

Development of a predictive dashboard for falls prevention in residential aged care: An architecture towards prescriptive decision support

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Abstract

Background: Falls are a prevalent and serious health condition among older people in residential aged care facilities (RACFs) causing significant health and economic burden. However, the likelihood of future falls can be predicted, and thus, falls can be prevented if appropriate prevention programs are implemented. Current falls prevention programs in RACFs rely on risk screening tools with suboptimal predictive performance, leading to significant concerns regarding resident safety.

Objective: Our aim was to develop a predictive, dynamic, dashboard to identify residents at risk of falls with associated decision support. This paper provides an overview of the technical process, including the challenges faced and the strategies employed to overcome them during the development of the dashboard.

Methods: A predictive dashboard was co-designed with a major residential aged care partner in New South Wales, Australia. Data from resident profiles, daily medications, falls incidents, and falls risk assessments were utilised. A dynamic falls risk prediction model and personalised rule-based falls prevention recommendations were embedded in the dashboard. The data ingestion process into the dashboard was designed to mitigate the impact of underlying data system changes. This approach aims to ensure resilience against alterations in the data systems.

Results: The dashboard was developed using Microsoft Power BI and advanced R programming by linking data silos. It includes dashboard views for those managing facilities and for those caring for residents. Data drill through functionality was utilised to navigate through different dashboard views. Resident level change in daily risk of falling, along with risk factors and timely evidence-based recommendations were output to prevent falls and enhance prescriptive decision support.

Conclusions: This study emphasises the significance of a sustainable dashboard architecture and how to overcome the challenges faced when developing a dashboard amidst underlying data system changes. The development process utilised an iterative dashboard co-design process, ensuring successful implementation of knowledge into practice. Future research will focus on the implementation and evaluation of the dashboard's impact on health processes and economic outcomes.

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Original Manuscript

Original Paper

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Conclusions: This study emphasises the significance of a sustainable dashboard architecture and how to overcome the challenges faced when developing a dashboard amidst underlying data system changes. The development process utilised an iterative dashboard co-design process, ensuring successful implementation of knowledge into practice. Future research will focus on the implementation and evaluation of the dashboard's impact on health processes and economic outcomes.

Keywords: falls prevention; dashboard architecture; sustainability; challenges; aged care; decision support

Introduction

Falls are the second leading cause of unintentional injury deaths worldwide, with those older than 60 having the highest risk of death or serious injury [1]. People living in residential aged care facilities (RACFs, i.e. nursing homes and care homes) are three times more likely to fall than their community-dwelling peers and are ten times more likely to sustain fall-related injuries [2]. Studies have found that falls are often predictable and preventable and that the health and economic burden of falls could be minimised if effective prevention strategies are implemented [3-5].

Falls prevention is an issue of major importance in RACFs. Various falls risk assessment tools (FRATs) are utilised by RACF staff internally to identify residents at greatest risk of falls [6]. However, when assessed, the predictive performance of these tools has generally shown to be poor [6, 7]. Moreover, FRATs are most often completed when residents are admitted to a facility and/or after a falls incident and thus only represent data collected at a single point in time, resulting in a static prediction which does not reflect changing falls risk factors (e.g., if a resident's medication use changes) [6].

As a growing number of RACFs implement electronic health record (EHR) systems, new opportunities have emerged to develop a personalised, dynamic approach to predicting residents' falls risk by taking advantage of multiple potential contributory factors [8]. Some studies have integrated routinely collected EHR data including vital signs, into the development of fall prediction tools through the application of machine learning models [9]. Despite these tools exhibiting superior performance in contrast to conventional FRATs, the risk predictions generated are often difficult to interpret and apply in practice. Thus, relying solely on these models will not enhance decision making to provide a personalised care strategy for falls prevention and management. Health dashboards which can integrate these predictive models in combination with visualisation features may be a more effective intervention for supporting staff in RACFs.

A dashboard can be defined as an at-a-glance real-time or near real time processing interface, showing graphical presentation of the current or the recent status, along with historical trends or organisational key performance indicators to support decision-making [10]. There have been some attempts to develop a dashboard for fall preventions purposes globally. The falls dashboard, developed by the Network of Patient Safety Databases (NPSD) and managed by the US Department of Health and Human Services, collects non-identifiable patient related falls incident data from health care service providers. These data are then aggregated to a national level, analysed and visualised using the NPSD dashboards and chartbooks to identify and track patient safety risks nationally [11]. Similarly, the New Zealand Health Quality and Safety Commission has established a falls and fracture outcomes dashboard to help the health sector evaluate the benefits of the services

provided to older people [12]. Such aggregated dashboards are helpful for monitoring although they offer limited assistance in predicting and preventing falls in routine care settings. To the best of our knowledge, no previous study has reported the development of a dashboard designed to predict falls risks for individual residents and aid decision-making in preventing and managing falls. As part of a comprehensive research program aimed at enhancing falls prevention and the well-being of older adults in RACFs [13], this paper details the design and development process of a predictive analytics dashboard with prescriptive decision support for falls risk prediction, prevention, and management. We discuss the challenges encountered and the strategies employed to overcome them during its development.

Methods

Participants

This project was conducted in collaboration with a large, aged care provider that operates 24 RACFs in Sydney, Australia. The development process of the dashboard spanned from January 1, 2022 to December 31, 2023. For the dashboard views and study sample, this study utilised data from both respite and permanent residents who were present in a RACF between January 1, 2021, and December 31, 2021. The dashboard was designed using participant data that was extracted on to excel sheets from the provider. After the development, the dashboard was connected to the provider's live data sources through a data lake.

Ethical considerations

All methods and analyses in this study were conducted in accordance with the principles of the Declaration of Helsinki. The study received ethics approval from the Macquarie University Human Research Ethics Committee (No. 52019614412614). As a retrospective cohort study utilising de-identified, routinely collected aged care data, a waiver of informed consent was granted by the committee, in line with the Australian National Statement on Ethical Conduct in Human Research (Sect. 3.3.14(a)), which allows for the use of previously collected de-identified data.

