ALICE moves into warp drive

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Abstract. A Large Ion Collider Experiment (ALICE) is the heavy-ion detector designed to study the physics of strongly interacting matter and the quark-gluon plasma at the CERN Large Hadron Collider (LHC). Since its successful start-up in 2010, the LHC has been performing outstandingly, providing to the experiments long periods of stable collisions and an integrated luminosity that greatly exceeds the planned targets. To fully explore these privileged conditions, we aim at maximizing the experiment's data taking productivity during stable collisions. We present in this paper the evolution of the online systems towards helping us understand reasons of inefficiency and address new requirements. This paper describes the features added to the ALICE Electronic Logbook (eLogbook) to allow the Run Coordination team to identify, prioritize, fix and follow causes of inefficiency in the experiment. Thorough monitoring of the data taking efficiency provides reports for the collaboration to portray its evolution and evaluate the measures (fixes and new features) taken to increase it. In particular, the eLogbook helps decision making by providing quantitative input, which can be used to better balance risks of changes in the production environment against potential gains in quantity and quality of physics data. It will also present the evolution of the Experiment Control System (ECS) to allow on-the-fly error recovery actions of the detector apparatus while limiting as much as possible the loss of integrated luminosity. The paper will conclude with a review of the ALICE efficiency so far and the future plans to improve its monitoring.

1. Introduction

1.1. The ALICE experiment

A Large Ion Collider Experiment (ALICE) [1] is the detector designed to study the physics of strongly interacting matter at extreme energy densities at the CERN Large Hadron Collider (LHC). ALICE consists of a central barrel and a forward muon spectrometer, allowing for a comprehensive study of hadrons, electrons, muons and photons produced in the collisions of heavy ion nuclei. The ALICE collaboration also has an ambitious physics program for proton-proton and proton-ion collisions.

After 15 years of design and installation, the ALICE experiment has been collecting and recording data since the LHC start-up. In 2011 alone, ALICE has recorded more than 2.5 PB of data for further physics analysis.
1.2. The ALICE DAQ
The ALICE Data Acquisition (DAQ) system [2] [3] is responsible for handling data flow from the
detector to permanent data storage in CERN’s computer centre. Data obtained by the many sub-
detectors is sent via optical fiber Detector Data Links (DDL) to Local Data Concentrators (LDC),
computers which perform the readout of these event fragments. After validation, the subevents are
sent from the LDCs to Global Data Collectors (GDC) for event building and temporary storage in the
Transient Data Storage (TDS) system located in the experimental cavern. Finally, the data is
transferred to the computer centre to be stored on tape.

2. ALICE operations
Since its restart in 2010, the LHC has been operating with a proton-proton (p-p) period of several
months (normally from March to October) followed by a heavy ion (HI) period of approximately 4
weeks and by a winter shutdown for maintenance and upgrades. As seen in table 1, the LHC
performance as measured by integrated delivered luminosity has increased drastically for both p-p and
heavy ions.

| Year | p-p          | HI         |
|------|--------------|------------|
| 2010 | 0.5 pb⁻¹     | 9.3 µb⁻¹   |
| 2011 | 4.8 pb⁻¹     | 143.6 µb⁻¹ |

The LHC provides colliding beams in periods of several hours, called fills. Data taking sessions are
divided into runs - time periods with a predefined and constant data taking configuration (e.g. sub-
detectors and trigger configuration) - ranging from few minutes to several hours.

Trained shift crews control and monitor the operations 24/7 (except during the planned accelerator
shutdowns) and a team of on-call experts provide constant backup support.

A top priority for ALICE is to use as much as possible the luminosity provided by the accelerator,
especially in the HI periods. After several analyses of the data taking activities using the metadata
stored in the ALICE bookkeeping facility – the ALICE Electronic Logbook [4] (eLogbook) – two
inter-connected conclusions emerged:

- The number of runs was high, often surpassing 10 for a typical fill of several hours.
- Starting and stopping a run was a costly operation, normally involving several minutes of
downtime.

