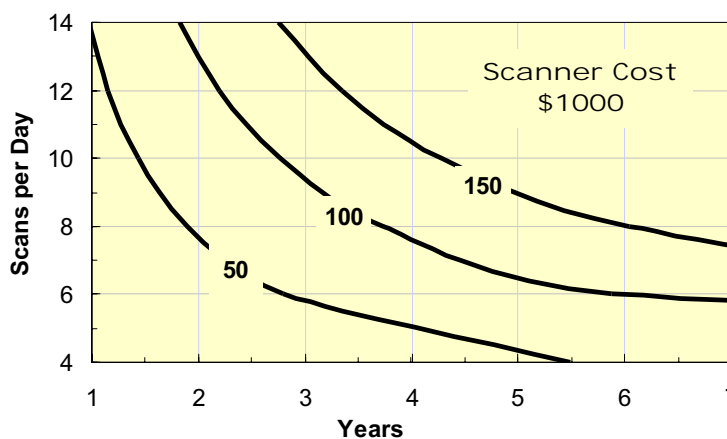


Figure 2. The Discounted Pay Back Periods Based on Variable Scanning Workload.

These criteria are applied on the same three cost options and the results are shown in Table 7. In examining the table, the IRR leads to the same decision made earlier based solely on NPV. Similarly, the discounted payback is the fastest in the same cost option. The table also shows that each EAC is different, yet still favors the low-cost option.



Investment	Profitability Measures		
	NPV (\$K)	IRR %	DPB (Yrs)
Low-Cost Scanner	100	0.61	1.43
Mid-Range Scanner	60	0.36	2.76
High-End Scanner	21	0.20	4.28

Table 7: Comparison Of NPV, Internal Rate of Return And Discounted Pay Back

## 5 CONCLUSIONS

In this paper, the economics of image acquisition alternatives for digital photogrammetric production is discussed. These alternatives are direct digital acquisition and scanned film photography. Direct digital acquisition includes digital frame cameras and high-resolution satellite imagery. High-resolution imagery is increasingly available for photogrammetric production. This source has the potential of becoming economically feasible, particularly for medium scale mapping, and also in special applications.

Scanning of film photography includes outsourcing and in-house capability. A methodology has been presented for cost and benefit analysis of these imagery sources as used for softcopy photogrammetric operations. The methodology is applied with a specific set of variables, assumptions, and a forecasting risk that is within acceptable limits. These variables include anticipated workload, future cash inflow, discount rate, equipment cost, depreciation, overhead, and cost of commercial scanning. The validity of the analysis is as good as the reliability of the estimate of these variables. In this particular analysis, the variables have been defined with reasonable accuracy, such as the initial capital, annual cash flow, depreciation, and net working capital.

The most critical factor in deciding between outsourcing and establishing in-house capability is the estimated future cash flow. This in turn is a direct function of anticipated scanning workload. Furthermore, the capital needed for in-house scanning capability can be justified with sustained workload for the duration of the scanner's lifetime.

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