

A Hybrid Visual Analytics Framework to Evaluate Trauma Incidences and Enhance Patient Care

Waqar Haque¹^a, Jordan Oliver²^b, Sonal Bajaj²^c and Navjot Kaur¹^d

¹Department of Computer Science, University of Northern British Columbia, Prince George, Canada

²Northern Health, Prince George, Canada

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Abstract: Large volumes of data has been collected on unintentional injuries and mortality. Besides years of life lost, traumatic injuries account for a significant portion of healthcare expenditure. With intelligent visual analytics, the collected data can be used for informed decision making and resource allocation. A multi-dimensional online analytical processing (OLAP) cube has been developed using data from BC Trauma Registry (BCTR) and Discharge Abstract Database (DAD). We propose a comprehensive framework which uses the OLAP cube, a web-based data entry platform populating a standalone database, filters consistent with Accreditation Canada (AC) measures, AC inclusion/exclusion criteria, and tools which render reports from historical and operational perspectives. These reports are grouped in higher level categories with intuitive drill-down capabilities for navigating at finer granularity along multiple dimensions. Access control for data entry is enabled with provisions for nested groups.

1 INTRODUCTION

Trauma is a global health concern and traumatic injuries can have an impact on individuals leading to long term disability and even deaths in some cases (Provincial Health Services Authority, n.d.). Depending upon the severity of injury, trauma can be classified as minor, moderate or major. “Major trauma is the principal cause of death for people under age 45 in Canada. Over 700,000 people are injured each year in BC and more than half of them seek medical attention. Of these 700,000 British Columbians injured each year, about 1,800 die, 9,000 suffer permanent disability, 27,000 are hospitalized and an estimated 41,000 potential years of life are lost. The yearly cost of injury exceeds \$2.8 billion in BC and is close to \$19.8 billion nationally. Falls and motor vehicle-related injuries are the main causes of injury-related hospitalization in BC.” (Provincial Health Services Authority, n.d.) This raises a compelling question whether any of these injuries or

deaths could have been prevented by providing better trauma care and timely assistance.

To analyze the factors associated with each specific trauma case and to identify gaps in trauma care, the aid of analytical tools is vital. Business Intelligence (BI) is defined as “broad category of applications and technologies for gathering, storing, analyzing, sharing, and providing access to data to help enterprise users make better business decisions” (Ali -Özkan, Crvenkovski, & Johnson, 2016). BI can integrate data from a wide variety of internal and external data sources and provide an effective information platform for decision makers in healthcare (Foshay & Kuziemsy, 2014). The extracted information can then be displayed in the form of an intuitive dashboard providing a visual analytics platform for decision makers to take appropriate actions and enable enhanced trauma care. The metrics of interest include injury severity score (ISS), location of incidence, time taken for trauma care to be provided, type of trauma care provided, transport information, risk groups, and mortality rate.

^a  <https://orcid.org/0000-0002-6921-8097>

^b  <https://orcid.org/0000-0002-7031-0528>

^c  <https://orcid.org/0000-0002-9323-9453>

^d  <https://orcid.org/0000-0001-5542-7501>

The data is collected by various Health Service Delivery Areas (HSDA) in several formats and sent to the Provincial Health Services Authority (PHSA) for standardization and use in an integrated provincial trauma system. Over the last few years, the Trauma Services of BC wing of PHSA has developed a data warehouse and built a very stable online analytical processing cube. Several measures and dimensions have also been identified (Microsoft). We have integrated this cube with a database thus creating a hybrid platform to provide the integrated reporting layer together with ASP.NET based web forms to enter data related to Trauma Team Activations (TTA) and other local data sources.

2 RELATED WORK

The application of BI concepts in healthcare is growing rapidly. Many healthcare institutes (Institute for Health Metrics and Evaluation (IHME), n.d.) (World Health Organization (WHO), n.d.) (University of Utah, n.d.) (Fojut, 2016) (The Trauma Audit & Research Network (TARN), n.d.) (UMC Utrecht, n.d.) have used their own data repositories to develop online analytics and visualization tools for various diseases (such as cardiovascular, diabetes, cancer, etc.) and injuries. The Institute of Health Metrics and Evaluation (IHME) provides a tool which analyzes data (1990-2016) related to premature deaths, disabilities, and injury from over 130 countries and can be visualized along several dimensions including demographics, mortality, disease causes and risk factors. The visualization is available in different formats such as map, treemap, line chart, patterns bar chart, pyramid chart, arrow chart and heat map. The dashboard can be drilled down to specific countries and states (Institute for Health Metrics and Evaluation (IHME), n.d.). The WHO's GHO (Global Health Observatory) is a web-based analysis and visualization tool for global health priorities (World Health Organization (WHO), n.d.). The data presented is in form of 35 different theme pages where each theme presents summary and reports on global health conditions such as HIV/AIDS, child health, tuberculosis and road safety. These dashboards are not completely trauma data centric and do not provide any information about the causes of trauma related incidence and deaths, or trauma patient movement.