Dashboard development process

We followed an iterative process to co-design the dashboard, with intended dashboard end-users (i.e. RACF staff, general practitioners and consumers at RACFs), along with domain experts in the field of falls prevention and management. Figure 1 highlights the dashboard development process followed during the study. The stakeholders were involved continuously in Stage A and Stage B through regular discussions, interviews and workshops which will be described in detail elsewhere. The steps coloured in blue are described in this paper and the final steps relating to implementation and evaluation coloured in green are in progress and will be reported in subsequent papers.

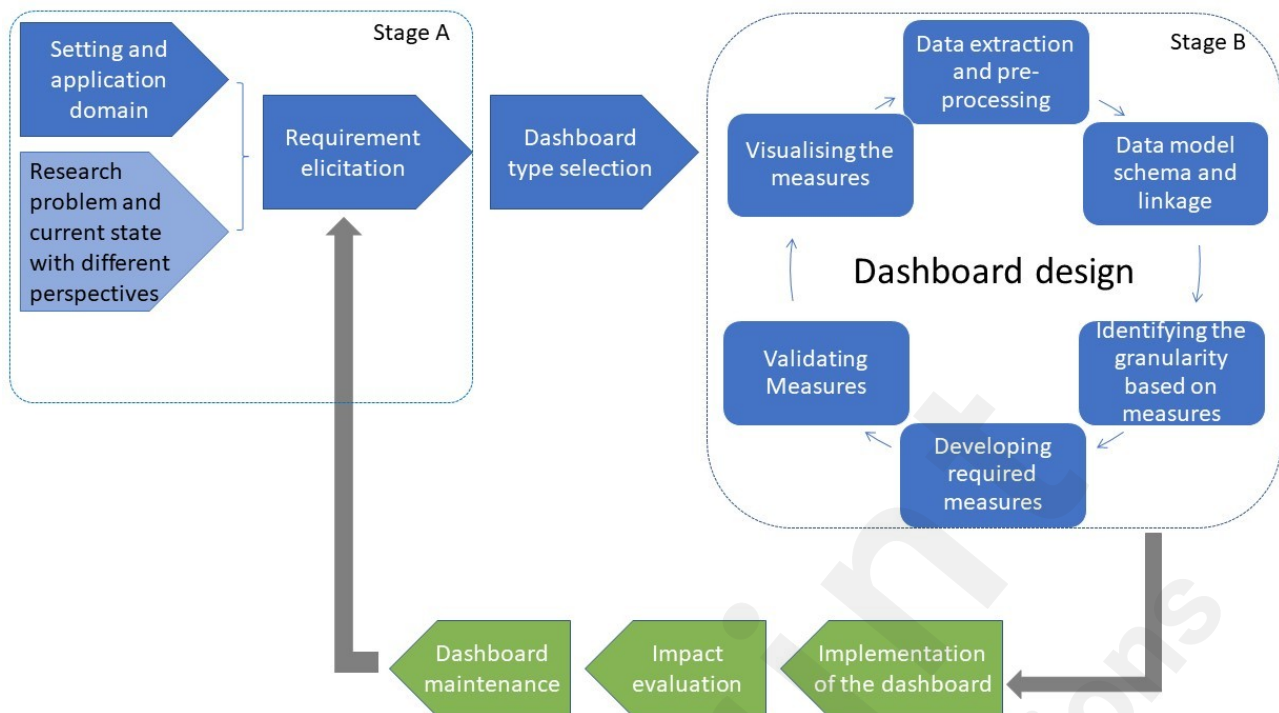


Figure 1: The dashboard development process

Setting and application domain

Domain knowledge can be defined as the knowledge about the environment which the proposed system will operate [14]. Domain knowledge was obtained from the aged care provider through discussions and analysis of data related to falls incidents and the Peninsula Health Falls Risk Assessment Tool (PH-FRAT) risk assessments (i.e. to determine the current falls rate across facilities, the characteristics of falls incidents and contributing factors listed in falls incidents). PH-FRAT, was developed in 1999 by Peninsula Health in Victoria, Australia, which is a validated and user-friendly tool for screening and assessing fall risk, as well as managing strategies to reduce this risk [15]. Information about predictors of falls and strategies used to prevent falls in the RACFs was obtained by systematically reviewing published literature on predictive models for falls prevention, and the effectiveness of fall prevention interventions [16, 17]. The identified predictors of falls in elderly populations have been incorporated into the development of the embedded predictive model which is reported elsewhere [18].

Research problem and current state with different perspectives

Considering the suboptimal predictive performance of current tools [6] there is a need for a dashboard embedded with dynamic predictive model and decision support (*research problem*). Moreover, falls prevention and management requires action at different levels of an organisation's hierarchy from management to clinical staff. Therefore, it was important to gather different perspectives. For this purpose, a series of discussions were held between researchers and RACFs stakeholders across a 2-stage process (Figure 1). In Stage A discussions, different perspectives of falls prevention and management in RACFs were gathered while identifying the dashboard stakeholders and their information requirements. In Stage B, dashboard stakeholders engaged in rounds of iterative feedback workshops to support the dashboard designing process. A qualitative analysis of these interviews will be reported elsewhere.

Requirement elicitation

The *requirement elicitation* stage was based on three fundamental tasks: (1) identifying the individual stakeholders; (2) eliciting stakeholder requirements depending on the role of the stakeholder; and (3) integrating, refining and organising the requirements identified [19].

In Stage A, baseline interviews were conducted to understand the current utilisation of healthcare data and information by potential dashboard end-users. The aim was to identify the information requirements essential for enhancing decision-making in a clinical dashboard. In this process the individual stakeholders and information providers of the dashboard were identified along with their high-level user expectations [10]. This also facilitated a precise understanding of the individuals with different perspectives of falls prevention and management, who would be accessing each dashboard view. The information collected from these interviews was used to define *measures* that should be generated in the dashboard backend.

From these identified measures, the designers then evaluated the variability of information and organised the information requirements based on level of reporting in the dashboard (i.e. resident level, facility level, or organisational level). This further supported the dashboard design stage in arranging visual plots and tables within views.

Dashboard type selection

Microsoft Power BI (PBI) was selected on the grounds of interactive data visualisation, easy implementation at the user end and stable R programming integration for advanced statistical analysis and plots. In this step, the initial prototype of the dashboard was created and shared with our partner organisation and refined through collaborative efforts.

