MAXIMIZING THE PROFITABLITY OF MULTI-CHANNEL TRAINING DISPLAY SYSTEMS

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Abstract

Multi-projector alignment systems capable of comprehensive alignments within a few minutes per channel were first developed for flight simulation trainers in 2001. While the maintenance technicians who use these systems respond favorably, the expected cost savings associated with their use have been difficult to demonstrate. The analyses presented in this paper illustrate that a fast and accurate display calibration system is a necessary but not sufficient means for reducing costs associated with simulation training. The fast and accurate calibration system is better described as an "enabling technology" that allows the use of other technologies and maintenance procedures that are the source of significant cost savings. This paper illustrates how the use of a capable display calibration system in conjunction with COTS projectors and a rapid swap maintenance strategy can save the simulation training center operator several hundred thousand dollars over the life of a system.

Proposition 1

Suppose that you used an automated alignment system with enough speed and accuracy that you could reliably perform a display system calibration within two minutes per channel…

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What would be the value of this system? Debate on this topic began in 2000 when work started on the first modern, comprehensive[1] alignment system for multi-channel flight simulation display systems (see Lloyd, et. al., 2003). While no one has disagreed that faster is better, the expense of a very capable alignment system has been more difficult to justify financially than one might expect. Some reasons for this are described in this section. In the following two sections we show that it is not until you combine the fast display calibration capability with specific display system features that you achieve significant financial benefits.

Reduced time to run calibrations

The typical way simulation professionals initially assess the value of Proposition 1 is to compare it with their existing alignment system. The typical automated alignment system of today is used once every few days to

1. Circa 2000 all alignment systems used in the flight simulation training industry used camera systems that measured one alignment mark at a time requiring 20 to 30 minutes per channel to complete a spatial alignment. In 2002 Lloyd et. al. first installed a system that measures 100+ alignment marks per camera image and uses measurements of 400+ alignment marks per channel to compute the settings of 200+ projector geometry controls. This system completes all geometry, convergence, and blend zone co-alignment adjustments within two minutes per channel. Using eyepoint based measurements, this system corrects distortion produced by stretched-film collimating mirrors. This same system also performs static and dynamic focus, gamma correction, and white point adjustments.

weeks, most often during a regularly scheduled maintenance interval. Assuming these systems require on the order of an hour to align three channels and that the proposed system requires six minutes[2]:

Value: Savings of about 54 minutes, once every few days to weeks.

Surprisingly, training center managers do not get as excited as you might expect at the prospect of very fast display calibrations. When pressed, they politely explain that their maintenance technician does not sit idle while their existing alignment system runs. Rather, the technician attends to maintenance tasks on other trainers during this time. In the unusual event that the maintenance interval for a single trainer fills up with required tasks, and that trainer is badly in need of calibration, a fast calibration system is more interesting. However, because this is an unusual event, the savings derived from a fast alignment system do not justify reducing the number of technicians per trainer the center must keep on staff. Thus, the cost savings expected due to a fast alignment system are not significant.

Expected Savings: ≤ a few K$ / year

When compared with a revenue stream of around 6 M$ / year per trainer[3], we must agree that the direct savings are not particularly interesting.

Improved Image Quality

A well agreed upon benefit derived from Proposition 1 is that the calibration system can be run every day. Thus, image quality of the display system would be consistently as good as possible. This potential benefit usually stimulates more interest by center technicians and managers who relate that they are too often criticized for not keeping all portions of the field of view perfectly converged or all blend regions perfectly intact.

Few simulation training professionals would disagree that sustaining high image quality would be *valuable*. Unfortunately, we do not know how to assign a defensible dollar value to this dimension of the proposition.

Value: Consistently high image quality
Expected Savings: Debatable

The net benefit expected from acquiring a fast and capable display calibration system falls somewhere between "not very" and "valuable but difficult to quantify." When the design of a new trainer is being discussed with customers during the proposal process it seems the ability to keep image quality in top shape is highly valued. When it comes to negotiating the cost of the trainer, the value of the display calibration system seems to decrease significantly.

