DØ Computing and Software Operations and Plan

The DØ Collaboration

September 2005

Abstract

This document reports on DØ Computing and Software operations as well as the current evolution plan for the next several years. It updates DØNote 4616, produced for last year's Run II computing review. It includes scope and cost estimates for hardware and software upgrades, with a detailed equipment spending description for the next few years. In view of the amended charge, particular discussion is devoted to the methodology and resources necessary to ensure a successful completion of Run II.

Contents

1. Introduction

This document reports on DØ Computing and Software operations as well as the current evolution plan for the next several years. It updates DØNote 4616, produced for last year's Run II computing review. It includes scope and cost estimates for hardware and software upgrades, with a detailed equipment spending description for the next few years. In view of the amended charge, particular discussion is devoted to the methodology and resources necessary to ensure a successful completion of Run II.

1.1 Overview

DØ's computing operation continues to run rather. Reconstruction has kept up with the accelerator's excellent performance and the detector's high data-taking efficiency, data handling (SAM) works extremely well, remote Monte Carlo production has doubled since last year, we are reprocessing most of the Run II data set remotely (on SAM-Grid) and analysis cpu power has generally been sufficient.

However, maintaining this state will require significant effort since the dataset is expected to roughly double on a yearly basis, while resources are expected to increasingly be diverted to the LHC experiments. Our computing model was based on distributed computing from its origin, with progressive evolution to the use of standard common tools on the grid, allowing us to use shared resources. Virtually all resources used for production activities, namely Monte Carlo and reprocessing, are already indeed at shared facilities. A data grid (SAM) has been used since the start of Run II as the sole means of data transport, enabling local / remote production tasks as well as FNAL-based / remote analysis (with local job submission). The focus for the computational grid (SAM-Grid[a]) so far has been on production activities, leading finally to user analysis as the most complex activity. All of the current reprocessing, including use of spare cycles on the central FNAL farm, is carried out via SAM-Grid. Full integration (as opposed to the current co-existence) of SAM-Grid with other grids, e.g. LCG and OSG is an ongoing project. At FNAL we are migrating the reconstruction farm to use SAM-Grid rather than custom scripts, and will then convert this farm, along with our central analysis resource (CAB) to OSG.

Whilst believing that this "grid path" is the necessary approach, there is still considerable ongoing development to make the experiment grid-compatible, particular as the LHC computing model (and associated grids) are also under evolution. DØ is one of the first experiments to follow the grid path, so despite developing shared solutions wherever possible (SAM is used by three FNAL based experiments), as a running experiment, unique solutions had, at times, to be

[a] SAM-Grid is supplied by the Fermilab Computing Division via a joint project with participation from the Run II Computing and Analysis Department, the CCF Department, and the CEPA Department, as well as external effort from the GridPP project and other collaboration effort.

implemented. Thus we are now, naturally, critically dependent on SAM-Grid and its ongoing evolution to make it compatible with other grids.

As well as the technological developments necessary for the 'grid path' it is also necessary to recognise the in-kind contribution represented by the provision of significant computing resources. After considerable discussion we settled several years ago on the concept of the 'virtual centre'. The 'virtual' cost of carrying out all computing tasks at FNAL is evaluated, using standard FNAL costings. A country's fractional contribution, as measured by events produced rather than nominal cpu provided, is used as the input to determine their in-kind contribution, in turn determining any common fund reduction. Using a model driven by actual contribution rather than nominal cpu provided has proven very successful. This model will be used as the basis for the costings carried out in Section 8.3.

1.1.1 Managerial Structure and Document Layout

The DØ computing management structure remains basically unchanged, with the additional creation of a deputy co-ordinator with primary responsibility for remote computing activities. Additionally there have been several replacements, and the up-to-date organisation chart can be found at http://www-d0.fnal.gov/d0_org.html.

The document follows the same structure as last year's, with particular emphasis on: remote activities, namely Monte Carlo and reprocessing, in Section 3; SAM-Grid development in Section 7 and manpower and budget issues in Section 8.

2 Computing Needs

2.1 Production Executables

In the previous years, the simulation and reconstruction has seen a number of successive production releases, often several a year. As the algorithms have stabilized, the efforts have shifted towards a better understanding of the detector and the differences between real data and simulated data. These efforts demand long and complex studies and for this reason only one major production release, p17, was introduced this year. Since January, the reconstruction version of p17 has been available, and we have recently released the improvements to the simulation code. All aspects of the code have been improved; the details will be highlighted below. The focus has now shifted to preparations for a first 'fixing' pass which will apply detailed corrections to the calorimeter calibration and the material in the tracker. A second primary focus is the preparation of the algorithm and infrastructure modifications to accommodate the Run IIb upgrades to the trigger and tracker systems.

2.1.1 Reconstruction

For the reconstruction code, the p17 release has included the detailed calibration of the electromagnetic portions of the calorimeter which have been determined for all data-taking periods in Run II. As of July, the detailed calibration of the hadronic layers of the calorimeter has also been available. The offline calorimeter calibration database has been brought into production running for the first time in Run II, enabling a reprocessing of all of the Run II data, which should be completed during October. The hadronic corrections will be applied during a further ``fixing'' pass through the data since they were not ready when the full reprocessing began in order to provide the full dataset by October. Sufficient information is stored in the thumbnail (most compact) data to allow this fixing to be done at this high level.

A new treatment of the material in the tracking volume will also be incorporated into the fixing pass. This will use the new material description of the detector developed over the past year, and will employ the novel feature of track refitting using the information stored in the thumbnail data tier.

As mentioned last year, the previous reconstruction version (p14) was reaching its limitation in terms of speed, as can be seen in Figure 1, at instantaneous luminosities around $10^{32}cm^{-2}s^{-1}$. A significant effort was initiated with help from the Computing Division to address this problem from the computing point of view (speed of the current algorithm) and the algorithm and physics points of view (tuning of algorithm versus physics trade-off). The results of "computing" improvements can be seen in the Figure, where the p17 reconstruction time versus instantaneous luminosity is compared with the previous version. The improvement varies from ~20% at low initial luminosities of 0.2 x $10^{32}cm^{-2}s^{-1}$ to more than a factor of two at luminosities of 0.8 x 10^{32} $cm^{-2}s^{-1}$. Currently algorithmic improvements are under study; additional, significant gains seem possible.

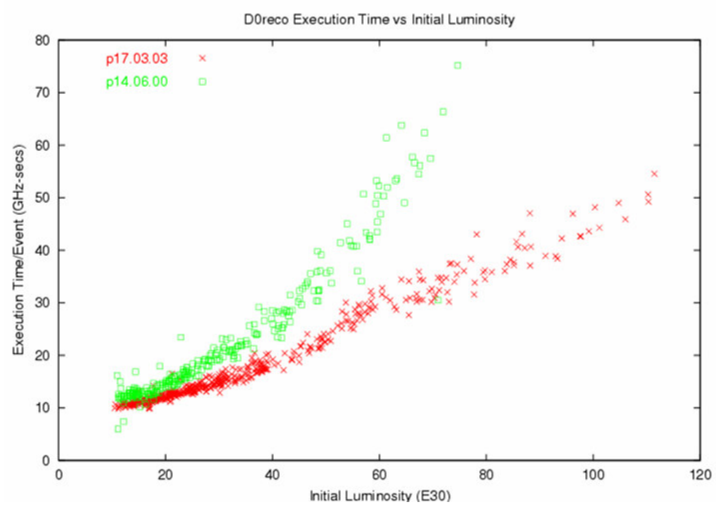

Figure 1: Average reconstruction time per event for p14 and p17 as a function of initial instantaneous luminosity for the run.

2.1.2 Simulation

It is essential for the DØ physics program to provide a realistic simulation of the detector. First, an improved description of the material within the tracking volume has been implemented in the simulation (and in the reconstruction). Second, studies have shown that overlaying real data events over generated signal events to simulate the effect of pileup and multiple interactions significantly improves the agreement between data and simulation of the tracking performances. These capabilities are now available for large scale Monte Carlo (MC) production; large datasets of zero-bias events have been processed to provide a proper luminosity- and time-weighted distribution of occupancy in all detectors. Significant effort has also gone into updating the existing MC generators, incorporating new PDF libraries, and adding new generator packages to the release. Effort continues on understanding the detailed description of the interactions in the tracking detectors and the calorimeters in order to improve the agreement between data and simulation.

2.1.3 Prospects

Sometime this Fall/Winter, the Run IIb upgrades will be installed in DØ. This will include a significantly altered Level 1 Trigger system and an additional inner silicon layer for the tracker. All of these components need to be properly read-out and incorporated into the reconstruction code. Their performance will also need to be simulated, both to develop the algorithms necessary for their incorporation into the reconstruction code and to optimize their performance. This effort is rapidly approaching maturity. The trigger simulation code is nearly complete, and has already enabled detailed rate studies during the design process of new trigger terms. For the new silicon Layer 0, GEANT and detector geometries exist, hits can be produced in simulation, and tracking algorithm development is well underway. We estimate that final algorithmic software work on both systems will be complete during the next month, after which the simulation can be used to optimize performance. Development of code for the upgrade of the central fibre tracker electronics has also begun; delivery of this system is expected mid-way through 2006, so time pressure is less severe in this case.

2.2 Data Analysis

2.2.1 Post-processing

After the data have been reconstructed on the farm, the Common Samples Group (CSG) runs it through the so-called “fixing” and “skimming” processes. The fixing applies corrections for improvements selected after the production release was cut or important algorithm modifications. It consists of unpacking the thumbnail, correcting some calorimeter cell energies, re-running jet, electron and missing E_T algorithms, refitting tracks, and then repacking the thumbnails. The skimming selects events, based on reconstructed physics objects, and writes them to corresponding streams. One or more of these ``skims" forms the base data sample for the vast majority of the physics analyses. We are currently in the process of fixing the entire Run II dataset, data that have been reprocessed with p17 but missing key corrections like the hadronic calorimeter calibration and fuller treatment of the material in the tracker. We anticipate that this will finish shortly after the reprocessing. Crucial datasets, such as that used for the determination of the Jet Energy Scale in the calorimeter, have been processed first to allow fast analysis of the final event sample.

2.2.2 Data Format

First we provide a brief history. Up to now, different physics groups and individuals have taken different approaches to using the thumbnails. Some have decided to work within the framework, using the thumbnails directly. Since the unpacking of the thumbnails depends on so much of the DØ code, however, linking of the executables required very significant amounts of memory, and remained slow even on well-equipped machines. The recently introduced possibility to used shared libraries has improved this situation dramatically, but this development was sufficiently late in the analysis history that thumbnail-based analyses had already been rejected by most groups in favour of analysis on root-based datasets. There exist multiple root formats however, used by different groups. Producing these, and keeping the data on disk proved to be a strain on analysis resources, and a Common Analysis Format (CAF) was developed. This is a root-based format that contains much of the information in the existing thumbnail. As well as reducing the required resources, a common format brings numerous efficiency gains, including easier sharing of data and analysis algorithms between physics groups and reducing the development and maintenance effort required by the groups. Such centralization should also lead to faster turn-around between data taking and publication. In addition to CAF, the CAF Environment (CAFÉ) has been developed; this very effectively provides a single, user-friendly, root-based analysis system, forming the basis for the common tools being developed. The analysis groups are currently developing such common tools for standard analysis procedures, such as trigger selection, object-ID selection and efficiency calculation, etc., so that all groups can benefit from shared effort. This development effort and the conversion of analysis code are expected to be completed as the reprocessed and fixed data from p17 become available.

2.2.3 Resources

The computing power available at Fermilab for data analysis has proven adequate. As the dataset grows however, disk and cpu demand is likely to increase in proportion. While we expect to be able to supply the necessary resources in the short term at least, as discussed we are working towards enabling the use of grid resources for individual user analysis jobs as well as production tasks. To achieve this without introducing a significant learning curve, the necessary tools and interfaces are being built into *d0tools*, with which the majority of DØ users are already familiar – see Section 7.2.