Dashboard design

The aim of this step was to meet the user requirements for preventing and managing falls by effectively presenting resident data and fall risk information to support informed decision-making. As in Figure 1 this step included an iterative process that included *data extraction*, *pre-processing* and *linkage* along with *identification of the granularity of data*, *development*, *validation*, and *visualisation of the measures on the front end*.

Data extraction and pre-processing: Access to four datasets were obtained: the resident profile (includes residents' demographics and admission information); all medications administered to residents; the organisation's PH-FRATs (this aged care providers used the PH-FRAT) to obtain information related to falls risk assessments; and incident dataset (includes information related to all fall incidents and pressure injuries) (Supplementary Table 1).

The profile data set included a free text field which reported the comorbidities along with other special needs of the patient at admission (i.e. health status). From this field, comorbidities present at admission were identified using the R programed version of the "aged care health status algorithm" [20] within PBI. The algorithm identifies the health conditions using free text fields from EHRs [21]. All medications in the dataset were coded using the Anatomical Therapeutic Chemical codes (ATC) [22]. These datasets were then linked in the dashboard backend.

The extracted datasets for the study period, underwent an external analysis for this study using R programming language [23] and also subsequently employed for its intended purpose within PBI. A

descriptive analysis of the admission related information from resident profile dataset is reported appropriately (Supplementary Table 2). Resident characteristics from resident profile dataset, FRAT dataset and daily medication administration data are recorded in Supplementary Table 3.

Data model schema and linkage: A star schema was adopted as much as possible where the *fact table* is centered and surrounded by the multiple *dimension tables*. Resident profile dataset was used as the main *fact table* that contains quantitative information (facts) about the residents [24]. Other datasets were utilised as *dimension tables* which describe the events that residents experience during their stay [24]. The data tables were then linked as presented in the simplified form of the database schema as shown in Figure 2. The real schema on the back end of the dashboard is an extension of this and more advanced.

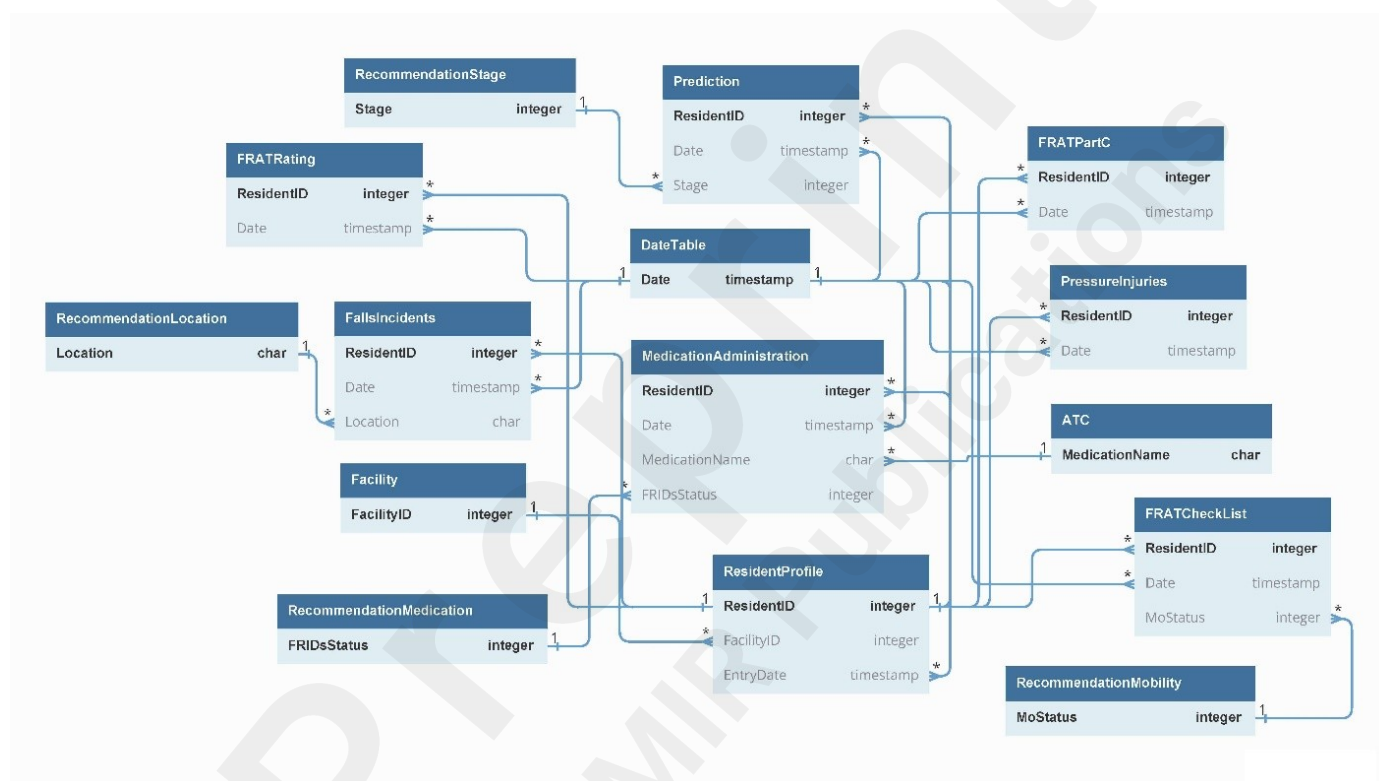


Figure 2: Simplified view of the data model schema

Identifying granularity based on measures: To determine the granularity of the data tables we considered the dashboard end users, information requirements (*measures*) and level of reporting that were pre-identified. This step was done in parallel or in a back-and-forth manner with the data model schema (i.e. preceding step) and development of required measures (i.e. proceeding step). A higher granularity was preferred for most of the datasets as to maintain sustainable analytical power to answer new user requirements within the designing stage [25]. Subsequently, the data tables were transformed to simply calculate the *measures* or *measure* calculations were adjusted in a way to meet the form and granularity in the extracted tables. In certain instances, highly granular data tables were summarised to a lower-level granularity to support the prediction model and avoid intricate calculations during *measure* development.