Proposition 2

Suppose that you could make all display system calibrations in the image generator rather than relying on projector-based corrections...

At first glance this proposition appears valueless since the vast majority of projectors used in the simulation training industry over the past decade employ projector-based corrections. Plus, most of the *new* projectors sold by the incumbent projector vendors in our industry provide projector-based corrections.

The value of image generator (IG) based display corrections is clearly illustrated when we look at the relative costs of these specialty projectors. For these comparisons, the quantity "dollars per mega pixel" (DMP) will be used rather than direct projector costs because the resolutions of the current crop of projectors vary so widely. The past few years have seen products proposed that sport 1.5, 2, 3, 8, 10, 16, and 32 Mpix.

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2. The FlightSafety Display Management System (DMS) can measure 1500 alignment dots and complete a full spatial calibration in 30 seconds per channel.

3. Assuming the typical "rent" on a trainer and instructor is 1000 $/hr and trainer is actually operated 6000 hr/year.

Raster-Calligraphic CRT Projectors

The great majority of Level D trainers in service today are populated with raster-calligraphic (R/C) CRT projectors from several vendors. Over the past few years the initial purchase DMP of these projectors is estimated to be approximately 35 to 65 K$/Mpix depending largely on the number of pixels the raster mode is set up to produce. Many would argue that the equivalent resolution of the calligraphic mode is higher than the raster. We agree with this position (see Lloyd, et. al., 2007), thus, we estimate an initial DMP of 20 to 40 K$/Mpix for the night/twilight mode of the R/C CRT projector.

Over 15 years a training center will spend 40 to 50% of the initial cost of the projector replacing consumables (primarily CRT assemblies), thus, the life cycle DMP for the R/C CRT projectors is estimated at 1.45 times the initial DMP.

Initial DMP:
35 to 65 K$/Mpix day mode
20 to 40 K$/Mpix for night/twilight
15 year DMP:
50 to 95 K$/Mpix for day mode
30 to 60 K$/Mpix for night/twilight

Non-CRT Simulation Projectors

Over the past five years several non-CRT projector technologies have been introduced for simulation training applications. The most heavily promoted of these has been the liquid crystal on silicon (LCoS) technology for which three or four vendors now sell viable projectors. In addition to LCoS, several vendors are selling simulation-grade 3-chip DLP projectors for training applications.

One projector of interest is the Sony 8 Mpix SXRD, an LCoS projector designed for the digital cinema market which is about 100 times larger than the simulation training display market. Over the past few years the initial purchase price of this projector with lens has listed at around 100 to 110 K$. Assuming a pixel utilization factor of 0.7 when this (or any other fixed matrix) projector is used in a typical simulation trainer, the initial DMP comes out to about 20 K$/Mpix.

When compared with the R/C CRT option described above the initial DMP of this projector looks quite promising. However, the reader is cautioned to carefully evaluate the DMP over the expected life cycle of the trainer. With most LCoS and LCD projectors as well as DLP projectors that use complex color separation and recombination optics with many cemented optical components (e.g., 3-chip), it appears that the "light engine" has a limited life. We have heard life estimates ranging from 10 to 35 thousand hours for these projectors. We understand that it is difficult for anyone to develop firm life estimates given the newness of these products and rate of change of their designs. Several vendors offer the option of rebuilding the light engine within the projector at a cost that is less than the initial purchase price of the projector. Expecting that a projector rebuild would require sending it back to the factory for at least some weeks, you would need several spare projectors on hand to avoid taking the trainer out of service during this time.

What this means to the simulation training center operator is that these projectors must be replaced or rebuilt somewhere between "twice" and "many times" over 15 years. Accounting for the need for spare projectors, projector rebuild or replacement costs, options, required accessories, and the cost of replacement lamps, the 15 year DMP for this class of projector is estimated at 2.5 to 4 times the initial DMP. Thus, relative to the R/C CRT we are so familiar with, the life cycle DMP of this particular 8 Mpix LCoS projector is not so attractive.