The Intermountain Injury Control Research Center (IICRC) at University of Utah is the central data repository for trauma-related data. IICRC compiles and analyzes trauma data making it available for

research (Bureau of Emergency Medical Services & Preparedness, Utah Department of Health, 2015). A Trauma Audit dashboard is developed by University of Utah School of Medicine and is available at state, hospital and region level. The key performance indicators (KPIs) used in the dashboard are age, population, ISS, mortality, field triage, level of care, transfers (inter or intra-hospital) and mode of transport amongst others (University of Utah, n.d.). Centura Health developed a trauma BI application for monitoring hospital's trauma system performance using data from trauma registry and other facilities (Fojut, 2016). The dashboard is made of pivot tables allowing users to analyze and report with drill-down capabilities. The reports can be filtered by injury type using ICD codes and can be further sliced by month, fiscal period, quarter, facility and regional groups. The reports provide insights into financial measures like cost per case or contribution margin.

The Trauma Audit and Research Network (TARN) (The Trauma Audit & Research Network (TARN), n.d.) has one of the largest trauma database in Europe, receiving data from 80% of trauma centers across the United Kingdom. TARN measures and monitors trauma care process and provides local, regional and national information on trauma patient outcome. The Major Trauma Dashboard provides quarterly and ad-hoc reports to the clinicians and also published population statistics on the epidemiology of trauma. Jedox (Jedox, n.d.) and Celcus B.V. (Celcus, n.d.), Netherlands based companies, have developed a trauma BI application for University Medical Centre Utrecht's (UMC Utrecht) (UMC Utrecht, n.d.) trauma centre. This application integrates data collection, reporting and analysis process. Users can enter data manually and the application validates and transforms the data. The data is then stored in relational data sources and is analyzed and visualized by using dashboards and dynamic reports.

3 METHODOLOGY

The purpose of our proposed framework is to provide healthcare professionals and decision-makers with real-time aggregated information on regional trauma cases, trauma team activations and other trauma-related information. The primary source of data is the OLAP cubes maintained by the Provincial Health Services Authority (PHSA) using the Discharge Abstract Database (DAD) and the British Columbia Trauma Registry (BCTR). The BCTR data includes moderate and severe trauma whereas the DAD cube

also includes cases categorized as minor trauma. Both of these cubes are coupled with a relational database for comprehensive reporting and regional data entry through web forms. Microsoft's BI tool stack consisting of SQL Server, various business intelligence components and ASP.net framework has been used for data integration, reporting and analysis [14]. A challenge in designing the framework was the integration of disparate data files from different data sources. An abstract level interaction diagram of the interrelated components of the proposed framework is shown in Figure 1.

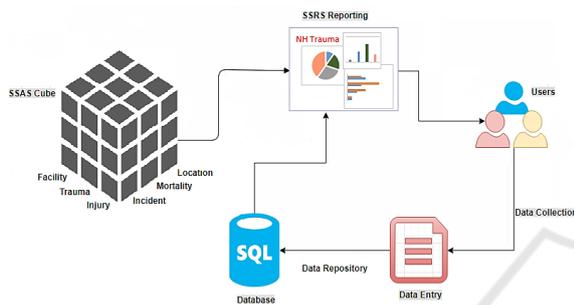


Figure 1: Framework Components.

Users interact with the framework through data entry components and reporting interfaces. The data entry web forms are accessible from remote sites and can be used to populate regional information such as Trauma Team Activations (TTA), ground and air ambulance services, and staff credentials. This information is currently outside the scope of OLAP cubes maintained by PHSA and thus is captured directly at designated sites. The web interface gives the user the ability to easily edit, delete and validate the underlying data. The information entered is stored in a relational database which is independent of the OLAP cubes, but integrated in the reporting module. The relational tables include information such as mechanism/motivation of injury, admitting services, methods of transport, mortalities, sites, and trauma team activations. This database has logical relationships between tables so that data can be accessed and re-assembled by the SQL Server Reporting Services (SSRS) to extract meaningful information. Likewise, the reporting component securely connects users to the aggregated information and drill downs of the underlying data. It renders different dashboards grouped by specific sets of reports such as Incidence, Mortality, Transportation, and TTA. These reports pull information from the database and cubes to provide a visual representation of various KPIs in the form of intuitive graphs, pie charts, tables, and bar/line graphs.

A server-based reporting platform, SQL Server Reporting Services (SSRS), has been used to create the reporting dashboard. Besides providing a visualization platform, SSRS has provision to export reports to applications such as MS Excel, MS Word, PDF, etc. In addition, SSRS provides the ability to create reports with drill through/drill down actions, expand/collapse toggles, tooltips and report parameters for interactive navigation. The SSRS reports can also be filtered, grouped and sorted according to user's requirements. Once deployed, the reports can be viewed by multiple users via a standard browser through a web-based connection and does not require any configuration of the client machine. Users can open data entry web-form and reporting dashboard in different windows and can use both components at the same time. Access control is accomplished through an Active Directory. Data entry can only be done by designated sites/staff whereas the reports can be viewed broadly upon authentication.

4 DATA VISUALIZATION

The reporting module consists of over forty reports representing data from the sources mentioned earlier. The top level dashboards display aggregated results in visually appealing formats and allow intuitive navigation to finer granularity via drill down and drill through reports. The framework allows tracking of several metrics including transportation times, injury severity, most responsible diagnosis, inter-facility transfers for higher level of care, mechanism/motivation of injury, trends, all broken down by gender, demographics and other specified parameters. These dashboards not only provide access to useful information but also enable administrators to make more informed decisions. Where applicable, historical data is used to show trends. The reports are highly optimized and render within 2-7 seconds.