Developing the required measures: In this step *measures* were calculated on the transformed tables using Data Analysis Expression (DAX). Measures related to some figures such as funnel plots were created using embedded R programming in PBI backend.

Validating the measures: To ensure the accuracy and the reliability of the information presented, the calculated measures were validated with provider extracted datasets. The user input filters on each view were also tested during the validation process to identify whether there were any errors. If errors were identified in the data, remedial action was taken after a thorough examination of the underlying cause(s), in data extraction, data linkage, data preprocessing, or DAX formula.

Visualising the measures: The calculated measures were appropriately visualised using statistical plots, tables and interactive figures on the dashboard, which comprises several dashboard views intended for various users at different levels in the hierarchy. The above-mentioned steps within the dashboard design stage were enclosed in a co-design process as explained below.

Dashboard co-design and work process features (Stage B)

The core constructs of integrated-Promoting Action on Research Implementation in Health Services (i-PARIHS) [26] framework were considered to facilitate innovation into the development of the dashboard: (1) *innovation*; refers to the alignment of new insights including the predictive risk of falls captured by the dashboard with the current priorities and practices for falls prevention at RACFs, (2) *recipients*; RACFs staff and other external stakeholders who will be affected by and influence the implementation of the dashboard, (3) *context*; RACFs including the organisation (inner layer) and wider health system (outer layer) around falls prevention and management, and (4) *facilitation*; the process which activates the implementation through assessing the characteristics of the three previously mentioned constructs.

The core constructs were integrated into the dashboard development process and the design was meticulously refined through a series of workshops (i.e., *facilitation*) involving diverse teams of experts from various layers. These teams included general practitioners, geriatricians, allied health staff from RACFs (including nurses and clinical care managers), and human-computer interaction experts (i.e., *recipients*). The collaborative workshops aimed to identify and implement enhancements to the dashboard, ensuring that it caters to the needs and preferences of all relevant stakeholders (i.e., *innovation*). The design features (e.g. colour, graph types, positioning, filters, slices and data views) and content for decision making (i.e., information included or missing on the dashboard and predictive model output) were considered. In these workshops the development stage prototypes were presented to gather information on decision making on client care and to identify the dashboard views that required improvements in managing falls. Current priorities and practices involved in managing falls at RACFs (i.e., *context*) were also identified.

Descriptive and diagnostic analytics: Measures, indicators, and statistical tests

All falls, injurious falls and falls requiring hospitalisation were identified as the main indicators in the dashboard. Total number of falls, crude incident rate (i.e. falls rate per 1000 resident days), percentage of injurious falls and percentage of hospitalisation were calculated for each outcome measure to enhance the decision support capability at organisational level.

Funnel plots were used to visualise crude incident rates with 95% and 99% control limits, relative to the number of admissions. A time series plot was used to visualise the percentage of injurious falls and hospitalisation due to falls.

Predictive analytics with resident tailored recommendations: dynamic falls predictive and monitoring model

A dynamic predictive tool was developed to classify each resident's risk of falls utilising a technique called stratified landmarking and reported in detail elsewhere [18]. Initially 116 variables were screened, and the most relevant variables on the falls outcome were selected using Collett's variable selection approach [27]. Two separate models based on dementia status were developed [18]. The final two models were based on patient demographics, dementia status, falls risk increasing comorbidities such as cerebrovascular accident, visual impairment and osteoporosis/fracture, medication use, falls history and other risk factors such as psychological status, mobility status, behavior status and activities of daily living [18].

The predictive model used in this study was developed and internally validated using retrospective data from the same provider [18]. The scores based on model coefficients and baseline hazards were then embedded into the dashboard back end and calculated the resident's probability of falling in a near real-time manner. The predictions generated by the model are updated every 24 hours given the modifiable risk factors such as medication use, previous falls incidents and comorbidities.

As mentioned in the introduction, relying solely on a predictive model will not improve decision-making for developing a personalised care strategy for falls prevention and management. Additionally, the dashboard that visualises risk factors at both the resident and facility levels should be used to enhance the interpretability of these predictions and other associated risk factors of falls. This dashboard visualises the risk factors for falls, along with changes in risk and risk stages derived from the predictive model. Furthermore, to offer a more prescriptive approach based on these predictions, evidence-based, resident-tailored recommendations have been developed as follows.

Resident-tailored recommendations are generated using a rule-based system in the dashboard's backend. The system identifies residents' mobility issues from PH-FRAT data and detects the use of fall-risk-increasing drugs (FRIDs) from daily medication records. Fall incident data is used to determine the most frequent fall locations, while a predictive model assesses the current falls risk. Based on these factors, rule-based recommendations [28-30] are created and displayed in *resident fall* view (Supplementary Table 4). Additionally, strategies identified through clinical judgment in the PH-FRATs are also displayed to enhance the personalisation.

Results

Descriptive profile of aged care provider, facilities, and residents

The aged care provider managed 24 RACFs. During the period of dashboard development these RACFs housed 3,686 resident admissions from 3,057 unique residents. The median facility size was 124 residents (IQR=86,160). Of the resident admissions, 71% (n=2,622) were permanent. The median length of stay was 373 days (IQR=41, 1,266 days) (Supplementary Table 1 and 2).

Dashboard evolution within the design stage

The Stage A interviews, and Stage B workshops identified themes and findings related to content, design, functionality and decision support. This led the dashboard to evolve through series of iterations (Supplementary Figure 1). Two dashboard views namely, *organisational falls* and *facility falls*, were designed for organisational managers, while another two views were design for care staff focused on residents are *resident falls* and resident level *medications in detail*. The intervention recommendations gathered on falls prevention and management from published randomised controlled trials, government reports, systematics reviews and meta-analysis [28-30] are included in the *recommendation panel* for education purpose.

Measures developed in dashboard views

Table 1 presents the measures developed for each dashboard view. Given the interrelatedness of these views, certain measures employed in the organisational level (such as total falls, falls rate (per 1000 resident days) etc.) were also included in the facility level, while certain measures utilised at the resident level (i.e., FRIDs use in last three days, polypharmacy indicator etc.) were included in the *medications in detail* view.