It also became clear that the eLogbook needed additional features both to better identify causes of
data taking inefficiencies and to quickly and easily provide access to this information.

3. End-Of-Run Reason identification
Runs can stop for several reasons, ranging from normal operations (e.g. change trigger configuration,
include or exclude a sub-detector) to abnormal incidents (e.g. high-voltage trip). Although for normal
operations the identification was clear, up to mid-2011 a shifter or an expert trying to determine the
cause of an abnormal situation often needed to access the data taking logs of a run (sometimes
comprised of thousands of messages). Moreover, since these reasons were then stored in the eLogbook
as a text-based message, their statistical processing over a large number of runs was often time-
consuming and error prone. It was therefore decided to include in the run’s metadata - stored in the
eLogbook - a clear and unequivocal reason for stopping the run – the End-Of-Run (EOR) Reason.

3.1. Changes in the Experiment Control System (ECS)
The ECS is the top-level online system that controls all data taking activities. Implemented as a state
machine, it controls the other online systems for the execution of pre-run, in-run and post-run
operations, thus allowing the shift crew to start and stop a run via a Graphical User Interface (GUI) with a single action. Given its nature, it can identify in which state a run stopped and therefore was the best candidate to identify the EOR Reasons.

All states were therefore changed to include the EOR Reason identification in the case of automatically stopped runs. For the manual stops, a panel was created to prompt the shifter - given a predefined list - for the EOR Reason (see figure 1).

![ECS End-Of-Run panel.](image)

**Figure 1.** ECS End-Of-Run panel.

3.2. Changes in the eLogbook

3.2.1. Database. To define the EOR Reasons for each run, two new tables were created in the logbook database:

- `logbook_run_eor_reason`: stores the EOR Reasons for each run.
- `logbook_eor_reason`: stores the EOR Reasons names.

The `logbook_run_eor_reason` table has the following fields:

- `id`: auto incremental ID.
- `run`: run number.
- `system`: name of the system that provoked the EOR Reason.
- `eorReasonId`: ID of the EOR Reason name.
- `source`: source of the EOR Reason identification.
- `obsolete`: flag indicating if the EOR Reason is still valid.
- `commentId`: ID of a text based eLogbook Log Entry attached to the EOR Reason.
- `log`: additional information.

The `source` field can have the following values:

- **ECS**: if a run is stopped automatically due to either an abnormal situation or a normal situation deemed incompatible with data taking (e.g end of fill).
• **OPERATOR**: if a run is stopped by a manual intervention of the shift crew (e.g., a sub-detector needs calibration).
• **WEB**: if a previously inserted EOR Reason was overwritten via the eLogbook’s GUI.

### 3.2.2. Application Programming Interface (API)

To allow the ECS to insert the EOR Reasons in the eLogbook DB, a new function was added to its C-based API.

### 3.2.3. Graphical User Interface

Several views were added to the eLogbook GUI to allow access to the EOR Reasons data:

- Run Details “EOR Reasons” tab: list of the EOR Reasons of a given run, also allowing the Run Coordination to add a new one and declare the existing one as obsolete (as seen in figure 2).
- Run Statistics “EOR Reasons” tab: list of all EOR Reasons associated with runs matching one or several search criteria.
- Run Overview “EOR Reasons” tab: list and plot of the top EOR Reasons and its associated systems (as seen in figure 3).
- Fill Details “EOR Reasons” tab: list and plot of the EOR Reasons during a given fill.

![Figure 2. eLogbook GUI page to change an EOR Reason.](image)
4. In-run recovery operations

As mentioned in section 2, starting and stopping a run is a time-costly operation, with the pre-run and post-run actions (e.g. sub-detector calibration tasks, Front End Electronics (FEE) diagnosis or trigger system configuration) time adding to the downtime of the experiment. In order to minimise the number of stopped runs, two in-run recovery operations were added to the control logic, thus allowing for certain error situations to recover without stopping the run.