4.1 Landing Page

The landing page (Figure 2) provides an overview of the dashboard together with the ability to navigate through various web pages. The page is divided into two sections for reporting and data entry. The reporting section is further divided into three sub-sections based on the data sources: BCTR, DAD and Pre Registry Database. As stated earlier, BCTR reports only include moderate and major trauma cases

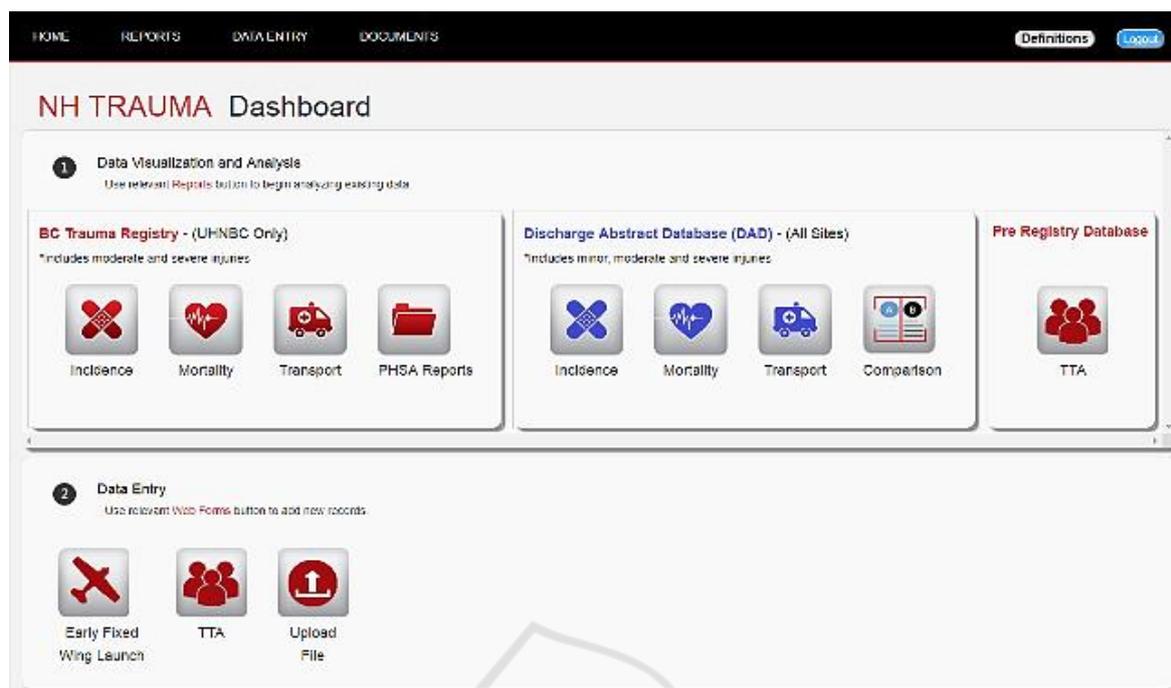


Figure 2: Landing Page

whereas DAD also includes trauma cases which are categorized as 'Minor Trauma'. The icons on the left side navigate to different dashboards representing the BCTR data (Incidence, Mortality, and Transport). In addition the PHSA Reports icon allows viewing of static annual reports which are periodically uploaded through the data entry section. The next three icons produce similar reports for the DAD data. In addition, a Comparison icon allows selection of up to three facilities for comparison purposes. Finally, the TTA icon generates a comprehensive report displaying various metrics related to trauma team activations. The data entry section presents different web forms for entering data which is not supplied by PHSA cubes. This includes Early Fixed Wing Launch, TTA, and uploading of Annual Reports compiled by PHSA.

4.2 TTA Web Form

The Trauma Team Activation web form (Figure 3) provides an interactive mechanism to enter information/records of all admitted cases where the trauma team was activated and those where the admitted patient met TTA criteria, but an activation did not occur. The data captured includes different sites, demographics, pre-registry number, emergent care (TTA Activated, Mechanism of injury, Motivation of injury, etc.), disposition (Admitting

services, OR arrival time Transferred, etc.) and outcome information (Length of Stay, ISS, Vital Status). This web-form is highly interactive with ability to search data, and enforces data integrity via validation constraints in real time. Existing records are displayed in a grid view under the form which allows easy editing and deletion of records. Any changes made through the web form are reflected immediately in the associated reports.

4.3 Incidence (BCTR)

The Incidence dashboard provides a snapshot of trauma incidence related statistics (Figure 4). The report header displays the total number of major trauma cases for the selected fiscal year and facility. A trend chart shows the number of moderate and severe trauma incidences over the last five years. The trauma incidence count is broken down by KPIs such as age-range, gender, Injury Severity Score (ISS), motivation/mechanism of injury, risk groups, falls, and alcohol related injuries. The mechanism of injury section provides transport and non-transport related, and work related trauma incidence statistics. These charts can be further drilled down for information on the specific KPI at finer granularity. In addition, there are several buttons on the dashboard which allow navigation to other drill-down reports. For example, Figure 5 shows the trend in Emergency Department

Trauma Team Activation Fiscal Year: 2016/2017 Facility: University Hospital of Northern BC