3 Computing Systems

3.1 Reconstruction Farm

3.1.1 Current Status

The current DØ reconstruction farm consists of 448 dual processor worker nodes, 12 dual processors for input staging and an 8 processor SGI Origin system which is used as a disk server to the workers as well as an output buffer and stager. The worker nodes are a mix of 1GHz PIII, 1.67GHz Athlon, and both 2.6 and 3.0GHz Xeon class machines. The total compute power of the system is approximately 1550 GHz in PIII equivalent units. In the last year one node has been set up to act as a SAM-Grid head node for running part of the farm as a Grid operation. Buffer space for the Grid operation is provided by the Origin machine.

At this point 240 of the worker nodes are located in New Muon Lab (NML) and 176 nodes in the High Density Computing Facility (HDCF). Operation of the farm with workers distributed at multiple locations has so far worked well, however stability of both power and cooling at NML have been problematic over the past year. We currently expect to move all worker nodes to HDCF this Fall. The current plan is to schedule the move concurrent with electrical work to be done at HDCF in the Fall of 2005.

3.1.2 Performance

Data taken after the Fall 2004 shutdown with the V13 trigger version have been processed on the farm with the p17.03.03 version of the reconstruction program (*d0reco*). This version has performed at a level comparable to p14.06 with respect to robustness. Data taken with the V14 trigger version have been processed with the p17.05.01 version of the reconstruction program.

Significant effort was put into fixing the residual failure modes of *d0reco* in the p17.05.01 version. We currently have processed about two months worth of new data with p17.05.01. So far we have no processing losses of data due to *d0reco* crashes except for ones attributable to a known corruption problem in the raw data.

Performance of the p17 version of *d0reco* has been significantly improved with respect to the p14 version. Figure 1 shows the performance of the reconstruction program under both p14 and p17. On its busiest days the DØ detector records abut 3.5 million physics events which go to the reconstruction farm. Assuming an 80% operating efficiency for the farm and 1550 GHz of compute capacity we can see from the plot that the farm can keep up with a detector running at 100% duty cycle if the average initial luminosity is no more than ~0.6 x $10^{32}cm^{-2}s^{-1}$. As the average luminosity grows beyond that we become dependent on the limited duty cycle of the accelerator and detector to keep up with data acquisition. With an accelerator and detector duty cycle of 33% we could survive up to average initial luminosities of at least 1.2 x $10^{32}cm^{-2}s^{-1}$. Note this is a lower limit and not an extrapolation. Current data do not give us enough information to clearly extrapolate to the exact cut-off point. Thanks to the highly efficient operation of the farm we have some spare capacity, and this is currently used for reprocessing via SAM-Grid. Note the above assumes that all cycles are available for reconstruction processing and that the data rate coming from the online system does not change. At present this rate to tape is limited by offline computing capabilities to 50 Hz. Our request to increase this, as originally planned for Run IIb, is discussed in Section 8.

3.1.3 Planned Expansion

The functionality of the SGI server node on the farm will be distributed to linux nodes over the coming year. The farm SAM station will be moved to an existing 2 processor worker node. A 2 TB fibre connected raid array has been purchased to replace the ageing disks on the SGI node. These disks will be served out by 4 existing dual processor worker nodes. This new disk array is already in place although the functionality has not yet been moved to the new array.

There will also be an expansion of the capability of the SAM-Grid headnode. This will be accomplished by distributing the head node functionality across three separate dual processor nodes. One node will handle the standard job submission actions, one node will be used for XML DB logging, and one node for I/O operations. Existing worker nodes will be used for this redeployment.

Current plans are to add 140 dual processor nodes to the reconstruction farm by the beginning of calendar year 2006. These are expected to be Opteron nodes equivalent to 3GHz PIII processors. This will bring the total capacity of the farm to 2390GHz. However, 240 existing Athlon nodes will fall off warranty in November 2005. These nodes will not be repaired as they fail so the average capacity over the 2006 calendar year will be somewhat less than 2390GHz. It is also expected that additional nodes will be added in FY 2006, see Section 8 for overall budget request.

3.2 Central Analysis Systems

As planned DØmino was retired at the end of CY04 and has been replaced by a linux-based login pool, with the mail server moved to the imapservers. In a similar way disk space is served from linux servers. We have ~ 60TB of scratch and project space and 130 TB of SAM cache served in this way. These disk servers are located in FCC and linked to the DØ network by at least gigabit connections.

Both CAB (Central Analysis Backend) and clueDØ (our cluster of institute maintained desktop linux PCs) continue to expand as planned and so only very brief updates are given below. CAB (together with clueDØ) have provided sufficient analysis power during the last year.

3.2.1 CAB

CAB is centrally provided and actually consists of two sets of nodes, cabsrv1 and cabsrv2; these now consist of 192 and 344 worker nodes respectively. These are linked to ~130TB SAM cache via ~20 server nodes. The benefits of this increased SAM cache are discussed in Section 5.1.1. As part of our 'grid' evolution CAB will be converted to the FermiGrid / OSG infrastructure during the next year.

3.2.2 ClueDØ

ClueDØ now numbers over 420 nodes, providing ~ 450 batch slots. Disk space continues to be provided as different volumes under /rooms/..; there are now some 120 rooms providing ~ 100TB of disk space. These IDE raid arrays are centrally located on the second floor in the DØ assembly building. System administration continues to be provided by a local administrator from each providing institute and a core team of 7-8 people. Recruitment can at times be problematic.

3.3 Remote Computing

There has been considerable activity in this area in the last year. A particular success is the ongoing reprocessing of virtually the full Run II data set (~10^9 events); this has been carried out entirely using SAM-Grid and has been possible through the very significant advances made to this project over the last year. In parallel we have produced some 75 million Monte Carlo events. We preserve here the 'historical' separation of the two tasks, though with the increasing use of SAM-Grid both should be considered simply as production computing.

3.3.1 Monte Carlo Production

In the last year the DØ experiment has produced some 75 million Monte Carlo (MC) events, twice the number produced in the year before. See Table 1 for a breakdown by site. The two largest producers have been IN2P3 and 'Nikhef'. All Nikhef production is actually carried out on LCG sites, accepting the DØ V0. This 'first step' of LCG interoperability has been in operation for several years, and is in the process of being fully automated / extended – see Section 7.1. The number of MC events could be larger, but for two major factors. The start of p17 reprocessing in the spring of 2005 reallocated very significant resources from MC production to reprocessing. In conjunction with this has been the transition from p14 to p17 MC over the summer. The transition has resulted in a relatively low number of available MC requests. These two factors are reflected in the drop off in MC production since spring. Over the first 8 months of the past year MC production averaged 13.6 million events per month. The last 4 months, after reprocessing had gotten underway in earnest, the average MC production was 2.1 million events per month. The bulk of production in these last 4 months has been from Nikhef because, as a non-SAM-Grid site, it is not participating in the p17 reprocessing.

Site	Events	Size (MB)
GridKa/Wuppertal	4552800	222052
LTU	501750	24471
LU	863263	46651
OU	1618000	86907
SPRACE	3687155	191528
Tata	793800	41997
UTA	2691941	147193
Wisconsin	12778	771
CCIN2P3	32066167	1939765
FZU	7740563	385985
Lancaster	4320975	176929
Manchester	100500	6276
Nikhef/LCG	17148986	883450
TOTAL	76098678	4153975

Table 1 Monte Carlo production by site.

As part of the ongoing migration to common tools, the DØSAR sites have been converting to SAM-Grid based production. LUHEP, OUHEP, and LTU have or will shortly convert from the McFarm jobmanager to the SAM-Grid jobmanager. SPRACE has converted from McFarm non-grid production to SAM-Grid based production. Production at Tata, Lancaster, and Manchester has decreased due to hardware upgrades and limited manpower at these sites.

As reprocessing winds down in the Fall, very significant resources will become available for MC generation, including both existing and new sites. Switch-over to MC from reprocessing requires very limited effort for these sites as the SAM-Grid infrastructure handles both types of jobs. Based on the reprocessing experience it appears possible to use non-DØ resources for MC production beyond the LCG activity mentioned above. The CMS-FNAL farm and the Wisconsin cluster are being operated via the grid, whilst OSG/SAM-Grid “co-existence” was successfully demonstrated for the first time on the OSCER and CMS-FNAL clusters. The ongoing programme of work relating to making SAM-Grid interoperable with LCG and OSG is discussed in Section 7.1. In addition, new resources are expected to come online and be available for MC generation, including new clusters at OU, in Rio De Janeiro, at LSU and University of Mississippi. It should be noted however, that the bulk of our MC production takes place at large, shared non-US Tier-1 sites.

Another positive development is the increase in bandwidth that is being put in place in the US and internationally. Many DØ institutions will be taking advantage of connections to the National Lambda Rail with similar improvements in Europe and South America underway. This additional network capacity will increase the efficiency of DØ's grid based MC production.

In summary, despite the reduced production numbers of recent months, the outlook for MC production appears bright. The reasons for the limited production are understood. Very significant resources will be available when reprocessing ends and new grid installations are planned for the near future. DØ MC has been a pioneering application in the use of grid technology and by further embracing and extending grid based production should be able to provide adequate simulated events for physics data analysis.

3.3.2 P17 Reprocessing

The investigation of real data leads to an improved understanding of the actual detector performance and thus improved reconstruction algorithms. Some of these improved algorithms can only be performed on the original raw data format, requiring data base access. To make these improvements available for data originally reconstructed with older software releases, the data have to be re-reconstructed. The most notable improvement of the new p17 software release is a new calorimeter calibration which is implemented with a database.

Before the November 2004 shutdown, after which the p17 software version became available, DØ had collected and reconstructed around 470pb^{-1} corresponding to 1000 million events. This amounts to 250TB of raw input data, to be processed into 70TB of TMB output files. At an expected processing time of 50s/event[b] the effort requires 20,000 cpu months or 1600 cpu years on 1GHz Pentium III processors. Given that the experiment required the task to be completed within 6 months, the number of required cpus was equivalent to 3400 1GHz Pentium III. As it was assumed that the d0farm was used to its capacity, or close to, by processing the incoming data, the complete cpu resources for this effort had to come from remote sites.

The TMB files produced as output by *d0reco* are much smaller than *0*(1GB) input files. As tape access is only efficient for large files, multiple output files must be merged to reach a file size of 1-2GB. A small number of files below this goal is acceptable. In addition, the files that are merged are required to stem from the same physics run and must be reconstructed with identical *d0reco*

[b] It should be noted that the above number contains contingencies that account for file delivery and inefficiencies occurring in cluster operations. Thus the actual running speed of d0reco is much faster.

versions. This requirement leads to a two-step application flow. In the first step, raw data files are fed into *d0reco* to reconstruct the physics event and to create TMB output files. During this step, access to the calibration database is needed. After all individual files have been reconstructed, they are then merged into larger files of the same format in the second step. Only these merged files are then stored to the tape system (enstore).

The entire effort was carried-out using SAM-Grid. Besides providing a common runtime environment, a grid also provides a common interface for the job submission, allowing the development and use of common tools for job submission, merging and recovery. SAM-Grid enables a submitted grid job to be performed by multiple parallel batch jobs on separate cpus. This feature is used to do the production step (step 1). Each file within the dataset of raw files associated with a single grid job is processed by a separate batch job. The resulting thumbnails are stored to a "durable" SAM location associated with the cluster on which the grid job is running. In order to distinguish these files from the final merged thumbnails, a specialised datatier, "unmerged-thumbnail", was created within SAM. The second step (merging) was implemented as a separate grid job. Even though a parallelisation would have been possible this wasn't pursued. Greatest effort was put into avoiding data duplication i.e. assuring that results from one and the same raw input file can't be merged into more than one output thumbnail. Both the SAM-Grid client (submission commands) and the scripts actually performing the merge verified that no other thumbnail produced from the same raw data file with the same application_name and the same version had been previously merged. The former check was implemented to create a fast job rejection in case of a conflict; the latter check is needed to minimise the possibility that such a conflicting file is produced between submission and completion. The intermediate unmerged thumbnails are not needed after the merged files are successfully stored to enstore and so are removed from disk and the SAM locations are erased. They remain as virtual files in the SAM database.