Initial DMP: 20 K$/Mpix
15 year DMP: 50 to 80 K$/Mpix

Today a half dozen models of "purpose built," 2 to 10 Mpix, LCoS and three chip DLP projectors are available from several vendors targeting flight simulation training. While we have not done a complete survey of costs, it appears that the initial and life cycle

DMPs of these products are similar to the Sony 8 Mpix SXRD.

The reader is encouraged to compute the initial and life cycle DMP of any proposed display system they are contemplating as this figure normalizes the effect of differing projector resolutions. Remember to account for the lens, options, cables, optical blend assemblies, and any other parts that are tied to the use of that projector. When comparing with our numbers, remember to divide by the pixel utilization factor in order to account for the unavoidable waste of pixels that occurs when fixed-matrix displays projected onto curved surfaces. Most importantly, remember to request the expected life of the projector (light engine) and lamps as these are the largest drivers of life cycle cost.

Digital COTS Projectors

As of Q1 2008 the huge investments of those projector manufacturers targeting the home theater market (about 10,000 times the size of the simulation training display market), have brought us some interesting projector options. Today you can purchase a 3 to 6 K$ home theater projector that rivals or surpasses the performance of many of the (non-CRT) simulation grade projectors of just three years ago. And it appears that the performance to cost ratio of the home theater projectors will continue to improve at a rapid pace.

Our assessment of the initial DMP for this class of projector is between 3.5 to 7 K$/Mpix considering the specific model, lenses, lamps, required accessories, cables, and pixel utilization factor. If LCoS or LCD projectors are selected you should expect the 15 year life cycle DMP to be on the order of 2.5 to 4 times the initial DMP as these types of projectors are expected to wear out at about the same rate as the LCoS projector described in the previous section. If a single chip DLP is selected, then a smaller multiplier can be used for the life cycle DMP as this type of projector is expected to last longer because there are far fewer optical components in the optical engine.

Initial DMP:
3.5 to 7 K$/Mpix
15 year DMP:
10 to 15 K$/Mpix for DLP 1 chip
14 to 20 K$/Mpix for LCoS, or LCD

Making comparisons across these three classes of projector reveals the significant cost savings afforded by use of the COTS projectors. The initial cost of COTS projectors is on the order of 15 to 30% of the cost of the projectors that have been purpose built for simulation training. Over 15 year life, the cost of the COTS option is about 20 to 35% of the cost of the simulation specialty projectors.

If the industry sticks with the typical three-channel, six to eight-ish Mpix display systems they have used for the past decade for Level D trainers, electing the COTS projector option potentially reduces the initial cost of the display system by 100 to 150 K$ and the cost over 15 year life by 250 to 350 K$.

Value:
Reduced initial and life cycle cost of projectors and related expenses.
Reduced dependence on a single specialty projector supplier.
More affordable spare projectors.

Expected Savings:
100 to 150 K$ initially,
10 to 15 K$ / year for remaining life

As you can see, substantial cost savings are available through the use of COTS rather than the more typical purpose-built projectors. But, the use COTS projectors is not possible unless all display system corrections can be made in the image generator. And this system is not likely to be practical unless it is supported by a capable automated display calibration system. The savings available from this class of display system are many times greater than the savings obtainable from simply adding a capable alignment system to a typical display system with projector-based corrections.

Proposition 3

Suppose that you could replace a failed projector within 3 minutes …

Coupling this proposition with a two minute recalibration time (Proposition 1) and a few minutes to let the lamp warm up, plus a few minutes for the maintenance technician to report to the trainer to make the swap, recovering from a catastrophic projector failure within 10-12 minutes becomes feasible. It would seem that this new "rapid return to training" capability offers significant value to the training center operator. In this section we attempt to quantify the value of this new capability. As you will see, this value depends on the potential frequency of training disruption due to display failures and the mean time required to recover from these failures.

In the analyses that follow, two commonly used acronyms will be used. MTBF refers to the classic "mean time between failures." In this paper the mean time to repair (MTTR) includes all activities that occur between the time of the failure and resumption of training.