Table 1: Measures available in the dashboard

Organisational falls	Resident falls	Facility falls	Medications in detail
Total falls	Current falls risk	Total number of residents	Polypharmacy indicator- without PRN ^a and Short course
Total falls requiring hospitalisation	Current risk category	Residents having stage 1 pressure injury	Daily FRIDs indicator
Total injurious falls	Daily percentage change in risk	Residents having stage 2 pressure injury	Daily change in FRIDs
Falls rate (per 1000 resident days)	Falls in last 6 months	Residents having stage 3 pressure injury	Daily change in Opioids use
Falls requiring hospitalisation rate (per 1000 resident days)	FRIDs use in last three days	Residents having stage 4 pressure injury	Daily change in Anxiolytics
Injurious falls rate (per 1000 resident days)	Change in FRIDs use in last three days	Residents having unstageable Pressure injuries	Daily change in Hypnotic and sedatives
Number of admissions per selected period	Polypharmacy indicator	Residents having deep tissue Pressure	Daily change in Beta blocking agents

		injuries	
Resident days per selected period	Antipsychotic indicator	Residents with a pressure injury	Daily change in Vasodilators
	Recent FRAT assessment date		Daily change in Antidepressants
	Recent cognitive status identified by PH-FRAT		
	Recent psychological status		

^aPRN - Pro re nata

Dashboard architecture

Data flows through four layers, to formulate the necessary information (Figure 3).

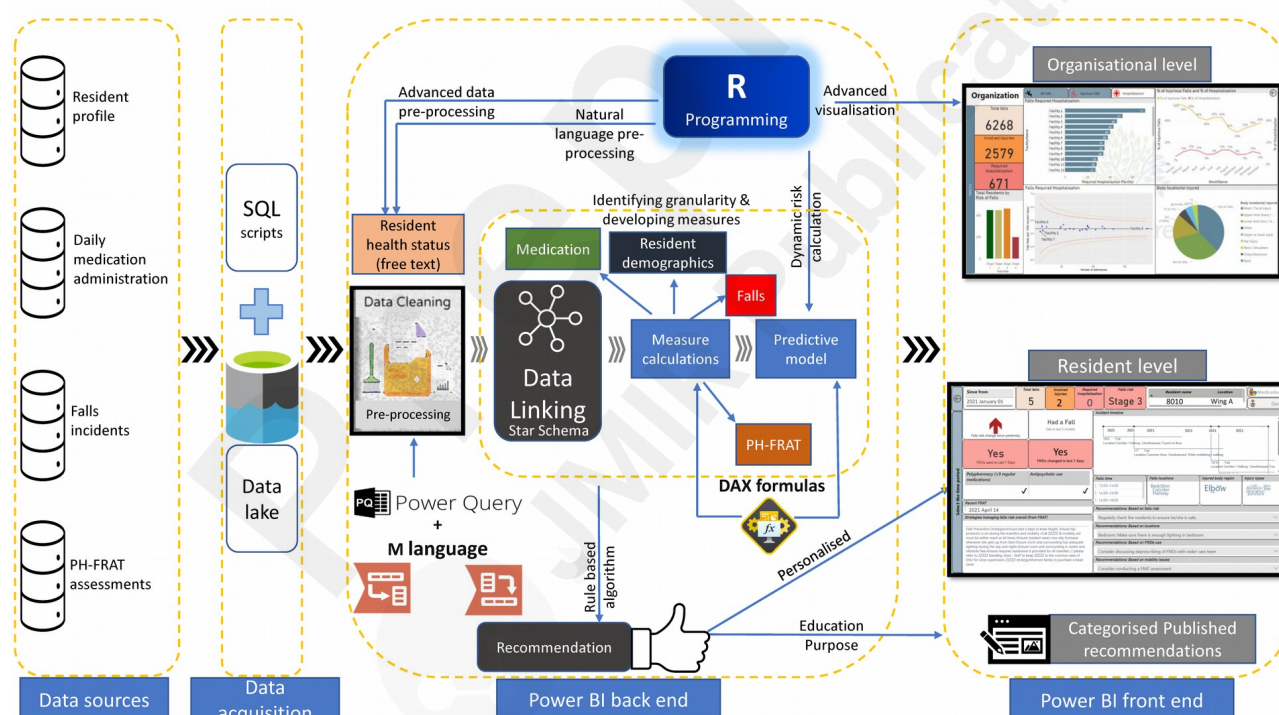


Figure 3: The dashboard architecture with four layers

The first layer includes the data sources where the aged care provider collects and stores data. The next layer is the data acquisition layer. It includes data extraction scripts such as SQL scripts which collect data from the previous layer. As the dashboard was developed without a direct connection to the above data silos (sources) the data extractions at the beginning were done using SQL scripts for each data silo, including the original variable names and formats. This layer is also helpful in maintaining the reliability of the dashboard when underlying IT systems change by storing the original form of data that is compatible with the dashboard

backend, which is the next layer. At implementation this layer will be replaced with a data lake which feeds provider level data to the dashboard back end.

Then the data extracted from the data lake are preprocessed and linked at the backend of the dashboard using the data model schema discussed (Figure 2). Previously identified measures and indicators are developed in this layer, to support the visualisation of data at the front end of the dashboard. For this purpose, we used power query M language, DAX and R programming. Risk calculations of the prediction model were carried out in this stage using R programming.

In the fourth layer the information requirement of stakeholders is satisfied by interactive visualisation and reporting. The front-end of the dashboard includes five views namely *organisational falls*, *facility falls*, *resident falls*, *medications in detail* and *recommendation panel*. The filters are applied to various dashboard views depending on user needs as identified during the requirement elicitation and dashboard design stages. Moreover, statistical plots are used to enhance valid comparisons of indicators between facilities and to support decision making.

Dashboard view: Organisational falls and facility falls

The *organisational falls*, and the *facility falls* are accessible by organisational and facility managers. Please note that some information of these views has been removed or modified to deidentify the residents and facility details.