Inevitably, in such a big production effort, one has to deal with errors such as disk failure, network interruptions, server crashes, etc. In contrast to MC production, special care needs to be taken to avoid any data duplication or data loss. Reliable book-keeping is necessary. An efficient way of recovering from failures is crucial for an efficient production, and a two prong approach was used. The SAM database keeps track of all stored files. The associated metadata allows the determination of the application_name and version used for production as well as the (list of) parent files. Thus the SAM database was chosen to determine the completion of tasks, to avoid data duplication and to construct recovery datasets. In addition, the JIM[c] component of SAM-Grid provides job monitoring information on the grid- and the batch-job level in an XML database that is also accessible through a Web interface. The information fed into this database was tuned to contain the main failure messages needed to allow fast diagnostics for system problems and thus a fast recovery of service.

---

[c] JIM, Job Information and Monitoring, provides the job submission and monitoring aspects for SAM-Grid.

As mentioned, the use of grid mechanisms for job submission provides a uniform interface for operators at all sites, allowing for the use of common operational tools. The tool developed, *d0repro*, consists of three layers. The lowest layer shields the creation of job description files (jdf) that describe the desired job. Only the dataset name and the *d0release* to be used need be specified. Other parameters needed by SAM-Grid are constructed from these or taken from the local configuration. This layer shouldn't be needed by the operators. The second layer adds the ability to verify the completion status of grid jobs. This information is stored in local files, imitating the behaviour of a request system. Based on the status information, the operator is protected from various common mistakes, such as submitting the same request twice or submitting a request without a sufficiently long-lived grid certificate proxy. This layer is used by the operators for manual operations. On top of these commands, a so called auto-pilot layer is built. The autopilot aims to suggest the most obvious next step and creates a script that can be used to automatically perform these suggestions e.g. for complete production jobs the corresponding merge job is suggested. The most recent version adds a feature to approve (and later submit) a production request for each merge job automatically, thereby allowing one to maintain a constant production load without intervention. This layer aims to reduce the workload on operators by automating reoccurring standard tasks but in its current form still requires manual supervision. The long term plan is to automate all production tasks, with the off-line shifter being responsible for initial job submission and monitoring.

Before the production effort was started, all aspects of the software and the infrastructure were thoroughly tested. The *d0reco* executable was deployed on the d0farm and 20pb^{-1} were processed with the standard procedures and then given to the physics and algorithm groups for verification. Each version of the *d0release* tar-ball for SAM-Grid was certified by comparing the plots from results obtained on the d0farm with SAM-Grid mechanisms to the equivalent plots obtained from thumbnails produced by the standard procedures. These plots were generated and overlaid using the DØ recocert package. To confirm that the grid infrastructure was operating correctly on all participating clusters the production and the merge step had to be certified by each site. The production certification was achieved by producing thumbnails for a specified dataset of raw input files and comparing the histograms produced to the reference histograms. The merge certification was done on separate datasets for each site. Plots obtained from the unmerged-thumbnails were compared to those obtained from the merged thumbnails. Both sets of comparison plots had to be approved by the algorithm convenors before a site was allowed to start official production.

The significant resources required for this undertaking were mainly provided by shared computing centres that provide their services to several experiments / user-groups with different requirements. To participate in the data-reprocessing, each site was required to provide one or more nodes on which some DØ specific services could be installed. The required services were the SAM-Grid job-manager for Globus to accept and manage jobs, an XML database server for monitoring information, a SAM station to provide data management, and a database proxy to cache information from the DØ calibration database. Participating sites are the CMS-FNAL farm, D0SAR-OSCAR, D0SAR-SPRACE, D0SAR-UTA, GridKa, IN2P3, Prague, UK (several sites), WestGrid and Wisconsin. The CMS-Farm at Fermilab was special in that the SAM-Grid job-manager was integrated onto the existing OSG environment and that the SAM services were provided by DØ nodes elsewhere on site.

The production started on 25th March 2005. The first sites to be certified and start production were Lyon and WestGrid. Others followed over time. Due to the improvements in the speed of *d0reco* it was also possible to use spare cycles on the d0farm, again using SAM-Grid. After 5 months nearly 80% of the data are reprocessed, see Figure 2. Continuing at the current speed the bulk of the project should be completed in October. Fuller details, including monitoring of both overall status and the site efficiencies, can be found at http://www-d0.fnal.gov/computing/reprocessing/ and in ref [1]. We intend to produce and publish in a referred journal a complete write-up of this activity.

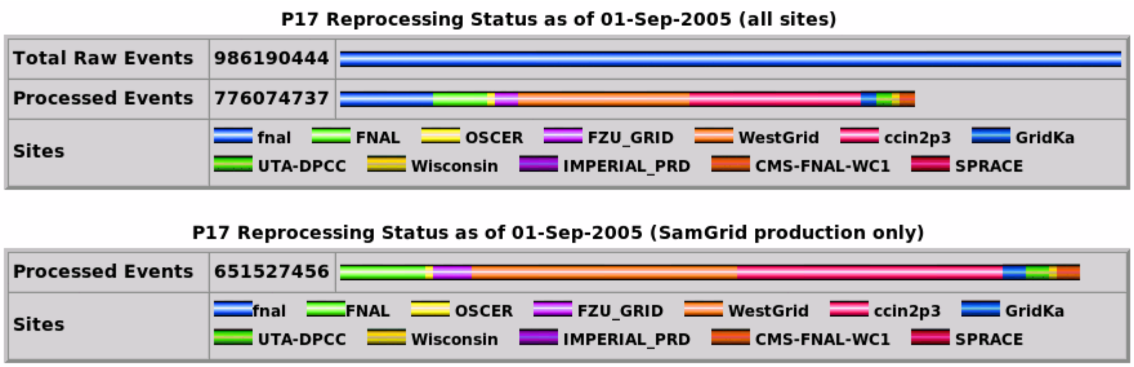

Figure 2: Status of p17 reprocessing as of 1st Sept 05.

3.4 Online Systems

The DØ online systems support data acquisition from the detector readout elements, slow control systems, data quality monitoring, and control room activities. The Level 1 hardware trigger for DØ accepts events at a rate of ~1.6 KHz. A Level-2 system, a hybrid of dedicated hardware and software elements, reduces the accepted event trigger rate to ~800 Hz, for which the entire event information is transferred to a Level 3 software filter farm. The event data readout path begins at ~80 VME readout crates, each containing a Single Board Computer (SBC). Under the guidance of a specialized SBC, the routing master, each SBC transfers event fragments via Ethernet through a Cisco Catalyst 6509 switch directly to a selected node in the Level 3 filter farm. The Level-3 software trigger reduces the accepted event rate to one which is deemed manageable for offline analysis, currently ~50 Hz. Accepted events are passed by Ethernet via a 2nd Cisco Catalyst 6509 switch to a chain of Host system applications: a Collector process which acts as the target of Level-3 transfers and which forwards the data stream to Data Logger processes and a Distributor process. The Distributor process distributes event data to data monitoring applications. The event data is buffered on local disk arrays, then transferred to the Feynman Computing Center (FCC) via the enstore and SAM systems. The slow control system consists of ~110 embedded VME processors, in both the DAQ readout crates and crates dedicated to controls. DØ employs the EPICS control system, and has expanded its functionality to provide a structured detector configuration architecture, a complete significant event (alarm) system, and a variable archiving and retrieval system. The Host system supports the "back end" of the DAQ task for logging and monitoring of event data. The Host system also supports detector control and configuration tasks, and houses an Oracle database for those purposes. The general online computing infrastructure is also supported by Host file servers, application servers, and web servers.

The bulk of recent additions to the Online system have been associated with the Run IIb upgrade project. There were three components of the upgrade associated with the Online: a Level-3 farm upgrade, a Host system upgrade, and a slow control system upgrade. Online network additions associated with the RunIIb upgrade are discussed elsewhere. With the expected increase in instantaneous luminosity expected in RunIIb, and the corresponding increased event complexity, it is necessary to expand the computing capacity of the Level-3 farm. In July, 2005 a 128-node (dual 2.8 GHz Xeon processor) addition was made. This brought the total Level-3 farm to 274 nodes (corresponding to ~1000GHz-equivalent processors). For RunIIb, the Host system was changed from one based upon a cluster of three AlphaServers to a much more flexible Linux cluster configuration. There are now four high-availability clusters sharing a Fibre Channel Storage Area Network (SAN). The SAN contains ~4 TB of JBOD disk for event data buffers, and ~6 TB for detector support functions. The linux clusters support the DAQ services, NFS file services, Oracle database services, and various Online application services. The upgrade to the DAQ servers now allows highly parallelizable data logging, with a rate capacity exceeding ~250 Hz. The final component of the Run IIb Online upgrade was the slow control system. Approximately 50 of the latest generation of PowerPC boards were purchased to upgrade the older, slower control system processors. A number of the replaced processors are now maintained as spares, with the expectation that there are sufficient numbers to satisfy needs for the remainder of the Tevatron running period. The newly installed upgraded processors allow a number of monitoring functions to now be enabled, providing for closer monitoring of detector behavior.

The funds for the Run IIb upgrade were expected to provide the online computing capacity sufficient for the duration of the DØ detector operation at the Tevatron. The one exception to this expectation was the Level-3 software filter farm. The 128-node addition for Run IIb was sized to meet the filtering application processing time requirements for a Level 2 accept rate (Level 3 input rate) of ~800 Hz at an instantaneous luminosity of ~2 x $10^{32}cm^{-2}s^{-1}$. The uncertainty in the extrapolations from current conditions used in this calculation, plus the expectation that the instantaneous luminosity will increase to ~ 3 x $10^{32}cm^{-2}s^{-1}$before Run IIb is complete, leads to the expectation that the Level-3 farm will need further enhancement. The expansion of the Level-3 farm is limited by several factors: funds, the number of network ports required to maintain the Ethernet based DAQ, and the DØ site power and cooling infrastructure. The timing of any expansion is also affected by the capabilities of the processors that can be purchased at any time. The introduction of multi-core processor architectures will ease several of the constraints. The DØ plan is to add Level-3 processing as needed and as late as possible. We expect to retire older systems to make way for new. The funding for expansion must come from operating funds - with an expected need of ~$50K per 32-node (multi-core, dual processor) addition. There may be need for several such additions if the accelerator performs as expected.

4 Databases

4.1 Offline Calibration Database

The calibration constants for the tracking detectors and the calorimeter are served to the reconstruction processes on the Fermilab reconstruction farm and to the jobs that users run for their own purposes via the DAN client-server system based on the CORBA technology and developed by the Computing Division and DØ. This system can also deliver calibration constants for the muon subsystems to *d0reco*. Up to now the muon group has not used this facility for *d0reco* processing, but is planning to use it in the near future, with updated database tables.

The database has been in use since June, 2003 and is fully reliable. There is one dedicated linux node for running the calibration DB servers for the farm, and another for the non-farm users. Since these nodes are not supported 24/7, there is a failover node and a procedure in case of troubles with the server nodes. However these nodes are three years old and will need to be replaced in the near future.

The DØ farm runs ~600 processes and requests a new set of calibration constants on average every 100 seconds. It takes about 90 seconds of wall-clock time for a *d0reco* process to receive one whole set from the servers, including the time for marshalling data on the servers and un-marshalling them on the client. The cpu usage of the farm server node is about 5-10% and the network usage out of the server node is about 30%. This implies that up to a three-fold increase in the number of the farm nodes can be handled without upgrading the network interfaces.

The p17 remote reprocessing started in late March and the calibration constants have been delivered to the remote processes through the remote proxy servers since then. There are now ~10 participating sites. The system is reliable and we have not had problems with serving calibration constants to the remote institutions.

One possible future problem with the system is that the interface to the Oracle database is based on a freeware python package that is no longer supported by the developer. It is preferable to be prepared to switch to a different, supported, interface.