Demographics
 Facility: University Hospital of Northern BC
 Fiscal Year: 2016/2017
 Pre Registry No:
 Date: MM/DD/YYYY
 Time of Admission to ER:
 Gender: M
 Age Group: <15

FAST Exam in ED: Yes
Drugs: No
Alcohol: No

Disposition
 Admitting Service: Discharged
 Time of Admission to Hospital: Not applicable
 OR Arrival Time: Not applicable
 Ward Arrival Time: Not applicable
 Special Care Unit Arrival Time: Not applicable
 ICU Arrival Time: Not applicable
 In Holding?: Yes
 Cohorted?: Yes
 Tertiary Survey Completed: Yes
 Transferred: No
 Time Transferred Out of Hospital: Not applicable

Emergent Care
 TIA Activated: No
 - Should Have Been Activated? Yes
 Trauma Team Leader Arrival in ER: Not applicable
 Was There an Inpatient Trauma Consult? Yes
 Mechanism of Injury: Unknown/Unspecified
 Motivation of Injury: Unknown
 Early Fixed Wing Launch: Yes
 - Should Have Been Launched? Yes
 Blood Product Administered? No
 CT Arrival Time: Not applicable
 Intubation: No

Outcome
 Did Patient Die in Hospital? No
 Length of Hospital Stay (days):
 ISS: Unknown

Submit

Search:

Figure 3: Trauma Team Activation Data Entry Web Form.

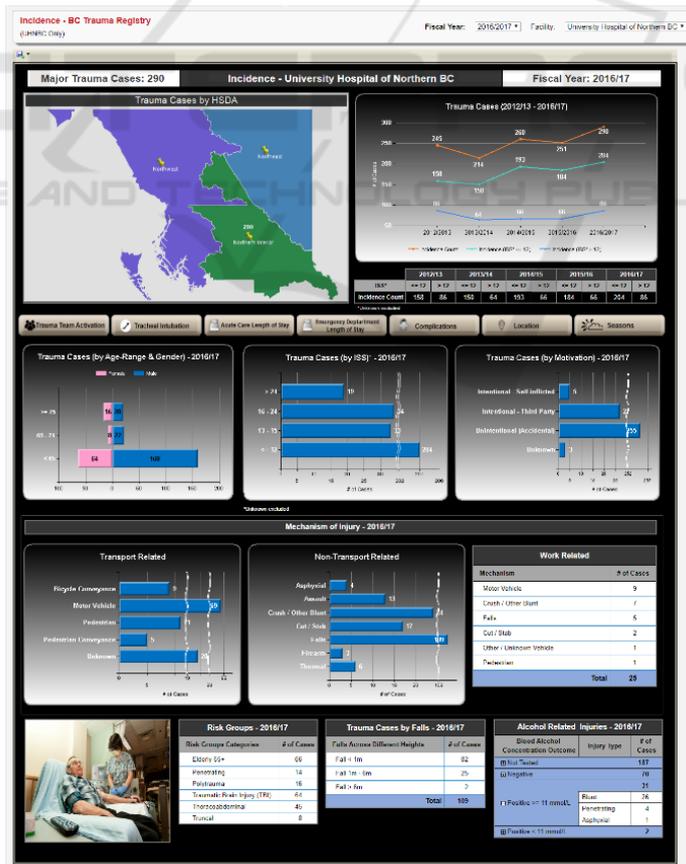


Figure 4: Trauma Incidences (BCTR).

Length of Stay (ED LOS) by months over the selected fiscal year. The blue bars show the total number of cases while the orange bars show the total number of ED LOS days for each month. The monthly trend of average patient length of stay is also displayed. For the fiscal year 2016/17, the total number of trauma cases admitted to the emergency department was 78 with a total of 177 emergency department days. Based on this, it is observed that a trauma patient spends on average two days in ED.

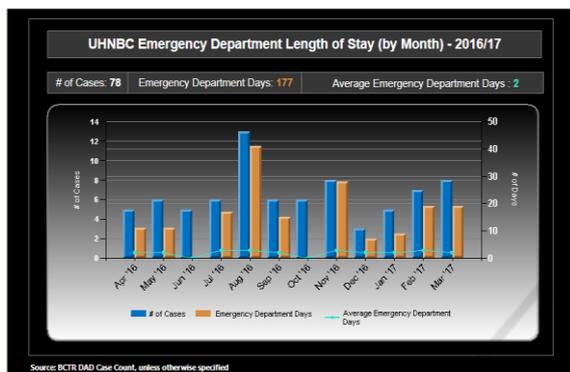


Figure 5: Length of Stay drill-down.

4.4 Mortality (BCTR)

The mortality report (Figure 6) uses BCTR data to report on the number of trauma related deaths by facility and fiscal year. A breakdown of this number by regions or local health authorities is shown on an interactive map. The mortality trend chart shows the number of deaths that occurred in the last five years with respect to the total trauma incidence count and severity level of the injury. Additional indicators displayed on the dashboard allow the user to view other parameters related to trauma mortality. For instance, the numbers are broken down by gender and age-group which illustrates that more male trauma patients died than female in the selected year.