4.1. Recovery procedure via the Detector Control System

The ECS continuously monitors the state of each sub-detector, stopping a run if a sub-detector changes to a state incompatible with data taking. Starting from 2011, a new state called ERROR_RECOVER was introduced, giving sub-detectors the possibility of recovering from error conditions (e.g. high voltage trip) without stopping the run.

Every time a sub-detector changes into ERROR_RECOVER, the ECS pauses the trigger system and waits for the sub-detector to change again into a state compatible with data taking. During this pause period, both automatic and manual actions can be performed in order to recover the sub-detector. After 20 minutes without any reaction, the ECS will permanently stop the run.

4.2. Recovery procedure via the DDL

Being a bi-directional link, the DDL provides a fast and reliable mechanism for configuring the sub-detectors’ FEE. Also in 2011, a new “pause and configure” (PAC) procedure was introduced to allow for in-run reconfiguration of a sub-detector’s FEE.

When a shifter detects the need to perform the PAC (e.g. single event upset in a sub-detector’s FEE), he/she can execute a PAC command in the ECS that will stop the trigger system, tell the DAQ to release the DDL link and execute a set of configuration commands that will try to unblock the sub-detector. Once this is finished, the DAQ will re-enable the DDL for data taking and the ECS will restart the trigger.

Plans to automate and make this procedure more robust are currently being implemented and are described in section 7.

5. Data taking efficiency

Since the LHC start-up, the data taking efficiency of ALICE has been one of the most important metrics for the Run Coordination to quantify the success of the experiment’s data taking activities. Given as a per-fill value, it is calculated using equation (1)
\[ E_{\text{fill}} = \frac{\sum (R_d - R_p)}{F_{sb} - F_{usb}} \times 100 \]  \hspace{1cm} (1)

where:

- \( R_d \): run duration, given by the difference in seconds between the stop and the start of the trigger online subsystem.
- \( R_p \): run pause duration, period in seconds during the run in which the data taking was paused.
- \( F_{sb} \): fill stable beams duration, given by the difference in seconds between the declaration of stable beam conditions and the end of the fill.
- \( F_{usb} \): fill unusable stable beams duration, period during a fill in which - even if declared as stable - the LHC beam was unusable for data taking (e.g. high background noise).

Up to 2011, these values had to be calculated manually combining both the eLogbook metadata and the LHC published information. Extensive effort was then put in populating the eLogbook with all the necessary data to present the data taking efficiency values for each fill in an easy and intuitive way.

### 5.1. Populating the eLogbook with LHC data

As mentioned before, several LHC related values are needed to calculate the fill data taking efficiency. These operational parameters are published by the accelerator team using the Data Interchange Protocol (DIP) [5] and made available, upon registration, to the experiment’s software.

In late 2010, ALICE deployed a software package to collect this information and store it in the eLogbook database every time a run is started. This allows not only the identification of which fill the run belongs to, but also the search of runs by different criteria such as beam energy, number of interacting bunches or beam mode. Additionally, it also stores, for each fill, the start and end timestamps and associated stable beams durations, thus allowing the calculation of the \( F_{sb} \) and \( F_{usb} \) values.

### 5.2. Displaying the data taking efficiency

Having all the needed data to calculate the fill data taking efficiency, effort was moved to displaying it. As seen in figure 4, the eLogbook GUI was therefore extended to include a fill view, displaying in a list, the efficiency for each fill. Given the existing feature to filter runs based on different criteria, it was decided not to store the efficiency value in the database but to calculate it every time it is displayed, taking only into account runs which match the active filters. Special care was put into dealing with parallel runs (logical groups of sub-detectors - called partitions - which can run with different trigger configurations, an important feature provided by the ECS).

A summary view was also introduced, displaying in a bar plot the efficiency per fill of a range of fills matching a given criteria (as seen in figure 5).