4.2 Luminosity Database

Many existing components of the luminosity software are based on ASCII files, a system which will become unmanageable in the life span of the experiment. In order to address this issue for the long term, the DØ Luminosity Group and the DØ Database Group have been developing the luminosity database application. Transferring the existing information to an Oracle database will allow us to profit from the better tools available with a modern database system.

This application is a large scale and complex project which, at its core, relies upon a set of 37 database tables and 2 views stored in a new offline production database instance on a new machine that is now being set up. The database itself contains information from many subsystems: the luminosity monitor detector, the trigger framework, the L3 system, the Tevatron accelerator and information about offline data processing (from SAM). The application includes components that will satisfy the following essential operations for the DØ experiment:

- Calculate and deliver a luminosity normalization for any given data sample
- Improve error tracking and characterization by making fundamental luminosity information available to offline programs
- Produce operations reports and graphs
- Produce quality reports by luminosity block[d] number
- Verify and certify data integrity for normalization purposes
- Additional customized reports also become possible using this system.

The database schema has been stable for a year now. Nearly all of the data taken by the experiment through 2004 have been loaded into the database tables. These data will be transferred to the production machine when the machine is available. We are in the process of loading data for 2005. The application that loads the data from the online system as the data are recorded is currently in development. With much of the data loaded, large scale testing of all the client applications, as listed above, is nearly completed. More detailed testing is underway with realistic operations use cases and actual analyses to bring each component to 'production' quality. To access the luminosity database from the analysis programs, we have developed a client-server system similar to the calibration system. The database server was generated using the same code generation system as the calibration system, and the client code (lmAccess) has been converted to use the CORBA protocol instead of reading the ASCII files. At this time, the new lmAccess performs as fast as, or faster than, the old system. We plan to move this application into production before the end of FY05.

4.3 Trigger Database

The trigger database stores trigger configuration parameters and settings entered by trigger experts including information from all trigger subsystems at each level of the trigger. These settings are downloaded at run time for physics, test and calibration data taking and used by the trigger simulator. The system includes interfaces to report this information to those physicists who are involved in optimizing data collection and/or performing offline physics analysis.

The trigger database application has been in use since the start of Run II. The trigger data base entry system and some command line interfaces rely on a database server that is similar to the SAM servers. In the last year, with personnel from the CD Database Software and the CD Run II Computing and Analysis Groups, major progress has been made to bring the web client and

[d] The luminosity block is the fundamental unit of time for the luminosity measurement.

database server components to completion. The progress has been facilitated and organized according to the trigger database project plan which describes all components of the application and includes a detailed, prioritized description of the work that needs to be completed [2]. The work, as listed in the existing plan, should be completed by the end of the calendar year. New trigger systems will come online in Run IIb and many of the new trigger features will be programmable through the existing system without changes to the database, client or server. Changes to the system may be required for some new trigger features, but how those features will be configured has not been completely specified yet.

Both the luminosity and trigger data base projects are challenging, yet rely on common key manpower. After an internal review over the summer, the experiment is working closely with the Computing Division to bring these projects to timely completion, in such a way as to provide the required functionality and maintainability.

5 Data Handling and Storage

5.1 SAM Overview

SAM (Sequential Access to Metadata) provides the only data handling mechanism for DØ, and was originally started as a joint DØ-CD division project in 1997 and has since been taken up by CDF and MINOS. A description of SAM (and SAM-Grid) and the project status are described in a different report to the review committee. This document will focus on information specific to SAM-Grid operations at DØ. In the last year, ~2.5Pbytes (~50 billion events) of (DØ) data have been shipped around the world, at up to 250TB/month. Figure 3 shows the number of gigabytes consumed per month on various stations, with Figure 4 showing the same in terms of number of events.

In addition to the SAM cache, we supply the physics and analysis groups with project space. This space is intended for highly specialized samples, code development, documentation and other group specific needs. For budgeting purposes, we assume that the amount of project disk needed is one sixth of the amount of space estimated for disk resident analysis samples. There were several important changes in the data handling infrastructure that occurred in the review period, and they are described in the following sections.

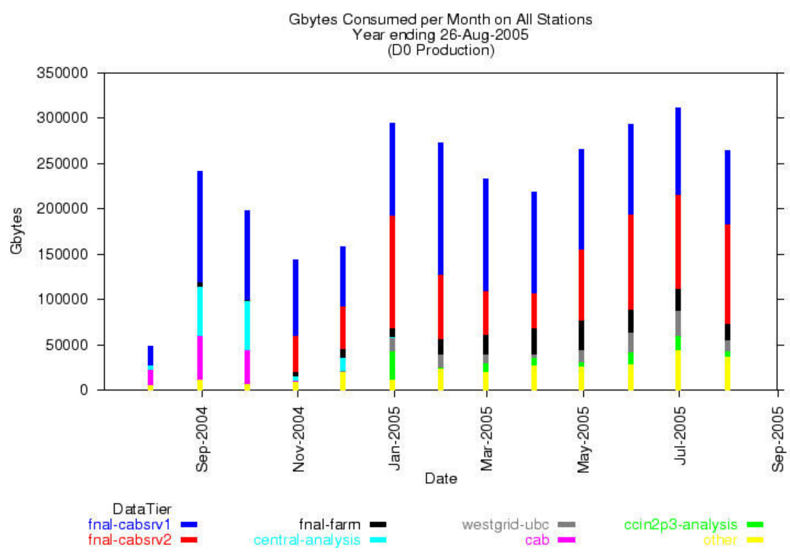

Figure 3: Gigabytes consumed per month on various stations, including central-analysis (cab, cabsrv1 & cabsrv2) and various remote sites (of which there are now, in total, ~ 50).

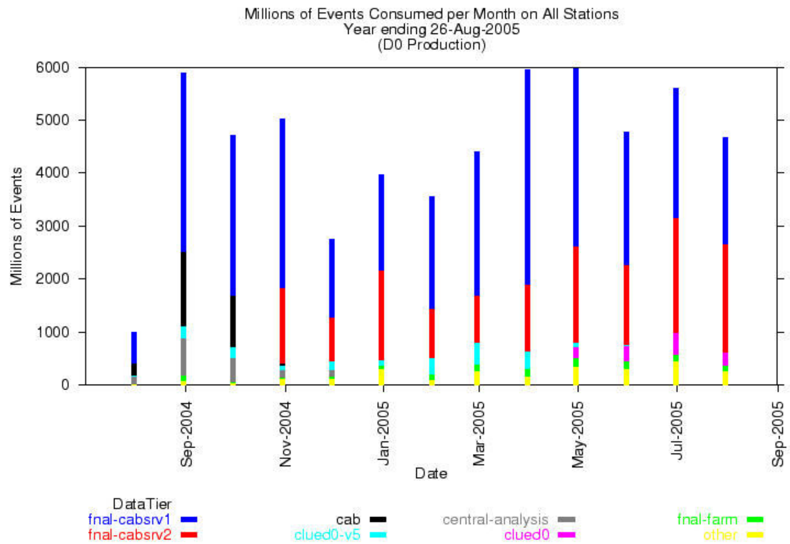

Figure 4: Events consumed per month on various stations, including central-analysis (cab, cabsrv1 & cabsrv2) and various remote sites (of which there are now, in total, ~ 50).

5.1.1 Analysis systems

DØ discontinued use of the central d0mino system in January 2005. D0mino hosted the *central-analysis* SAM data handling station, which served as the large SAM cache for the experiment. At the same time, it was noticed that the two analysis farm SAM stations (*cab* and *cabsrv1*) were pulling the majority of their files from tape, causing a large load on the tape plant.

Reorganizing the analysis farms mitigated the tape load problem. We added several *cache server* nodes with large RAID arrays to the *cabsrv1* station and route all external file deliveries through these nodes. SAM sees the server node caches as a large pool of cache, and thus files there have a much longer lifetime than files in the individual worker node caches. All external file transfers (e.g. from tape) are first routed through the server node cache and then delivered to the worker node. While this operation involves an extra disk copy than previously, the fact that files live much longer on the server cache means that subsequent requests for a file will more likely be serviced by the cache and not by tape. A quantitative analysis of the benefits is below.

Adding over 100 nodes to the analysis farm triggered another reorganization, leading to renaming the *cab* station to *cabsrv2* (for consistency). Instead of splitting the large server cache between the two stations, it was simpler to keep the cache on cabsrv1 and have that station act as a router for cabsrv2. That is all external file deliveries for jobs on cabsrv2 are routed through cabsrv1 and its large cache. The load on cabsrv1 for this routing is minimal and it ensures that files that are in demand by the entire analysis farm populate the large cache.

As of August 2005, cabsrv1 has 192 worker nodes and 22 server cache nodes. The total server cache is 133 TB. The cabsrv2 station has 344 worker nodes. To gauge the benefit of the large cache and the new routing policy, data file transfer statistics were examined for transfers occurring on the analysis farm stations between June 1, 2005 and August 22, 2005. Out of 842,000 file transfers, 32% were from tape, 38% were worker node to worker node transfers, and 30% were server cache to worker node transfers (this value does not include the extra copy required for the tape copies). Without the server cache (as was the case previous to January 2005), those latter transfers would have come from tape. Therefore, the large server cache decreases the load on the tape system by about a factor of two. This is an extremely positive development. We are in the process of evaluating if the percentage of transfers from tape to the analysis systems is at the steady-state level or not. One area under investigation is group caches with quotas to isolate data that should have short cache lifetimes such as picked raw data from samples that should have long cache lifetimes such as the skimmed tmb++ samples.

5.1.2 Upgrade to SAM v7

DØ had been using SAM v5 for several years, but much of the SAM dbserver and client code were rewritten for improved maintainability and performance and to include features essential to CDF as well as new features for DØ. This new code comprised SAM v6. Because this new version involves many more python libraries than v5 and because DØ accesses code from its d02ka NFS server, performance of SAM commands was very slow. The cause was traced to python's extremely inefficient strategy for loading external libraries (for each library, python attempts to open many files to determine the library type and if recompilation is necessary). Introducing a *frozen* SAM release, which we call v7, mitigated this problem. In the frozen release, the python executable and the SAM libraries are packaged in one executable file. This packaging reduced the SAM command time by approximately a factor of ten in some cases and has some nice side benefits, including divorcing the SAM python version from the DØ code python version and easier deployment of the SAM client code. In conjunction with the experiment schedule, the SAM team deployed v7 in stages over a three month period ending in July 2005.

5.2 Robotic Storage

The DØ data management system relies heavily on the hierarchical storage management system, enstore. Currently we write-out different types of 200 GB cartridges in three different robots. We use two STK Powderhorn silos (each with 5500 tape slots) currently writing with 9940b drives, and one tower (3500 tape slots) in an ADIC AML2 (a 3-tower system shared with SDSS who are using DLT media) writing with LTO II drives. DØ has enjoyed excellent performance and negligible data loss with the 9940b and LTO II series drives. In principle, LTO III drives could be put in the AML2; however, vendor support for that combination has not been secured as the AML2 is reaching “end-of-life”. The FNAL CD will be purchasing robot storage equipped with

LTOIII drives in FY2006 and stakeholders can purchase slots for an estimated $50 per slot (where each slot will hold a 400GB tape). This is not attractive to DØ at the moment given the large number of available slots in the AML2. At $8.50 per slot for the 200 GB tapes and the existing drive plant of LTO II, the additional cost of tape of staying with LTO II tapes would mean an increase of operating funds needed for DØ data to supply tapes, however with less in equipment funds to purchase new drives and robots. For the moment, we plan to use LTO IIs until the end of life of the AML2, and plan to add 4 or 5 drives per year. We do assume that the tape cost for LTO IIs (currently $50/tape) will fall by 20% per year. Indeed, currently it is possible to purchase TDK media for 20% less per cartridge; however the operations group insists on FUJI media, due to some concerns about the TDK media that were subsequently traced to a firmware problem. In FY2005, the DØ experiment traded some under-used 9940b drives to the STKEN system in exchange for the purchase of 4 LTO II drives. We will likely continue to use 9940b drives as an offset for other costs. Tape costs are summarized in Table 3 below.