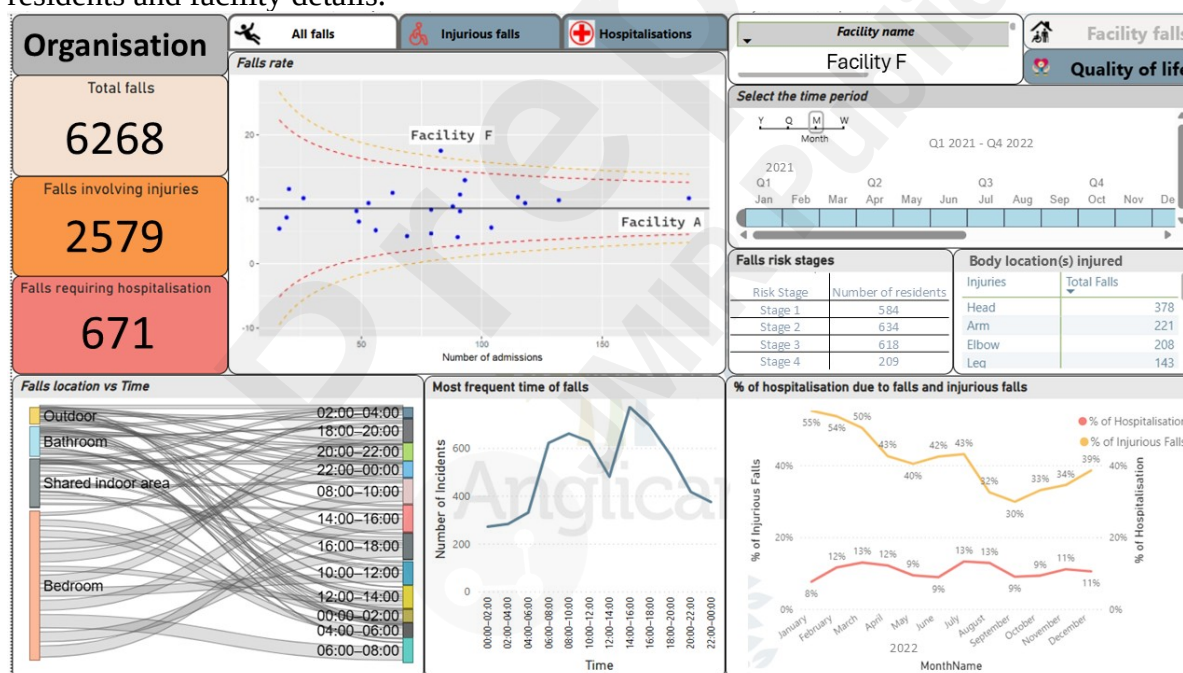


Figure 4: Organisational falls view.

The *organisational falls* view (Figure 4) includes organisational and facility level information relevant to falls incidence. The time-period and facility names are included as the filters. The information on this view can be updated with the values selected for these filters. Total number of falls along with injurious, and falls required hospitalisation are reported in the organisational level. The funnel plot in the view visualise the crude falls rate. Users can visualise this plot for the three outcome measures namely, all falls, injurious falls and falls

related hospitalisation. Funnel plots with the crude incident rates for each outcome measure enable valid comparisons between the facilities, as it can identify the outlying facilities with higher falls rates related to the number of admissions during the study period. The time series plot with percentage of injurious falls and percentage of hospitalisation enables the user to investigate overall patterns of falls occurring in selected facilities or at organisational level. This feature is helpful in identifying the longitudinal trend of injurious falls and hospitalization due to falls in facilities. The time series plot with the most frequent time of falls enables the user to investigate the time pattern of falls incidents. The most frequent locations of falls are linked with the time of falls by a Sankey plot. These plots are dynamic and interactive to the facility selected from the filters. Furthermore, the table with falls risk stages, indicates the number of residents within each risk classification predicted by the embedded predictive model. The most frequent injured body locations are also reported in a table.

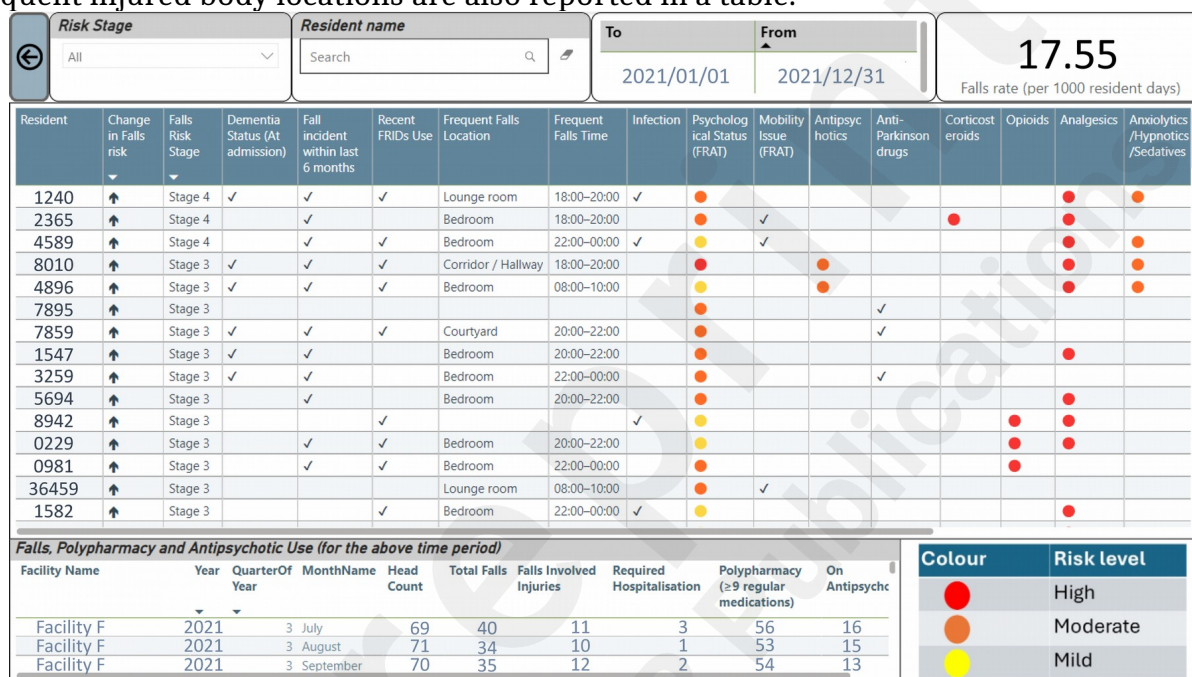


Figure 5: Facility falls view.