The monthly bar graph shows that more deaths were reported in November and December in comparison to other months. The mortality by location pie chart shows that three deaths occurred in the Intensive Care Unit (ICU), two in the Nursing Unit and one in the Operating Room. Clicking on this pie chart renders a detailed drill down that displays the location of the deaths by ISS level. Similarly, the other charts (tables, graphs) explain various trends and changes in mortality rates by falls grouped by four main ISS levels. The three tables at the end of the report allow the user to easily identify the

mechanisms, types and motivations of injury that contribute to the patients' deaths.

4.5 Transport (BCTR)

Transportation times are a key factor in the outcome from a traumatic injury. The ultimate goal is to identify bottlenecks and minimize transfer times. Figure 7 shows the average time it took for a trauma patient to arrive at a definitive care facility either from scene of injury, or as a transfer. The transfer times are also shown by the injury severity level. For instance, it can be seen that all severe trauma patients (ISS>12) arrived at the definitive care facility within four hours. A breakdown of the number of cases transported from scene and/or first facility to definitive care is an important metric to analyze patient's journey and identify bottlenecks, if any. These charts also show the distribution of patient transport modes such as land ambulance, private transport, and fixed-wing or helicopter ambulance. The trend line shows the average time to definitive care for the previous five years which allows one to assess the impact of resource allocation, if any.

Drill-down reports provide a monthly breakdown of this information. Often, patients are transferred to facilities where a higher level of care can be provided. This information is also displayed on the dashboard. In cases where such transfer occurs directly from scene, a report on regional transfers provides relevant information for the selected facility. Finally, the dashboard also allows drilling down to another KPI which shows the number of cases that required a higher level of care by different risk groups (i.e. penetrating, truncal, elderly, and polytrauma).

A similar set of reports is also available for the Discharge Abstract Database (DAD). In addition to the metrics defined earlier, this cube also contains data for minor trauma and provides a finer granularity comprising of all locations whether or not those are designated as trauma care facilities. Thus, the number of cases in BCTR is a subset of those included in the DAD cube. However, the ISS scores are not captured in the latter.

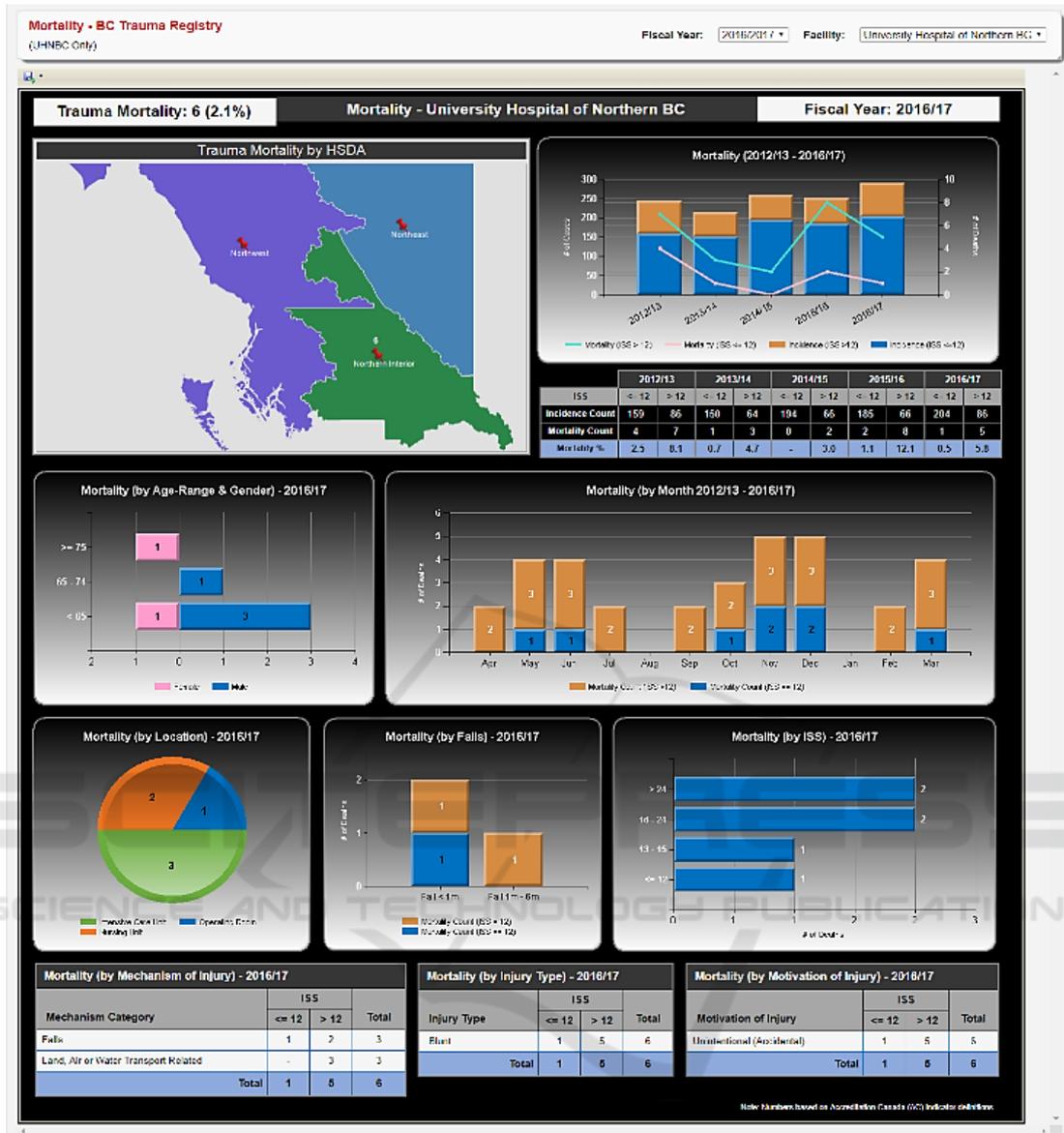


Figure 6: Trauma Mortality (BCTR).