5.3 Physics Considerations

In order to project our storage needs, we assume a data collection rate, a size for the various formats, and that all of the formats scale with the raw data rate. Whenever possible, we use our current experience as a guide. We assume that the disk cache under SAM control should be large enough to hold the most frequently accessed data samples with 100% over-capacity for other samples.

The experiment has discarded the DST format, storing additional information into the tmb+ data format, yielding tmb++. The p17 tmb++ size is 70 kBytes/event for data and 100 kBytes for MC to accommodate the truth information. Additionally, the new centrally supported root-based user format (CAF- 40 kBbytes/event) is now being deployed. For a variety of reasons we plan to keep the final step of the data processing available in both centrally supported formats (ie tmb++ and CAF) and that the SAM cache is sized to hold both. Past experience indicates that we'll need to reprocess the Run IIb data set once per year (though this may well be more frequent initially after the start-up), and run a fixing pass on the reconstructed data once per year, with a tmb++ output format. After that, the data are skimmed into samples for physics group use, with tmb++ output and root analysis format outputs. Current experience indicates that the ratio of the output to input of the skimming step is 1:1; we have asked the physics groups to reduce this to 3:4 by working towards more common samples in order to reduce duplicated events.

We assume that the peak event rate increases from 50 to 100 Hz in a two stage process, discussed in detail in Section 8.1 (and ref [3]). Folding in data sizes and scaling factors Table 2 shows the estimated amount of data for tape and disk storage. We purchase at the end of the fiscal year, so purchases in FY05 cover 06 running. We estimate the need for cache disk as a percentage of the raw data collected in a year. For *d0reco* development, testing, fixing and special analysis, we assume that we need cache space for 10% of the raw data (250 kBytes/event) and 30% of the

TMB++ and for analysis, we plan to accommodate the full skims in Common Analysis Formats and TMB++ formats as well as a modest amount of Monte Carlo data. We anticipate that the use of groups in SAM cache will enable us to isolate the analysis cache from the raw data cache. We assign a contingency of 40% on the cache space. The physics group project space is estimated at 1/6 of the cache space. In addition, university groups purchase fileservers for use on cluedØ.

Data samples (events)						
	Current	2005	2006	2007	2008	2009
Events collected	1.00E+09	8.16E+08	1.09E+09	1.09E+09	1.09E+09	1.09E+09
Total events		1.82E+09	2.90E+09	3.99E+09	5.08E+09	6.17E+09
Geant events		1.22E+08	1.09E+08	1.09E+08	1.09E+08	1.09E+08
PMCS events		0.00E+00	1.09E+08	1.09E+08	1.09E+08	1.09E+08
Tape data accumulation (TB)						
Yearly storage (TB)	**731**	**627**	**888**	**1,102**	**1,308**	**1,515**
Total storage (TB)	**731**	**1,357**	**2,245**	**3,347**	**4,655**	**6,171**
Disk data accumulation (TB)						
Total storage (TB)	**88**	**140**	**186**	**186**	**186**	**166**

Table 2: Data sample sizes and consequent tape and disk requirements

5.4 Cost Projections

The cost of tape is estimated in Table 3, assuming all of the year's data are written to blank tape. We do not include the cost of duplicating the data, nor the cost of migrating any data until 2009 when we assume that a 1TB technology will be available. A possible economy is the reuse of tape as older reconstruction versions become obsolete.

		2004	2005	2006	2007	2008	2009
DataVolume		731	627	888	1,102	1,308	1,515
# to retire		0	0	0	0	0	10000
Tape Cost		$182,650	$156,650	$177,680	$192,815	$229,005	$239,260

Table 3: Tape cost estimate. The 2004 number shown is not the 2004 increment, but the total amount of data DØ currently has on tape.

For the FY2005 project and cache disk purchases, we have ordered 15 TB useable disk space ATABeasts systems at a cost of $20,500 k per system. For out-year cost projections, we assume continuing with the ATABeast systems, and scaling up the size of the useable space by 20% per year. In the past, we purchased different types of systems for cache and project space in order to provide more reliability for project space while keeping the costs lower for cache space. The ATABeasts have the performance and reliability and features we desire for project space, with competitive costs for cache disk, so we are using this for all of our needs. The cost of disk storage is given in Table 4, with the data volumes coming from Table 2. The contingency is that used in the past and covers such things as the evolution of format size with luminosity and uncertainty in the use of cache space. (The associated costs for file servers are shown in Table 9.) The 2005 number is projected from the spreadsheet and is in reasonable agreement with the 2005 pending requisitions.

		2005	2006	2007	2008	2009
Data Volume (TB)		140	186	186	186	166
Project Volume		23	31	31	31	28
Total volume		164	217	217	217	193
Contingency		40%	40%	40%	40%	40%
Cost		$328,000	$348,500	$328,000	$307,500	$307,500

Table 4 Disk cost estimate.

6 Networking

6.1 Infrastructure

The principal elements of the network infrastructure supporting DØ Computing are noted in Figure 5 in Appendix 1. These elements and the functions they provide were described in detail in last year's review document. Significant changes during the previous year include:

- Two switches, s-d0-gcc-1 and s-d0-gcc-2, have been added to support nodes at the Grid Computing Center (GCC, aka HDCF). The gcc-2 switch currently has ~300 free ports, and is targeted for support of recent node acquisitions.
- The Feynman Computing Centre (FCC) CAB switch, s-d0-fcc2-cab, will soon also move to GCC. It is currently ~2/3 populated, and will provide ports for an additional ~100 nodes.
- The switch supporting the DØ Online system, s-d0-dab2cr-online, will soon have an upgrade of its router module and an addition of a 48-port Gb blade. This will allow it to serve a larger number of Gb-enabled Linux servers.
- The switch supporting the Level 3 system, s-d0-dab2cr-l3, has been fully outfitted with 48-port 100Mb blades in order to support the increased number of Level 3 filter farm nodes. A planned supervisor module upgrade will allow another 48-port blade to be utilized.

A Gb connection is now in place allowing direct communication between the CAS switch and Starlight (ref http://netweb.fnal.gov:8080/starlight.html). This path has been used, for example, in data transfers to WestGrid.

6.2 Utilization and Prospects

Figure 6, Appendix 1, shows recent network utilization, in bits per second, on the principal switch interconnects within the DØ network and to the external network. There are several links which show peak utilizations near the link capacity, primarily those serving the reconstruction and analysis farms in FCC, GCC, and NML (New Muon Lab). The external links to Starlight and the FCC core router are also heavily utilized. The network infrastructure appears adequate for DØ needs. Approximately 400 ports are available to support planned additions to reconstruction and analysis farms. The primary network interconnects are mostly operating comfortably within capacity. The largest anticipated growth in DØ network traffic is on the links to the new farms in GCC, to analysis operations at DAB, and off site via the Starlight connection. DØ is thus planning to upgrade each of these links to 10Gb, at a cost of ~$15K per link.

7 Data Handling, Resource Management and Tools

DØ uses the SAM-Grid data handling system at all levels in its online and offline systems, to move files, manage resources, to perform production computing & user analyses and handle process bookkeeping. SAM-Grid is supplied by the Fermilab Computing Division via a joint project with participation from the Run II Computing and Analysis Department, the CCF Department, and the CEPA Department, as well as external effort from the GridPP project and other collaboration effort. SAM provides the data handling mechanism and JIM (Job Information and Monitoring) the job submission and monitoring. Taken together, they are referred to as SAM-Grid. A fuller description of SAM-Grid and the project status is described in a different report to the review committee. This document will focus on information specific to SAM-Grid operations at DØ. The experimentally supplied tools which interface to SAM-Grid are undergoing a rolling programme of integration / standardization to provide greater commonality and maintainability.

7.1 SAM-Grid

7.1.1 SAM-Grid Status and Plans

During the past year, the SAM-Grid infrastructure has been enhanced to meet the computational requirements of the reprocessing project and to continue the effort of integration with other grid systems, in particular LCG and OSG.

The challenges of the reprocessing project stem from the volume of data and the intensiveness of the computational task. The goal of the project was to reprocess one billion events, organized in 250 Terabytes of input data, generating 70 Terabytes of output. The estimated processing power was 1600 GHz-cpu year, almost all of which had to be provided by remote institutions. In addition, the target duration of the project was approximately 6 months, so requiring some 3THz-cpu for this period. To achieve these goals, SAM-Grid had to be able to adapt to the available remote hardware configurations in order to coordinate and optimize the use of local resources, such as computing nodes (gateways and cluster worker nodes), storage, and network.

The Job and Information Management component of the SAM-Grid has been enhanced from the version used for Monte Carlo production in 2004. The major additions are the optimization of the resources at the gateway node of the site, the use of data queues to access storage resources, and the ability to optimize site resources according to application-specific parameters. These new features allow the control of the load of key resources, such as gateway nodes and data servers, resulting in higher efficiency and scalability.

In more detail, the standard implementation of the grid-to-fabric interface, available from the Globus Toolkit, starts up a proxy process (job-manager) at the gateway for every batch job. This limits the number of concurrently running jobs to about 200 for a gateway deployed on an average modern commodity cpu. SAM-Grid has modified the standard grid-to-fabric interface in order to split grid jobs into multiple parallel instances of batch jobs. For the typical DØ application, this reduces by two orders of magnitude the number of job-managers running at the gateway with respect to the standard implementation. In addition, job aggregation eases job management for the users, who have to track a few grid jobs instead of hundreds, and facilitates the optimization of resources. An example of such optimization occurs when reporting the aggregated status of the job to the grid. Caching the aggregated job status limits the interaction of the grid-to-fabric interface with the batch system in order to retrieve the status of hundreds of jobs, thus reducing the load on the gateway node. Another example is the usage of aggregate characteristics of the jobs, such as the "application type", in order to enforce local policies and optimization strategies. In particular, different application types are configured to run on different batch system queues and access storages via different data queues. This allows the prioritization of the jobs and the control of the load on the storage servers.

The enhanced SAM-Grid can manage continuously at least one thousand data intensive jobs concurrently running per cluster. This corresponds to a total average throughput of ten million events per day with an efficiency of 90%. The efficiency is defined as the ratio between the number of actual output files from the reprocessing activity over the number of expected files from the reprocessing request, at 1st try. The 10% inefficiency includes failures at the level of the application, of the fabric services and resources, and of the SAM-Grid infrastructure. More detailed studies would be necessary to discriminate the contribution of each of them to the inefficiency. We expect the final error rate to be at the 0.05% level. In October 2004, before many of the improvements to the SAM-Grid system, the inefficiency due to the grid infrastructure itself was measured to be less than 5%. The throughput and efficiency monitoring can be seen at: http://SAM-Grid .fnal.gov:8080/cgi-bin/plot_efficiency.cgi. For further details, see reference [4].

The past year has seen an increase in the work to make SAM-Grid interoperable with other grid infrastructures, focusing in particular on the Open Science Grid (OSG) and the LHC Computing Grid (LCG). A main motivation for the focus on interoperability is enabling SAM-Grid to access a large number of shared computing resources without the need to deploy SAM-Grid services on all remote sites. To meet this goal, the SAM data handling system had to be enhanced to lift the assumptions on the locality of the computational activity. The SAM station was modified to service requests coming from jobs running on external network domains with restricted incoming access. This was achieved by changing the notification interfaces, by implementing call-back instead of polling semantics.

The SAM-Grid team have deployed a proto-production system that allows jobs prepared by SAM-Grid to run on LCG computing clusters. The architecture of the system presents LCG to the SAM-Grid as if it were a large computing cluster. SAM-Grid submits jobs to a gateway, simply viewed as one of the possible computing resources, which submits the jobs in turn to LCG, acting as a "forwarding" node. Adaptation to LCG is provided at the gateway/"forwarding" node at the level of the SAM-Grid grid-to-fabric interface. In general, the interface coordinates the interaction with multiple fabric services (SAM for data pre-staging, data base servers for query aggregations, push-based monitoring, job environment preparation, etc.), including the batch system. The interface interacts with the batch system through a layer of abstraction called the “batch adapter”. Adaptation to LCG was provided by implementing an LCG-specific “batch adapter”. With this schema, the “forwarding” node prepares the job for execution on any “hostile” computing environment (using the job environment preparation service), then uses the batch adapter to schedule the execution on one of the LCG clusters. More information can be found in reference [5].