With the CRT projectors installed in the great majority of trainers today, three or four display system failures per year are typical and we assume that only one or two of these take long enough to repair that the pilots have to be re-scheduled. Using this as our baseline for comparisons, the projector MTBF is quantified in Figure 1 which shows a histogram of times between failures.

When projector failures occur, sometimes they can be diagnosed and repaired quickly enough (e.g., ≤ 15 minutes) that the pilots can complete their training with little disruption and no need to re-schedule. More often, the diagnosis and repair requires more time (e.g., 15 minutes to an hour) and the center may have to rearrange the training schedules for the remainder of the day to accommodate the students. Occasionally, the failure may be difficult to diagnose or your projector expert may not be on shift, or a significant recalibration must be done after replacing a part, or the parts required for the repair are not in stock and must be shipped. In the latter case, the trainer may be taken out of service for several training blocks or days. This situation is quantified in Figure 2 which shows a histogram of the expected repair times.

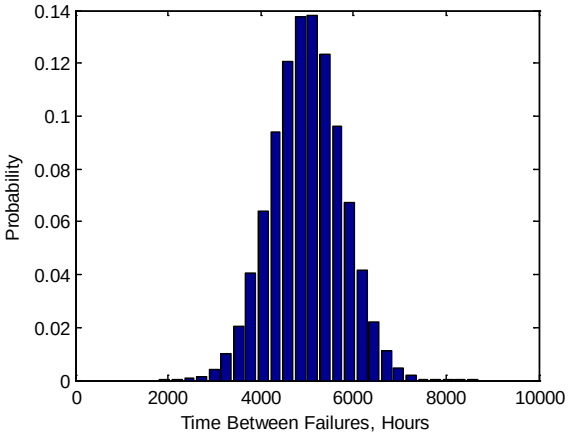

Figure 1. Histogram of the expected time between failures for a single projector with an MTBF of 5000 hours.

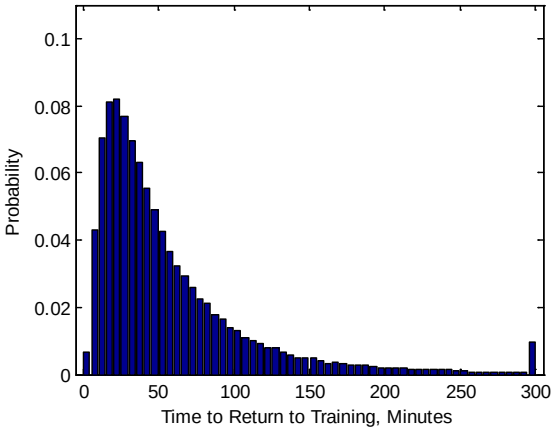

Figure 2. Example of expected repair times (MTTR = 60 minutes) for a projector that is not quickly replaceable.

Using the data conveyed in Figures 1 and 2, the expected loss of revenue over 15 years due to taking the trainer out of service can be computed using a stochastic simulation and assuming the trainer and pilot instructor cost $4000 per four hour training block. The results are shown in Figure 3.

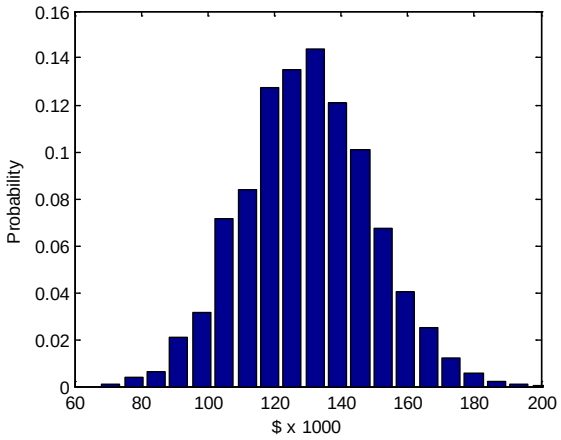

Figure 3. Expected cost of down time due to projector failures for the example three channel display system that does not incorporate quickly replaceable projectors. Analysis uses the data from Figures 1 and 2 and assumes the trainer and pilot instructor cost 4000 $/training block or 20 K$ per day.