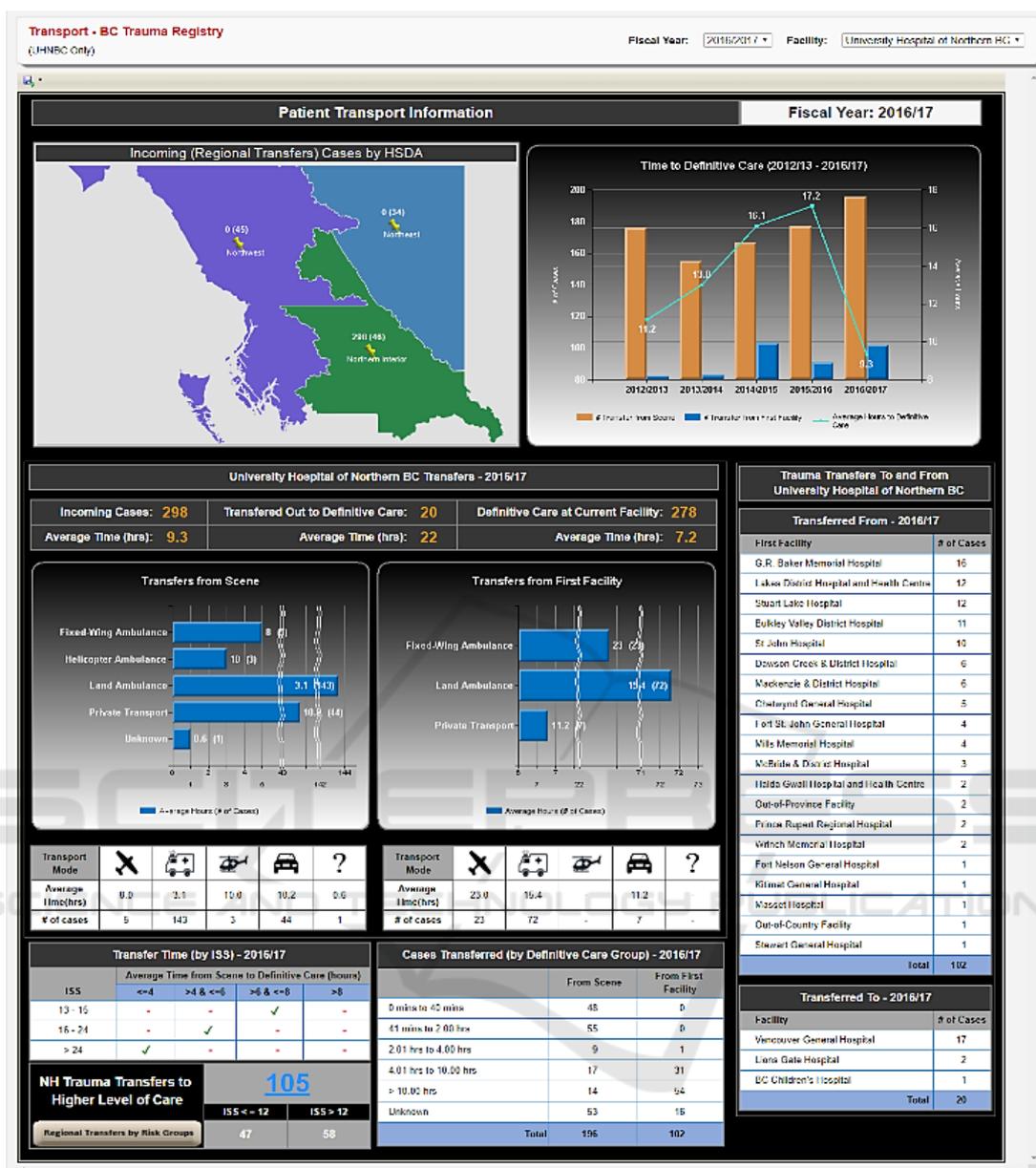


Figure 7: Transport Report.

4.6 Comparison

Trauma statistics at facilities which are similar in size and resources can be compared to obtain useful information. This is accomplished by a comparison report (Figure 8) which allows selection of up to three facilities for side-by-side comparison. The top section of this report provides a comparison of general trauma statistics such as incidence, mortality count, mortality percentage, complications, comorbidities,

and age range. The trauma statistics section provides a more comparison of other metrics such as injury type and motivation/mechanism of injury. The transfers section of the report shows the discharged and transferred cases by mode of transport for each of the selected facilities. With the ability to compare facilities side-by-side, executives/users have the ability to determine how incidences and mortalities differ across similar facilities.