The architecture achieves scalability by allowing multiple forwarding nodes, each interfacing a different region of the LCG system. The current proto-production system submit jobs to LCG using a “forwarding” node deployed at the University of Wuppertal, Germany, executing on the CCIN2P3 cluster in Lyon, France, and the LPC cluster in Clermont-Ferrand, France. The system uses a SAM station for data management deployed at the CCIN2P3 cluster.

The focus for next year in terms of development will be on moving the LCG interoperability infrastructure to production and to create a similar system for the OSG resources, with immediate emphasis on production tasks, such as Monte Carlo generation and reprocessing. In order to move the LCG interoperability proto-production system to production, the following steps are planned. First, implement a dynamically deployable scratch management system, which could choose the best file system for execution once at the LCG worker nodes, considering the specific I/O requirements of the DØ applications. Second, integrate the output sandbox services of LCG with SAM-Grid, in order to provide the users with greater capabilities for analysing job failures. Third, limit the range of ports required by the SAM station, making new deployments easily compliant with site network security requirements. In parallel we will expand the test bed certifying new LCG clusters for the DØ production applications. More details can be found in reference [6].

The integration with OSG is planned in two phases. First, work with the OSG community to deploy a resource selection service for the OSG resources. Second, implement a SAM-Grid interoperability test bed using the forwarding technique developed for the LCG integration. The first step is a necessary pre-requisite for the second. The presence of a resource selector in LCG was one of the reasons for the priority given to LCG in the interoperability effort.

Effort will also be devoted to assisting new sites with deployment. In the longer term user analysis jobs will also be incorporated into the full grid environment. Note, off-site analysis, with locally submitted jobs, has been underway for several years as SAM provides a complete remote data handling system.

7.1.2 SAM-Grid Effort

While significant progress has been made, limited manpower remains a major issue. In the long term, the SAM-Grid roadmap for DØ is to continue supplying the experiment with a performant and robust data handling system able to respond to the changing grid environment and so provide access to the additional resources needed as the Run II datasets multiply. To achieve this, sufficient manpower is needed to:

- Maintain production level performance with existing functionality.
- Improve / extend functionality e.g. scalability improvements associated with reprocessing, extension to user analysis.
- Completion of integration projects with other grids, in particular LCG and OSG.
- Assistance with SAM-Grid deployments at new sites.

Manpower for the DØ "part" of the SAM-Grid project in the main follows from two routes: the core SAM team provides the lead, with significant support (in particular testing) from D∅ collaborators associated with facilities with significant computing resources (for the most part shared with LHC experiments). Effective interplay between the central team and institutional based effort has been essential for progress. It is the institutional based effort that is responsible for installing, maintaining and running the DØ grid software, and delivering the Monte Carlo and reprocessed data to the collaboration. To ensure that the developments are well integrated with / matched to the experiment we have needed post-doc and guest scientist support from FNAL CD, as well as benefiting from the overall project integration / management provided by those at the associated scientist level. Additional manpower is required to ensure that sufficiently timely progress can be made on all fronts listed above.

7.1.3 SAM-Grid Performance

The use of the SAM data handling system, as measured by the volume of data consumed, grew modestly compared to the previous review period (now = 8/2004-8/2005; previous = 8/2003-8/2004). There were 106,195 projects run on fifty SAM stations world wide. The top ten most active stations are shown in Table 5.

Station	# Projects this period	# Projects previous period
cabsrv1	36,111	12,180
cabsrv2	16,942	(not present)
clued0-v5	10,665	12,094
fnal-farm	7,828	8,034
ccin2p3-analysis	5,233	7,206
central-analysis	5,225	16,326
cab	4,938	26,615
westgrid-ubc	4,318	(not present)
clued0	3,754	(was clued0-v5)
ccin2p3-grid0	2,060	(not present)

Table 5: Top ten active stations from 8/1/04-8/1/05 (this period).

The comparison to the previous period is somewhat confused by the reorganization of the SAM stations (e,g, central-analysis was discontinued, cab was renamed to cabsrv2), but it is clear that the use of the Fermilab analysis farms has increased from the previous period by ~50%. ccin2p3 and westgrid are remote stations. The data consumption statistics are shown in Table 6.

Station class	# of Files	Billions of Events	PetaBytes of Data
Fnal-analysis	3,794,279	52.9	2.2
Fnal-farm	392,957	1.1	0.2
Remote	644,316	2.1	0.3

Table 6: Data consumed from 8/1/04-8/1/05

While the consumption on the analysis and reconstruction farm (Fnal-farm) increased during this period compared to the previous period, the consumption on the remote sites dropped significantly (about half the number of events compared to the previous period). This drop could be due to a more efficient reprocessing effort and more effort going into MC production (which consumed few files). File consumption errors were analyzed in the report for the previous period. There was little change in those values for this year.

7.2 Tools

As well as suitable data handling and grid infrastructures we require the appropriate tools to manage DØ-specific applications and their interactions with this infrastructure, including applications such as reconstruction software aimed at a production environment as well as user applications. Here we briefly describe the ongoing programme of tool development & integration.

7.2.1 OS Compatibility, Run Time Environment and Sandboxing

To use a grid environment we need to need to package and export our software suitably, as well as ensuring that it will run in the remote environment, despite "local" differences. To address these needs DØ has developed an OS-compatibility system, a developer-level system to publish lists of required files (*d0rte)* and a sandboxing mechanism to package the user environment and pass it to SAM-Grid.

The OS compatibility system consists of UPS/UPD products that accompany each release, providing enough system-level code with each release to allow executables to run on many flavours and versions of linux. *D0rte*, already used to create the Monte Carlo (MC) tarballs distributed to remote production farms, provides developers with a straightforward mechanism to publish a list of required libraries and runtime files for their component or executable. In considering how best to integrate *d0rte* with DØRunjob (see next section), the DØ sandbox product was created as part of the runjob project. This allows for the creation of a hierarchy of environments starting from the general DØ release and ending with a small "user" tarball that can be quickly and easily distributed to many nodes in a farm. Sandboxing of DØ executables is now being tested using this new infrastructure.

7.2.2 DØ Tools, DØRunjob and Runjob

Historically people in DØ have used two independent packages to run their executables: *D0tools* and MCRunjob. Whilst the former's traditional role was code testing and debugging with local job submission it organically grew such that it became un-maintainable and could not be extended to the grid environment. The latter was primarily used for production activities, originally MC (and now reprocessing) on remote farms as its strength is workflow management i.e. chaining together appropriately the various executables. While it was originally referred to as MCRunjob it has since been rewritten, generalized and adopted as a Fermilab Computing Division project known simply as Runjob. The DØ-specific interface to Runjob is referred to as DØRunjob. For ease of long term maintenance we decided to consolidate these two executables by re-writing *d0tools* as a command line user interface to DØRunjob. As a first step DØ tools has been re-implemented in python. As planned originally it could then effectively become a macro-generator for DØRunjob while maintaining the existing *d0tools* UI, so addressing user concerns about the user interface to DØ Runjob (users strongly dislike a macro language approach to simple tasks) while allowing support for grid tools to be concentrated in Runjob / DØRunjob. Support for Runjob and DØRunjob was provided by the Fermilab Computing Division and UK personnel (GridPP) respectively; however the long term future of the common runjob project is under question, a cause for concern. Furthermore the original plan was for DØRunjob to be available, with the interfaces for *d0tools* and the new sandboxing mechanisms described, for the current p17 reprocessing. Unfortunately the release is now expected for autumn of this year. The experiment is critically dependent on individual effort in this area at the interface between grid and experiment developers and the delays to DØRunjob serve as typical example. To help remedy this, DØ carried out an internal review of the DØRunjob project over the summer. The reviewers agreed to the revised schedule, but strongly commented that the extension of the project to user analysis would require extra effort for it to be accomplished in a timely manner.

8 Manpower Requirements and Budget Summary

In view of the amended charge this year we have extended this section to include areas of "vulnerability" and to list our "requirements" both in terms of manpower and resources to ensure a full success of Run II. These are discussed in section 8.1.

In sections 8.2 and 8.3 we present our usual two budgetary concepts; namely the "yearly cost" targeted towards estimating the best use of the FNAL equipment budget and the "virtual center" that would be required to meet all of DØ's computing needs. As in previous years we budget for an increased rate to tape in Run IIb as in the original Run II plans. To mitigate the incremental costs we split this increase across two years, increasing the L3 rate to tape to 75Hz in FY06 and 100Hz thereafter, to follow the expected luminosity profile. The physics motivation for such an increase is discussed in section 8.1.

8.1 Requirements

8.1.1 Hardware

The original plan for Run IIb called for an increased rate to tape to match the increased instantaneous luminosity. The experiment has recently produced a separate document detailing the continued need for such an increase, see ref [3] for details. A brief summary is given here.

The DØ collaboration has prudently handled data manipulation and economically managed computing resources, resulting in efficient use of resources and successful publication of physics analyses. By way of examples: Data collection efficiency has averaged 84% over Run IIa and now averages close to 90%, ~70% of all data taken are finally used in at least one physics skim, processing keeps pace with data collection and in some analyses over 0.6 fb^{-1} of the 0.8 fb^{-1} of data recorded to tape have already been incorporated. At present the data rate to tape is limited by offline computing capabilities to 50 Hz. Since 2001, the collaboration has planned an integrated approach to the expected Run IIb increase in luminosity by improving trigger rejection and doubling the data rate to tape. These upgrades are necessary to maintain current measurement and discovery sensitivity for the experimental priorities such as precision measurement of the W mass, discovery of single top production, investigation of the B-sector, and searches for SM and SUSY Higgs. Any reduction in the offline capabilities effectively reduces the Tevatron luminosity.

Studies carried out by all physics groups are detailed in ref [3]. At a luminosity of 1 x $10^{32}cm^{-2}s^{-1}$ and with current trigger requirements the highest energy jet triggers, the W mass measurement, the high priority top and B-physics programs, and the searches for SM and non-SM Higgs already saturate the 50 Hz bandwidth. Reasonable adjustments of the thresholds to maintain 50 Hz at $2x10^{32}cm^{-2}s^{-1}$ will entail a 20% loss in trigger efficiency for the W mass, efficiency losses of at least 15% for the top trigger suite, statistics limited b-quark measurements, and up to 20% loss in the high priority Higgs searches. This essentially translates into a loss of ~1-2 fb^{-1} for the remainder of the run. Furthermore remaining at 50Hz will require increased manpower to develop the necessary trigger algorithms and to deal with the additional trigger complexity in the offline analyzes. We thus request funding to increase the rate to tape for Run IIb as originally planned. In an attempt to mitigate the additional cost and match the expected luminosity profile we request incremental restorations to the computing equipment budget to allow us to increase the rate to 75Hz in FY2006 and to 100Hz in FY2007. Fuller costings are given in Section 8.2.

8.1.2 Manpower Issues

As part of the Directorate's Run II manpower study the CDF and DØ experiments along with the Computing and Particle Physics Divisions have produced a report detailing manpower requirements in the offline computing area. Areas of vulnerability and recommendations to overcome them have been made. They can be broken down into two areas: those pertaining to areas of immediate vulnerability, and those that apply in particular to future strategies for dealing with the increasing data volumes associated with the increasing luminosity, namely a full, efficient use of the grid. The taskforce results will be discussed separately and here focus is given to the DØ aspects, though it should be noted that the taskforce's conclusions are basically cross-experiment.

Taking the non-grid issues first; such vulnerabilities may arise through personnel problems, with limited suitably qualified experts available from either the experiment or CD. The following areas fall into this category:

- Database support: Effort is required to bring the luminosity and trigger data base projects to completion, and to provide suitable support for long term operation of the various database projects at DØ.
- Online system: Currently, support for the critical online systems is carried out largely by a single individual.
- Offline code management, build and distribution systems. This important task has long been staffed by a single individual, from CD, who has had now to be primarily redeployed.