The *facility falls* view (Figure 5) provides more details of the facility specific falls along with facility characteristics. This view can also be accessed through the organisational level view using the “*drill through*” functionality in PBI. This view highlights the facility specific falls rate per 1000 resident days for a specified time. To enhance the interpretability of the predictive model, resident-specific risk factors extracted from the model are reported in this view. Importantly, residents classified under each risk classification along with change in falls risk compared to previous day, can be accessed in this view for effective falls prevention and management. The view also identifies comorbidities that increase falls risk (e.g., dementia) and modifiable risk factors (e.g., recent falls within the last six months, frequent locations and times of falls, mobility issues, psychological status, and the use of antipsychotic, opioid, and analgesic medications), all color-coded based on the level of risk identified by the predictive model. Additionally, facility specific monthly indicators including four national mandatory quality indicators namely percentage of care recipients: who experienced one or more falls; who were prescribed nine or more medications; who received antipsychotic medications and with pressure injuries, are also reported in this view. This view will also be included in a daily email notification to users once the dashboard is implemented.

Dashboard view: resident falls and the detailed medications

Care staff will have access to the *resident falls* view which includes time period, facility name, falls risk classification (i.e. derived from predictive model) and resident identifier as filters.

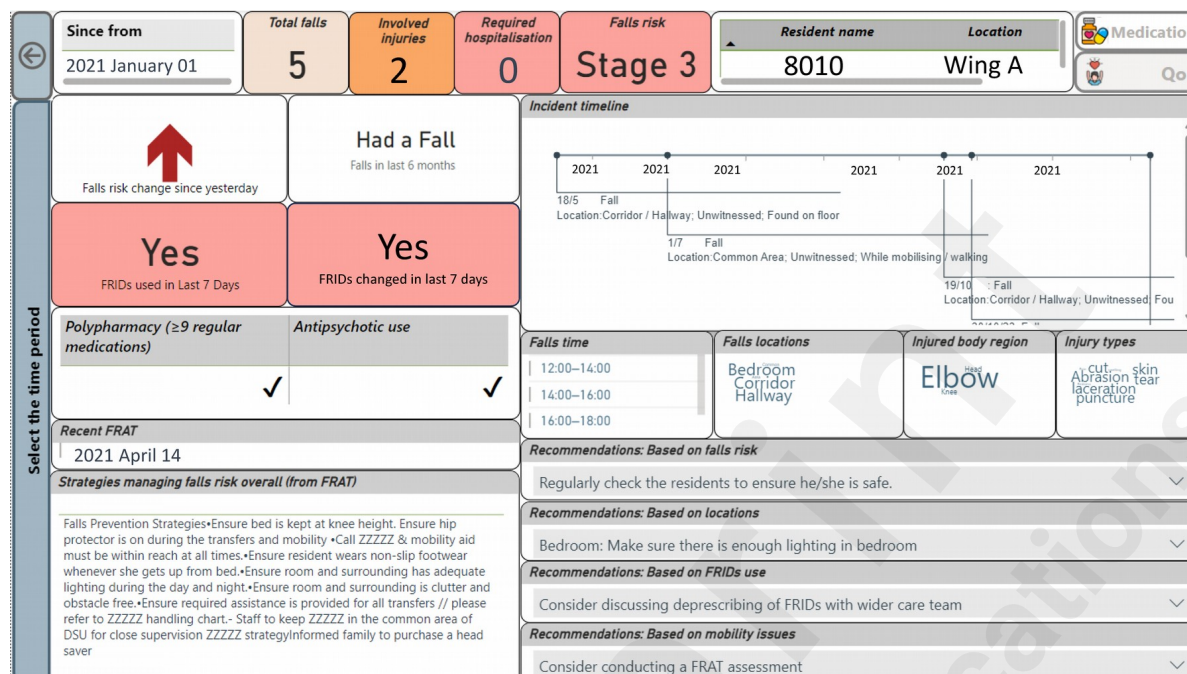


Figure 6: Resident falls view.

The *resident falls* view focuses on the resident specific falls information along with recommendations to prevent falls. This can also be accessed using the *facility falls* view using drill through functionality in PBI. The polypharmacy, FRIDs and antipsychotic medication use are identified using resident's daily medication administration data. This view presents the current risk category along with the total number of falls faced by the resident during their stay. Risk classification derived from the predictive model is shown using color codes (i.e., green to red) and text (i.e., stage 1 to 4). Most importantly the number of falls faced within last 6 months are shown in this view. Patient specific fall history is also visualised using a timeline along with the details of the events (i.e., event type, injury status and witnessed or unwitnessed). The sequence and the gaps between the fall incidents are highlighted in this plot. Furthermore, the word clouds visualise the injured body regions, injury types, locations and time of the falls. At the bottom of the view personalised recommendations are provided to the resident which align with falls risk categorisation, falls history, medication use and mobility issues.

Medicines in detail		Resident name	Location	FRIDs used within last 7 days
		8010	Wing A	Yes

Change in FRIDs									
Date	Change in Daily FRIDs	Change in Opioids	Change in Vasodilators	Change in Sedatives-hypnotics	Change in Beta blocking agents	Change in Anxiolytics	Change in Antidepressants	Polypharmacy (≥9 regular medications)	Antipsychotic use
2021 December 31									✓
2021 December 30									✓
2021 December 29	✓						✓		✓
2021 December 28									✓
2021 December 27									✓
2021 December 26									✓
2021 December 25									✓

Medication administered													
Date	2021 December 31					2021 December 30				2021 December 29			
Brand Name	6:22:00 AM	8:55:00 AM	12:14:00 PM	4:01:00 PM	7:07:00 PM	9:08:00 AM	12:05:00 PM	4:16:00 PM	7:19:00 PM	8:48:00 AM	12:16:00 PM	4:34:00 PM	7:20:00 PM
CO LAXATIVE WITH SENNA 90		✓											
DULOSE		✓		✓		✓		✓		✓		✓	✓
EGO QV CREAM 1KG		✓				✓				✓			✓
ENSURE TWO CAL 200ML	✓		✓	✓		✓	✓	✓		✓	✓	✓	
EPILIM		✓			✓	✓			✓	✓			✓
FLAVOUR CREATIONS NUTRITIONAL POWDER		✓				✓				✓			✓