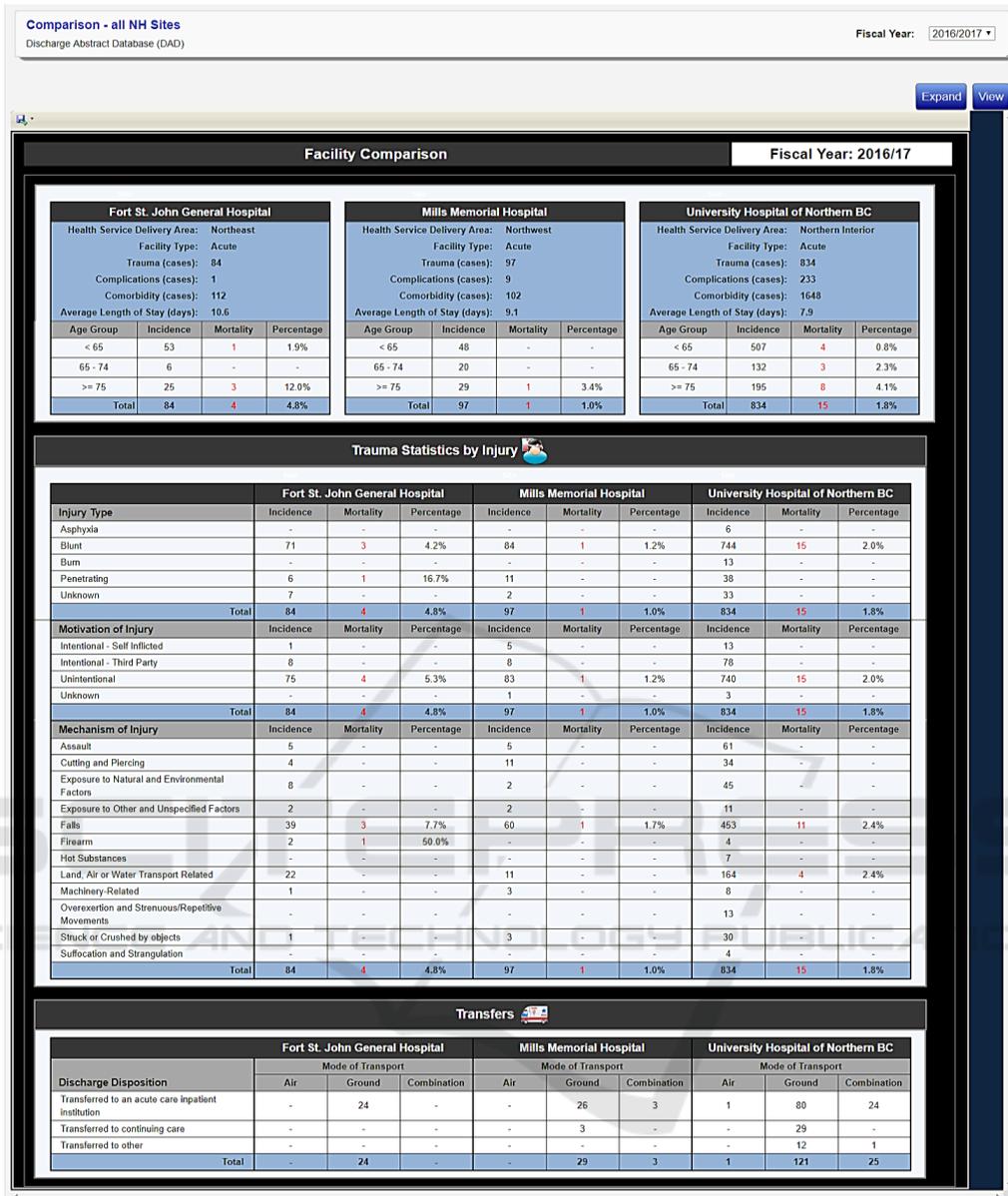


Figure 8: Facilities Comparison.

4.7 TTA

Trauma Team Activation (TTA) is the pre-hospital notification by Emergency Medical Services (EMS) based on scene triage criteria that is provided to the emergency department. This ensures that the trauma team is immediately available upon patient arrival to address the clinical needs of seriously injured patients. This information is entered through web forms and can be simultaneously seen in the reporting module. The report header displays the total number of trauma team activations (split by gender) for the selected fiscal year and facility (Figure 9). An

aggregated overview of the data entered is displayed in top portion of this report. Some of the key statistics include inpatient trauma consults, number of TTAs cohorted, number of early fixed wing launches, average length of stay and peak periods of arrival. Average times and total number of cases for various departments (CT, Hospital, OR, Ward, SCU and ICU) are also presented.

The report further groups the TTA cases by ISS, month, age range, motivation/mechanism of injury, admitting services, mode of transport and transfers. For instance, Figure 8 shows a total of 91 TTAs, out of which 6 died in ER, ICU and Ward. For 2017/18,

July was the peak month with twelve trauma team activations. Additionally, the highest number of TTA injuries had a reported Injury Severity Score (ISS) less than 9. A total of 31 cases were transferred into UHNBC, out of which 15 arrived directly from the incidence scene. The highest number of cases were transferred out to Vancouver General Hospital.