Additionally there are areas where central consolidation of hardware support could reduce overall manpower needs. These include:

- Level-3 trigger hardware support: Currently, collaborating institutions support and maintain both the service-level and the computing farm hardware.
- CluedØ support: This is currently provided by members of the collaboration.

These issues are under discussion with the Computing Division. Solutions which both satisfy the immediate and longer term are being sought, building where appropriate on CD's stated intention to increase the consolidation of key central tasks. Such consolidation is one of the taskforce recommendations.

Increased use of shared resources using grid technologies offers the most viable route to the increased computing resources required as Run II progresses. This route has long been the plan of both DØ and the Computing Division, and there is strong collaborative effort. Using common solutions wherever possible, significant progress has been made. Some of the most recent is detailed in this document. Despite this progress significant vulnerabilities remain.

- Deployment of SAM-Grid and grid technologies: Deployment of the required products remains specialized and a labour intensive activity. Achieving such deployments in a manpower effective way will become increasingly important as the need for grid-based services grows.
- SAM-Grid interoperability: The core feature of grid technologies is interoperability between grid sites, enabling a V0 (in this case the DØ collaboration) to access sufficient shared resources. The Computing Division and the DØ experiment have invested effort into making SAM-Grid interoperable with existing LHC grid infrastructure (LCG and OSG). Completion of this project will be required for the long-term success of DØ computing.
- User analyses on the grid: We have concentrated thus far on production activities, i.e. Monte Carlo and data reprocessing. Primarily this has been because these areas present our most pressing need; SAM provides worldwide data-handling and cpu local to sites or at FNAL has proven adequate so far. Individual data analysis jobs on the grid represent the most challenges, and so to achieve this in timely fashion will require additional effort.

To address these issues the taskforce recommended:

- "Grid deployment team. The Computing Division should form a grid deployment team charged with the responsibility to assist remote sites deploy the products required by the experiments to better exploit a grid-based computing model. The additional personnel will allow the existing developer base to focus on such tasks as creating viable grid-based analysis models for the Run II experiments."

- "Interoperability. Fermilab should aggressively pursue the implementation of interoperable solutions for distributed computing by the Run II experiments. The first goal should be to make SAM-Grid fully interoperable on OSG and LCG computing resources. Funding for these projects should be sufficient to ensure success in a timely manner."

The taskforce also recommended increasing the number of guest scientists and the number of Associate Scientists and Research Associate positions. We would like to confirm our support for this, as these persons playa key role within the experiment's computing, particularly topical are those who ensure the effective integration of grid technologies into the experiment.

8.2 Yearly Cost

There are four major costing areas used for equipment budget planning; worker nodes for processing tasks, disk and associated servers, components for the mass storage and infrastructure hardware needed to support the computing and user access. To the greatest extent possible, we use our knowledge about the past use of the system and past hardware costing trends to estimate future need and equipment cost. In general, we purchase the bulk of the equipment at the end of the fiscal year in order to get the most computing value for the budget. For out-year projections, we assume that the hardware cost per unit for compute nodes and fileservers remains constant, while scaling up performance based on our understanding of history and trends. This scaling remains speculative; in FY2005; the performance per cost varied by 20% between available choices based on DØ benchmarks. The benchmark performance for CDF and DØ code on a Xeon 3.2 differed by 25%. Our best estimate at this time is to scale up performance by 25% per year, using this year's purchase as a baseline.

In our experience, the data collection rate (Table 7) and total number of events (Table 2) are useful estimators for scaling usage as a function of time. We assume an increased rate for Run IIb, though stepped, rather than a direct increase to 100Hz as originally planned, bearing in mind that we purchase computing at the end of the fiscal year—thus the 2005 purchases cover 75 Hz in 2006.

The estimate of computing cycles needed for a task (reconstruction, Monte Carlo generation, user analysis) will depend on the efficiency at which a facility can run a task, the rate at which the task needs to be accomplished and the processing time per event. We also add some contingency to the estimate.

			2005	2006	2007	2008	2009
Peak event rate			75	100	100	100	0
Average event rate			25.86	34.48	34.48	34.48	0
Weekly average			37.5	50	50	50	0
Geant MC rate			3.88	3.45	3.45	3.45	3.45
PMCS MC rate			0.00	3.45	3.45	3.45	3.45
Events collected	1.00E+09						

Table 7 Data rates in Hz. Note that the data rate in the 200x column is used to calculate the computing needs at the beginning of the following year as we generally purchase equipment as late as possible. For example, the data rate in the 2005 column refers to an increase in the rate in 2006. We assume for this document that data collection ends in 2009, covered by the 2008 purchases and do not present projections for 2009.

For the FNAL farm, we assume that the facility keeps up with data collection. The current p17 timing appears linear in the current luminosity regime (see Figure 1), reducing our ability to extrapolate to higher luminosities at this time. Using Figure 1 we assume 85 GHz*sec per event in 2006 budget calculations with 100 GHz*sec per event after, consistent with past estimates. Keeping to this linear extrapolation will be very challenging, requiring continued effort on *d0reco*, and may require contingency at the 20% level. We calculate the total number of cycles needed to keep up and subtract off the existing system, and then estimate the number of nodes to purchase. Because the existing plant has an effect on the out-year projections, the purchase of dual-core Opteron 265 systems in FY-2005 has a positive effect. Those systems have been benchmarked on DØ reconstruction code as 2.45 times the speed of PIII per processor. This enabled us to purchase 20% more computing cycles for the same cost than we initially planned, putting us in a good position for the rate increase. Table 8 details this process step by step.

Year	2006	2007	2008
Average Rate	34.48	34.48	34.48
Efficiency	80%	80%	80%
Contingency	20%	20%	20%
Reco time	85	100	100
Required CPU	2092759	2462069	2462069
Existing system	902761	1704485	2025993
Nodes to purchase	208	106	49
Node Cost	$666,665	$339,534	$156,352

Table 8: Primary reconstruction cost estimate.

The same procedure is followed for the FNAL based analysis system, using the average weekly data consumption and past system usage as estimators. On the analysis system, the usage pattern is less steady than on the farm, however, the average usage scales with the number of events collected and reconstructed. Mechanically, we maintain a series of linked Excel spreadsheets that contain the assumptions, and calculations. Current versions of these spreadsheets are available at ref. [7]. For the FNAL farm estimate, in addition to the primary reconstruction, an estimate for the number of computing cycles needed for the post-production fixing was made, and found to be within the contingency. The estimates for disk are detailed in Section 5.4.

Mass storage estimates focus on the amount of tape to buy and insuring that we have enough slots in the existing robots to accommodate them. We do not yet have a good data rate driven model for estimating the number of drives to purchase based on fundamental parameters, and typically use the capacity of the system at peak as an indicator that more are needed (or not).

The other large spending category is infrastructure, which covers equipment for database support, interactive use, networking, and I/O support for the farm and analysis cluster. Based on the estimated number of nodes and fileservers to purchase at FNAL, we make a crude estimate of the networking costs, which is refined and then added to the infrastructure total. For other items, we look at the aging elements of the system and work out strategies for replacement. In the past year, we replaced most major components, at a lower than estimated cost. The Network Appliance that will replace the SGI machine for serving home areas cost $63K instead of the estimated $120K. Additionally, we were able to avoid the purchase of a new switch by working to judiciously reuse components and by purchasing dual core worker nodes. At this point, we estimate that we'll average around $100K/year in infrastructure costs, primarily disk for the database machines, networking components and disk for the home areas.

As a point of interest, comparisons between the estimates for 2004 and 2005 ($1.5M guidance) and actual purchases are shown in Table 9. In general, within a constant budget, DØ has typically chosen to purchase worker nodes over infrastructure to maintain rate to tape. In past year, we have addressed the aging infrastructure, which came in well under the budget.

	2004		2005	
	Projected	Purchased	Projected	Purchased
FNAL Analysis cpu	$339,000	$277,000	$420,000	$400,000
FNAL Reconstruction	$83,000	$370,000	$450,000	$400,000
File Servers/disk	$490,000	$350,000	$360,000	$325,000
Mass Storage	$230,000	$254,700	$40,000	$20,000
Infrastructure	$290,000	$140,000	$500,000	$276,171
FNAL Total	$1,432,000	$1,391,700	$1,770,000	$1,421,171

Table 9: Projected and spent budgets for FY2004 and FY2005.

The current cost projections for 2006-2008 are shown in Table 10. Even with the data collection rate increase to 100 Hz, we are only slightly above the guidance of $1.5M per year for 2006 and below for 2007 By 2008, we fit within the projected $1M guidance. This represents a difference relative to the figures that we presented in the 100 Hz document (ref [3]), There are several factors at work. The first is a reassessment of the infrastructure and tape drive costs; we are not planning on purchasing LTOIII drives or other major hardware, which represents a difference of $200K. Additionally, we have assumed that the analysis programs will become faster by 20%, through the change of format. Finally, the 2005 purchases had a 25% improvement in performance for cost for DØ with the Dual Core Opterons. Purchasing more computing cycles than anticipated in 2005 reduces the amount of computing needed in 2006 for a fixed set of assumptions, and the 2005 costs are used as a baseline for estimating the performance for cost for the out-years.

If the guidance is reduced to $1.25M for 2006, DØ experiment would either have to reconcile the physics program with a 75 Hz output rate or, more likely, would aggressively work to further reduce the analysis cost for worker nodes and disk. We do not fully understand the effects of the Common Analysis Format however it is a reasonable assumption that the efficiency and speed will enable us to save in the area of analysis. Additionally, there are options to pursue offsite analysis or to use FermiGrid as a way of levelling out the analysis needs to steady-state but this will require additional manpower to be achieved quickly.

	Purchase 2006	Purchase 2007	Purchase 2008
FNAL Analysis CPU	$449,308	$475,835	$404,720
FNAL Reconstruction	$666,665	$339,534	$156,352
File Servers/disk	$ 348,500	$328,000	$307,500
Mass Storage	$57,000	$97,500	$97,500
Infrastructure	$100,000	$100,000	$100,000
FNAL Total	$1,621,473	$1,340,869	$1,066,072

Table 10: Projected budgets for FY2005 through FY2008.

8.3 Virtual Centre Value

As well as the technological developments necessary for distributed / grid computing it is also necessary to recognise the in-kind contribution that the providing of significant computing resources represents. Our calculation of the value of the Virtual Centre is designed to recognize that non-FNAL computing contributions can be used to offset contributions to the DØ operating fund. The value of the centre is calculated by assuming that all necessary nodes and fileservers to do all production activities (including reprocessing and MC production) and FNAL analysis would be purchased in the current year. In this way, for past fiscal years, we can calculate a cash value based on a country's fractional contribution to a given activity as measured by the number of events delivered[8]. The 2005 value is calculated from the observed production, including the six months of intense use of the computing for the reprocessing. We assume that we will continue to reprocess at the remote centres in the out-years—fewer events, but with a shorter duration, which leads to a comparable value as DØ would request a large amount of computing for a relatively short time while the rest of time that computing would be put to other uses.

For future years, we estimate the value in a way similar to that described above. Currently, analysis at remote facilities is not considered to be part of the virtual centre; however, that is likely to change once SAM-Grid is fully deployed. Note that the concept of “value” is one that we are still developing. The estimates of the infrastructure value are difficult to make for systems that are purchased and function for many years at time. We do not currently assign a value for infrastructure. For the FNAL mass storage system, we have calculated the value in the past based on pro-rating drives and the libraries. At this point, we assign that a constant value of $800K, rather than attempt to adjust yearly for a small number of added drives. The virtual centre cost estimate is given in Table 11.