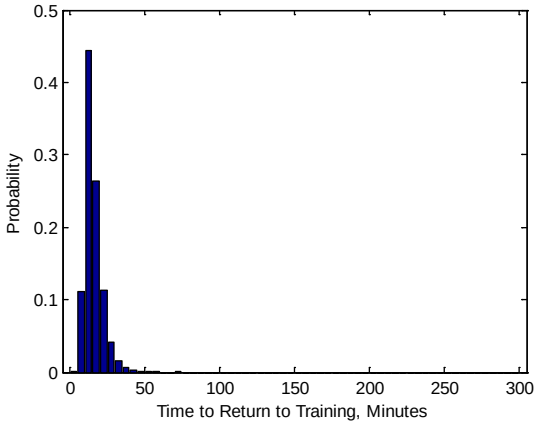

Figure 4. Example of expected repair times (MTTR = 15 minutes) for projector that is quickly replaceable.

In this example, the trainer was out of service due to display failures an average of only 6 days in 15 years for a mean revenue loss of 135 K$. At an MTBF of 5000 hours per projector and an MTTR of one hour, we see that the potential for revenue loss due to display failures is many times larger than the cost saving potential of implementing only Proposition 1 as described in the first section of this paper.

Next we examine the effect of using quickly replaceable projectors on revenue loss over the life of the display system. The histogram shown in Figure 4 represents the time required for a maintenance technician to report to a trainer with a failed projector, swap out the projector, let the lamps warm up, and recalibrate the display system. From these data you can see that we assume it will be a very rare occasion where you have to cancel training and reschedule the pilot due to a projector failure.

Using the data in Figures 1 and 4 to re-compute the stochastic model, we find that the expected revenue loss due to projector failure induced loss of training is less than 5 K$ over 15 years.

Managing the Risk of New Technology

In today's world of rapidly changing technology it is difficult if not impossible to obtain meaningful estimates of the mean time between failures (MTBF) for the newest projectors. The reason for this is MTBF measurement requires a stable product design that gets tested over many units over a long period of time. At the current rate of design change, few projector manufacturers will likely afford the time to collect these data. At their typical production volumes, the simulation specific projector manufacturers are not likely to be able to commit a sufficient number of units to life testing.

With the typical display system design of today, for which the projectors are not quickly replaceable, the training center operator is at risk of revenue loss that is approximately proportional to 1 / MTBF of the projector. If the projector MTBF of the previous example were 2500 hours rather than 5000, the expected revenue loss would increase to 270 K$.

The expected revenue loss is also approximately proportional to the number of projectors. For example, the expected loss for a seven channel display system with 5000 hour MTBF projectors is 315 K$ over 15 year life. We believe it this scaling of the expected down time with the number of channels that is the primary reason customers are wary of increasing the channel count.

So how do you convince a potential customer that your proposed display system will have high availability and thus cause insignificant loss of revenue? You are not likely to tell a convincing story if your argument is based on claims of a high projector MTBF because you are unlikely to have credible performance data for the projectors.

A much more convincing case can be made for very high system availability if you work the MTTR angle. It is far easier to *demonstrate* the MTTR of a projector than it is the MTBF. Today we can demonstrate for you that we can reliably disconnect, remove, replace, reconnect, and automatically calibrate a failed projector in under 10 minutes.

We expect the most highly variable subtask in the failure recovery process is the time it takes for the maintenance technician to show up at the trainer to make the swap. Assuming the mean time to report to the trainer is 5 minutes, we believe that you can achieve a mean time to return to training of 15 minutes. This time is short enough that you will rarely loose training revenue due to a failed projector.

As you can see then, it is the "quickly replaceable" and not the "high MTBF" attribute of the projector that allows the display system vendor to guarantee very high display system availability. The MTTR can be readily *demonstrated* to the customer prior to their committing to the purchase. The MTBF cannot.

What if you ended up with lemons?