Each chart in the TTA report can be further drilled down to compare the TTA data of the selected Facility with other Trauma sites. Figure 10 is an example of the drill down from “Cases by Age-Range & Gender” chart. The drill down report shows a higher number of overall TTA cases for males when compared to females. Across all three TTA sites, the highest number of cases are recorded for the age-

range 15-24, followed by 25-34 and 35-44.

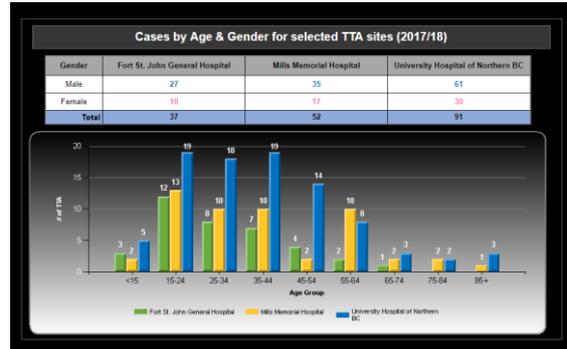


Figure 10: TTA Cases by Age and Gender.

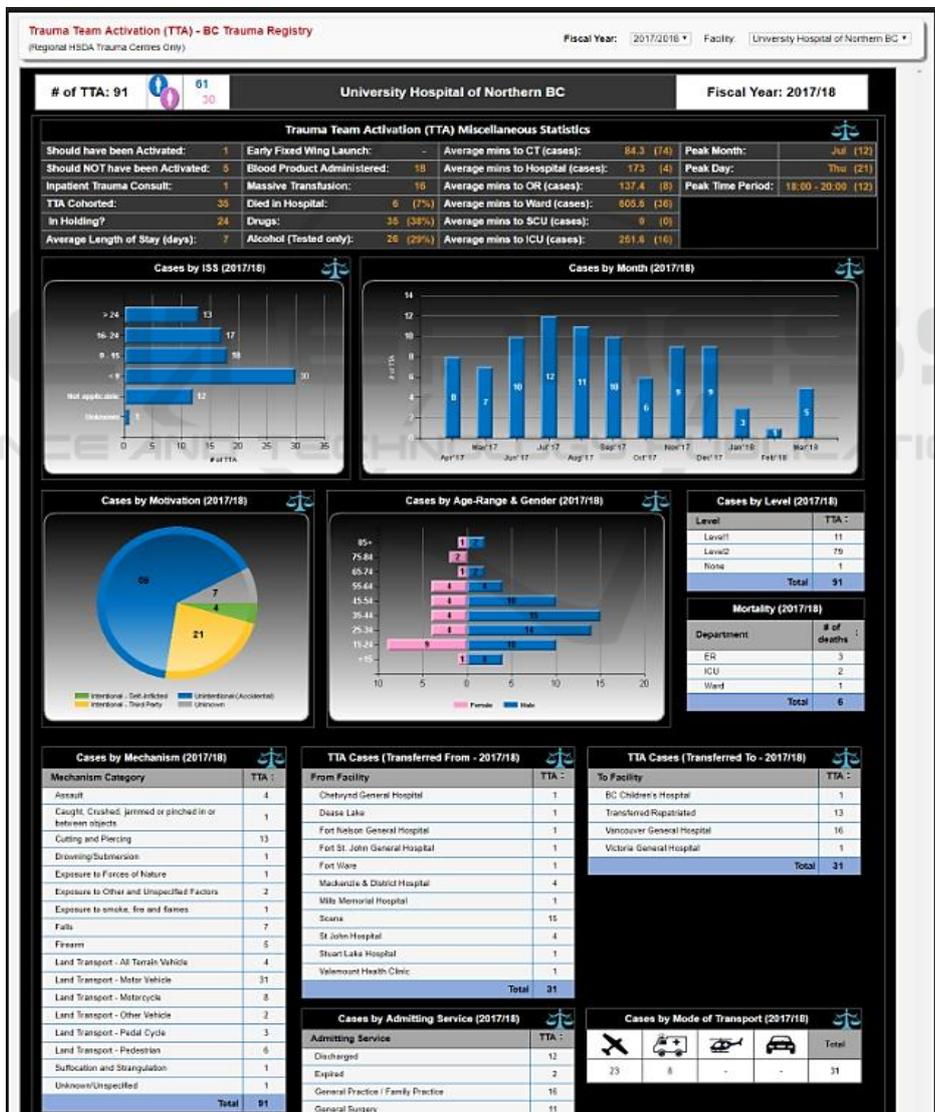


Figure 9: Trauma Team Activations (TTA).

5 CONCLUSION

A large amount of data related to trauma incidences has been residing in multiple repositories in legacy formats. A multi-dimensional OLAP cube was built by PHSA, but the data still remained in a format which could not be used for decision making. We have proposed a framework which allows visualization of this data along several KPIs. The dashboard provides a platform which can be easily navigated to reports at finer granularity. The reports are grouped on the basis of incidences, mortality, transportation and trauma levels, and are tightly coupled with web forms which capture data not included in the OLAP cubes. This creates a hybrid environment where data is extracted from both cubes and relational databases in a transparent manner. Simultaneous users can access the interface through standard web browsers while access control is implemented using Active Directory.

The interactive platform allows decision makers to view trends, bottlenecks and performance along multiple dimensions to identify areas which can result in improved trauma care. The platform is extendable to seamlessly include other health service delivery areas and add other metrics of interest.

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