![Figure 4. Per fill data taking efficiency presented in a list.](image-url)
6. Reporting

To support the daily operations of the Run Coordination and the follow-up of the EOR Reasons stopping runs, several reports were introduced that not only provide an overview of the data taking activities but also improve the dissemination of the information through email notifications and presentations in daily meetings.

6.1. Online eLogbook reports

In the eLogbook GUI a new section was introduced to provide a per-fill view of the data taking activities. Called “Fill Details”, these web-based reports provide not only the global and per-detector efficiency during a fill but also a graphical representation of the downtime associated with each EOR Reason, thus giving an intuitive view of the fill’s timeline (see figure 6).

6.2. Fill summary slides

For the 2011 HI run, the Run Coordination requested that a summary slide (Microsoft PowerPoint compatible) be generated for each fill and presented in the following daily meeting. It should include a general description of the fill, the global and per sub-detector data taking efficiency, a pie chart with the distribution of EOR Reasons systems and a graphical representation of the fill’s timeline.

Figure 5. Per fill data taking efficiency presented in a bar plot.

Figure 6. An example of a graphical representation of a fill’s timeline.

For the 2011 HI run, the Run Coordination requested that a summary slide (Microsoft PowerPoint compatible) be generated for each fill and presented in the following daily meeting. It should include a general description of the fill, the global and per sub-detector data taking efficiency, a pie chart with the distribution of EOR Reasons systems and a graphical representation of the fill’s timeline.
As a first iteration, the generation of these summary slides was performed manually during the 2011 HI run and sent via email to the Run Coordination. In 2012, we deployed an automatic procedure that collects the necessary information from the eLogbook repository, generates the slide and sends it via email to a predefined mailing list. An example of such a slide is shown in figure 7.

7. Results from the 2011 HI run
During the 2011 HI run, approximately 203 hours of stable beams conditions were delivered by the LHC for the experiments. ALICE took data during 147 hours, finishing the 2011 HI run with a global data taking efficiency of 72.2%. A detailed per-fill data taking efficiency is presented in figure 8.
8. Future evolutions
With the EOR Reasons identification consolidated and being used in the daily meetings, the next step will be to integrate them with an issue-tracking system to ensure that repetitive problems are properly addressed and resolved. During 2012, we plan to integrate the EOR Reasons in the eLogbook with Atlassian’s JIRA [6] issue-tracking platform, allowing the Run Coordination and project leaders to follow the evolution of identified issues. Another goal is to further increase the visibility of the EOR Reasons via email notification.

Concerning the recovering procedure via the DDL, we plan to introduce a special software trigger denominated SYNC to enforce the synchronization of all data sources after the execution of the recovery. Additionally, it is also planned to allow the sub-detectors to request a recovery procedure via a special bit in the events Common Data Header, removing the need for a human intervention.

In terms of reporting, the use of existing business intelligence tools is being considered for easier generation of new reports and adhering to best practices, ensuring an optimal decision making support by the ALICE coordination teams.

Finally, an expert system is being designed to assist the shift crew in diagnosing and resolving issues in order to decrease the work load for the on-call experts and to reduce the time needed to recover from abnormal situation.

9. Conclusion
After two years of operations, the ALICE experiment has already collected hundreds of millions of events that are helping physicists all around the world to study the properties of the Quark Gluon Plasma. Moving the focus to operations, the collaboration has dedicated enormous effort into improving the data taking efficiency, thus making better use of the luminosity delivered by the LHC.

The addition of the EOR Reasons has allowed not only the clear identification of the issues responsible for downtime, but also provided the Run Coordination with information to prioritize and address them.

The introduction of recovery procedures for certain in-run errors has also contributed to the reduction of the number of stopped runs, saving precious time which otherwise would have been spent in pre-run and post-run operations.

Finally, the automation of efficiency calculation and summary reports reduced the need for manual compilation of information, while its dissemination both via email and web interfaces has helped to raise the visibility of top issues and therefore stimulated their correction.

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