	Value 2005	Value 2006	Value 2007	Value 2008	Value 2009
FNAL based CPU	$813,950	$1,542,407	$2,050,126	$2,068,644	$1,865,336
File Servers/disk	$410,000	$758,500	$1,107,000	$1,291,500	$1,353,000
Mass Storage	$800,000	$800,000	$800,000	$800,000	$800,000
Reprocessing	$3,891,431	$4,479,991	$4,379,131	$6,686,987	$5,572,489
MC	$424,015	$283,744	$226,995	$181,596	$145,277
FNAL Total	$6,339,396	$7,864,642	$8,563,252	$11,028,728	$9,736,103

Table 11: Virtual centre cost estimates for FY2005 through FY2009.

9 Summary

As can be seen DØ computing continues to operate well. We have continued to make progress along our long term plan of migration from distributed computing to grid computing, most noticeably with the success of the p17 reprocessing using SAM-Grid. This is the largest such grid activity in HEP.

Despite the significant progress / success, DØ computing however continues to be manpower limited, and in the last year vulnerabilities due to this have become particularly apparent. These relate both to the immediate situation and to the continued development of grid technologies needed to provide access to the larger resources required as the Run II data sets increase. Overcoming these issues is essential for the success of DØ.

In addition we strongly request the restoration of sufficient funds to allow us to write to tape at 100Hz in Run IIb. We can achieve this with funding which fits the \$1.5M guidance for the next two years, and subsequently below the \$1M projected guidance for later years. The tape budget needed to achieve this is very reasonable. These modest additional sums are entirely motivated by the effective luminosity saving of order 1-2fb^{-1} that they represent.

10 Appendix 1

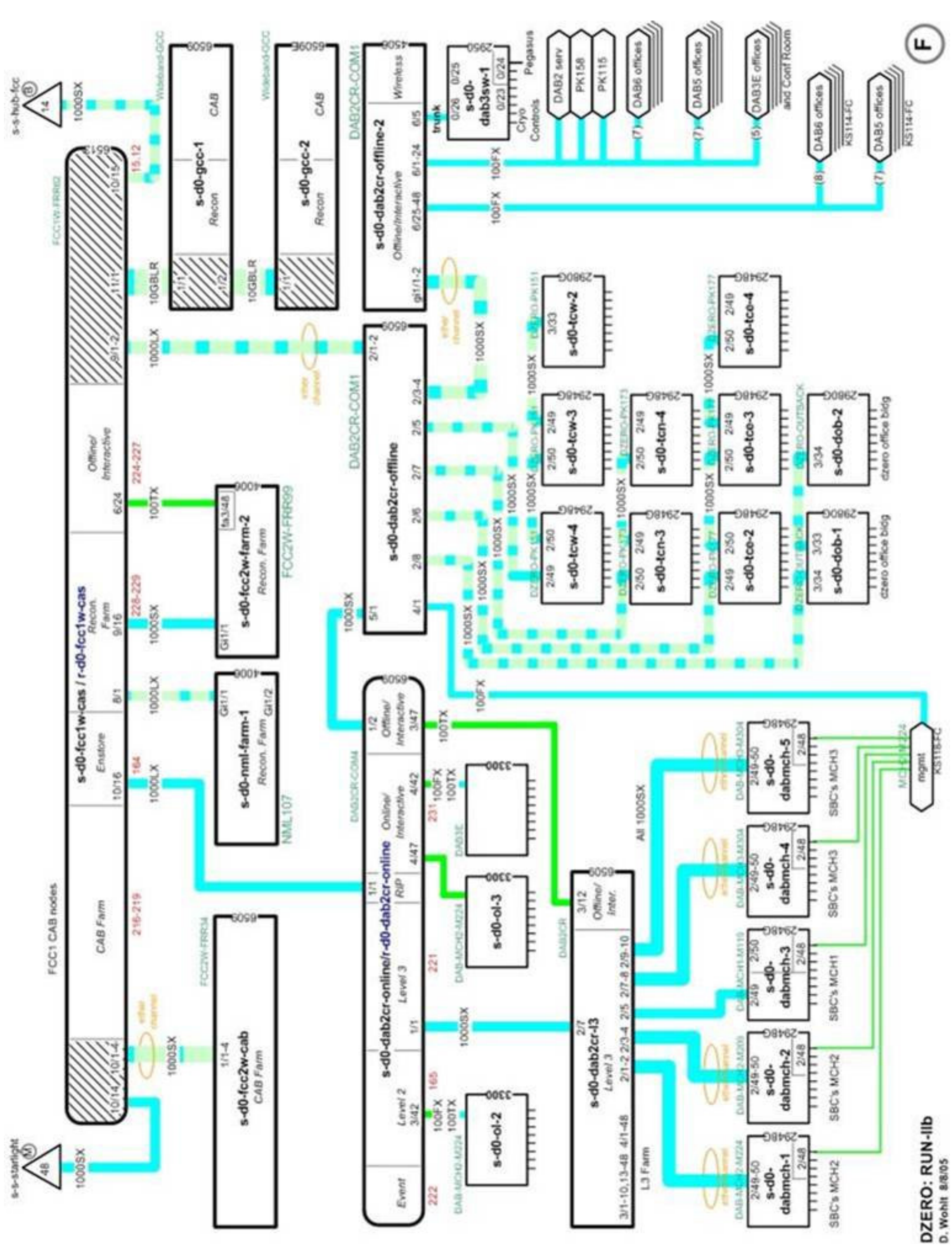

Figure 5: Principal elements of the network infrastructure supporting DØ Computing.

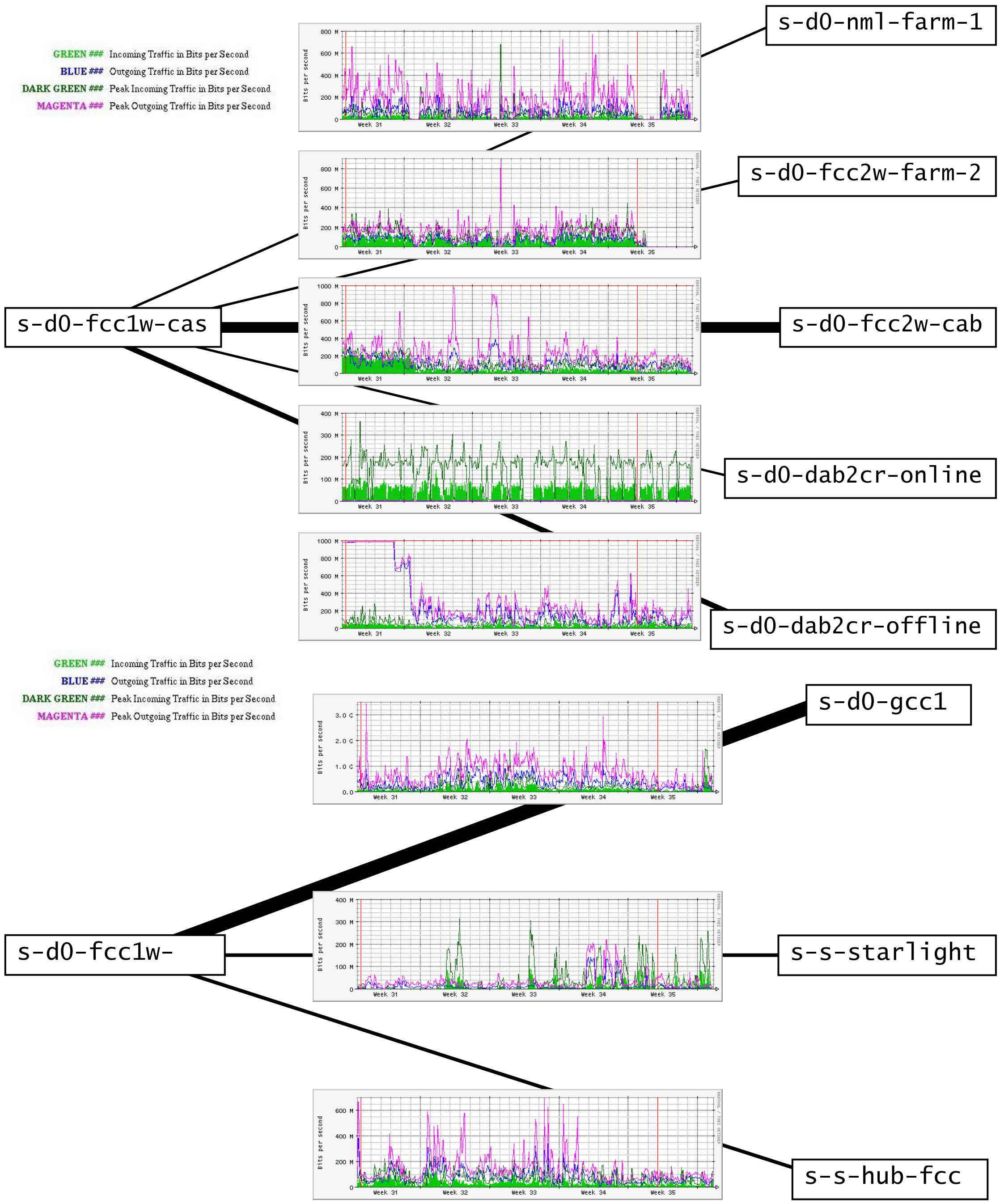

Figure 6: Network utilization, in bits per second, within DØ.

11 References

[1] The p17 data reprocessing webpage: http://www-d0.fnal.gov/computing/reprocessing/p17/ ;

Fermilab Press release (26 Apr. 2005, http://www.fnal.gov/pub/presspass/press_releases/dzero_datagrid.html) published in FermiNews (28 Apr. 2005, http://www.fnal.gov/pub/today/archive_2005/today05-04-28.html);

Science Grid (29 Apr. 2005, http://www.interactions.org/sgtw/archive/20050428.html), Science Daily (5 May 2005, http://www.sciencedaily.com/releases/2005/05/050504175948.htm).

[2] http://d0db-dev.fnal.gov:8514/atrig/TDB_Plan.html

[3] http://d0server1.fnal.gov/projects/Computing/Reviews/Sept2005/Index.html

[4] A. Rajendra, "Integration of the SAM-Grid Infrastructure to the DØ Data Reprocessing Effort", Thesis of Master in Computing Science, The University of Texas, Arlington, Dec. 2005. http://www-d0.fnal.gov/computing/grid/papers/Thesis-A.Rajendra.pdf

A. Nishandar, "Grid-Fabric Interface For Job Management In SAM-Grid, A Distributed Data Handling And Job Management System For High Energy Physics Experiments", Thesis of Master in Computing Science, The University of Texas, Arlington, Dec. 2004. http://www-d0.fnal.gov/computing/grid/papers/Thesis-Aditya.pdf

S. Jain, "Abstracting the hetereogeneities of computational resources in the SAM-Grid to enable execution of high energy physics applications", Thesis of Master in Computing Science, The University of Texas, Arlington, Dec. 2004 http://www-d0.fnal.gov/computing/grid/papers/Thesis-Sankalp.pdf

A. Nishandar, D. Levine, S. Jain, G. Garzoglio, I. Terekhov, "Extending the Cluster-Grid Interface Using Batch System Abstraction and Idealization", to appear on Cluster Computing and Grid 2005 (CCGrid05), Cardiff, UK, May 2005. http://www-d0.fnal.gov/computing/grid/papers/CCGrid2005-sj.pdf

A. Nishandar, D. Levine, S. Jain, G. Garzoglio, I. Terekhov, "Black Hole Effect: Detection and Mitigation of Application Failures due to Incompatible Execution Environment in Computational Grids", to appear on Cluster Computing and Grid 2005 (CCGrid05), Cardiff, UK, May 2005. http://www.d0.fnal.gov/computing/grid/papers/CCGrid2005.pdf

[5] http://www-d0.fnal.gov/computing/grid/doc/SAMGrid-LCG-integration.pdf

[6] http://www-d0.fnal.gov/computing/grid/doc/SAMGrid-LCG-integration-Lyon-report.pdf

[7] http://d0server1.fnal.gov/projects/Computing/Reviews/Sept2005/Index.html

[8] http://d0server1.fnal.gov/projects/Spokes/FinancialCommittee/Scrutiny.html