Suppose your three channel display system somehow got populated with a projector model that performed well out of the box but turned out to have a low MTBF, let's say 2000 hours rather than 5000. In this case the MTBF of the set of projectors would be 667 hrs and you should expect 9 projector swaps per year. But since you can now reliably swap out a failed projector and return to training within 15 minutes, you are not at risk of revenue loss. The primary penalty you will incur is that your maintenance technicians may get a bit ornery due to their increased workload. You may also find yourself purchasing another spare projector or two after the fact.

In the unfortunate event that you ended up with lemons, you do not have to live with them for very long as you are protected by Propositions 2 and 3. Because of IG-based display corrections, the display system can tolerate the use of several models of projector, all of which cost far less than the typical purpose-built projectors historically used in our industry. And because your projectors are quickly replaceable, changing or upgrading to a new projector model is relatively painless.

Continuous Upgrade Strategy

Speaking of upgrades, the combination of Propositions 1, 2, and 3 provide another high value benefit not attainable with the typical display plus automated alignment system of today: the ability to continuously upgrade the display system. The fast and capable display management and calibration system described here depends on no specific features of any particular model of projector, and because the projectors are easily swappable, you can adopt a more cost effective upgrade strategy. Gone are the days of the "all or none" strategy where you must take your trainer out of service for weeks to tear it down and rebuild it with the projector upgrade. Rather, with a display system defined by Propositions 1-3 you simply replace old or failed projectors with new, one at a time if you wish.

Riding the Technology Wave

Three to four years ago you could not find a projector with a CR greater than 1000 or as many as 2 Mpix for less than 20 K$ Today the home theater vendors have available dozens of 2 Mpix models with CRs in the range of 5 to 10000 for well under 10 k$. We expect the performance of these products to continue to improve and their cost to continue to decrease.

Looking across the pack of manufacturers of consumer projectors, we see that new models with distinctly better performance are brought to market a couple of times a year. The product design and launch cycles of the incumbent projector vendors seems to be between one and two years for their simulation-grade projectors. By the time they can decide on what the simulation training industry wants, develop and test the design, and transition the design into production, the home theater projector manufacturers beat them to market with much less expensive products that provide nearly the same value.

Maintenance Skill Requirements

The sudden existence of inexpensive, light weight, capable, and quickly swappable projectors will have a significant impact on training center maintenance activities. With the new display systems, if you even *suspect* a projector is malfunctioning you swap it out and perform the diagnosis on the work bench. You may even adopt a strategy of changing lamps on the work bench rather than up on the trainer as this requires you to clean air filters and paths and check the general condition of the projector regularly.

It seems the days of complex and time consuming manual adjustments, board swaps, oscilloscopes, tweak tools, and week long projector training courses are waning. With this new class of display system your maintenance technicians will need to become adept at lamp changes, projector swaps, filter cleaning, and packing up and shipping projectors with any significant problems back to the vendor for repair. These skills are significantly easier to acquire than the expertise needed to keep a set of R/C CRT projectors in continuous operation and looking good. The impact of simplified maintenance on training center profitability derives from the fact that *any* of your maintenance technicians can quickly learn the rapid swap procedure. Your ability to avoid revenue loss will no longer depend on the availability of your "projector specialists" who cannot possibly be on site every shift.

Conclusions

- The savings expected from upgrading an otherwise typical display system with a fast and capable automated alignment system is estimated at less than a few thousand dollars per year.
- The addition of IG based corrections enables significant cost savings because much less expensive COTS projectors can be used. Savings in the range of 250 and 350 K$ can be expected over a 15 year life cycle.
- The addition of a quick projector swap capability is expected to significantly reduce revenue loss due to display failures. For a three channel system with a projector MTBF of 5000 hr. and a MTTR of 1 hr., the reduction in lost revenue of about 130 K$ over a 15 year life cycle.
- The expected availability of new display systems of the typical design is nearly impossible to estimate because the MTBF of new projectors is not likely knowable. The use of rapidly replaceable projectors reduces the MTTR to the point that high display system availability can be demonstrated at the time the trainer is purchased.
- Adoption of a fast, capable calibration system, IG-based corrections, and quickly replaceable projectors reduces the level of skills and experience required of maintenance technicians to the point that any of your technicians can rapidly and reliably recover from a display failure.

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