Special needs (at admission)	Recommendations based on FRIDs use
DEMENTIA (DIAGNOSED IN NOVEMBER 2015) , MIXED ALZHEIMER'S DISEASE AND LEWY BODY DEMENTIA (AS PER BRAIN SCAN IN 2017) BPSD, URINARY AND BOWEL INCONTINENCE, OA , CHRONIC BACK PAIN AND HIP, RECURRENT UTIS, COGNITIVE IMPAIRMENT, HALLUCINATION, DEPRESSION AND ANXIETY	Consider discussing deprescribing of FRIDs with wider care team Consider requesting a medication review Double-check FRIDs and their effects on the resident Make sure resident is receiving correct dose, frequency and type of FRIDs Monitor effect of FRIDs

Figure 7: Medicines in detail

The *medications in detail* view (Figure 7) focuses on the resident specific daily medication use. This view can be assessed using “drill through” functionality enabled in the *resident falls* view. Here changes in falls risk increasing drugs (i.e. whether the resident has previously used the drug, whether a medication was omitted or a new drug added to the medication profile) within the last three days are identified and displayed, along with polypharmacy and antipsychotic medication indicators. The resident’s use of FRIDs is highlighted at the top. Daily medication administration records can also be accessed using this view. The special needs (i.e. comorbidities, and allergies) identified at the admission are included in the view to highlight the comorbidities, special needs or risk factors of the resident.

Dashboard view: Recommendation panel

As falls are affected by intrinsic and extrinsic factors [31], recommendations are grouped and reported in the recommendations panel (Figure 8) in three groups, namely: resident (intrinsic); environment (extrinsic); and others followed by sub categorisations.

Level, Category, Sub Category	Recommendations
☐ A). Environment ☐ 1. Reduce fall risk in Bedroom ☐ 2. Reduce fall risk in Shared indoor area ☐ 3. Reduce fall risk in Bathroom/toilet ☐ 4. Reduce fall risk in Garden/outdoor area ☒ B). Residents ☐ 10. Footwear and Clothing ☐ (10-1) Recommendations of safe shoes ☐ (10-2) Consult a podiatrist for podiatry assessment, particularly if residents experien... ☐ (10-3) Avoid long, baggy clothing. ☐ 11. Leisure activities & lifestyle ☐ 5. Fall assessment ☐ 6. Medication ☒ 7. Eyesight ☐ 8. Nutrition ☐ (8-1) Recommendations to improve nutrition taking and avoid falls due to thirsty an... ☐ 9. Mobility devices and protectors ☐ C). Others ☐ 12. Fall education ☐ (12-1) Regularly explain to residents about the falls risk. ☐ (12-2) Help residents familiarise with the location of emergency call system in their ... ☐ (12-3) Educate residents how to properly get up when a fall happens. ☐ (12-4) Encourage/remind residents to use staff assistance and device ☐ 13. For residents requiring intensive care and falling frequently ☐ 14. For resident to be transferred to hospital ☐ 15. Specific for residents with dementia/Parkinson's ☐ 16. Specific for residents with cognitive impairment	☐ Have residents' eyesight and glasses assessed by an optometrist ≥ 1 time per 2 years and yearly by your doct... ☐ Keep residents' glasses clean, within reach and placed in consistent place. ☐ Take extra care on steps if residents wear bifocals or multi-focals. ☐ Wear sunglasses and a hat outside.

Figure 8. Recommendation panel

Illustrative usage scenario

Organisational managers (Figure 4): A total of 6268 fall incidents were reported from the 3057 unique residents (729,410 resident days, Supplementary Table 3) between 1st of January 2021 to 31st of December 2021. Of these 2579 (41%) falls were injurious and 671 (11%) required hospitalisation. The average falls rate was 8.36 per 1000 resident days for the study period (funnel plot). The percentage of injurious falls shows an overall gradual decline from 56% to 38%, whereas the percentage of falls requiring hospitalisation is stable between 7% to 13% between 1st of January 2021 to 31st of December 2021. The majority of falls occurred in residents' rooms. Injurious falls most often involved injuries to the head and face followed by upper limb. When considering all falls, Facility A reported highest number of falls. Facility F had the sixth highest number of falls. However, the rate was above the 99% upper control limit (funnel plot), indicating a higher fall rate (per 1000 resident days) compared to other facilities with a similar number of admissions. Therefore, organisational managers can prioritise Facility F in intervening. They also can select Facility F and *drill through* to the *facility falls* view for more detailed investigation.

Facility managers (Figure 5): A total of 83 admissions were reported for facility F during the study period, with a falls rate of 17.55 per 1000 resident days. As of December 31, 2021, 3 residents (4%) were categorized with a falls risk of stage 4, while 13 residents (18%) were categorized with a risk of stage 3. Most of these residents had experienced a fall within the last six months and were on falls risk-increasing drugs (FRIDs). The resident bedroom was identified as the most frequent location for falls among the majority of residents. The majority of residents in this facility had cognitive impairment and dementia. It was clear that 54 (77%) and 13 (18%) residents were on polypharmacy and antipsychotics respectively for September, 2021. Organisational managers and facility managers can utilise the dashboard information to

identify facility level risk factors and to assist them with mandatory quality indicator reporting.

Nurse or personal carer (Figure 5 and Figure 6): On the *facility falls* view, a stage 3 resident (i.e. resident: 8010) was selected and drill down to *resident falls* view to analyse the resident level risk factors, falls incident characteristics and personalised recommendations to prevent and manage the future falls risk. Risk factors: Resident 8010 was in stage 3 (as of 31st December 2021) with delirium, dementia and stroke (Figure 7). The resident was on polypharmacy and antipsychotic medications as of 30th December 2021. There was an increase in falls risk compared to 30th of December 2021 which was generated by the embedded predictive model. The resident had five falls during the study period, in which two were injurious. When considering the resident's incidents timeline, four fall incidents had occurred in last six months. The resident was on polypharmacy along with FRIDs (as of 31st December 2021) where he had a change in FRIDs in last three days (i.e. 29th December -31st December 2021). Characteristics of falls incidents: Most of these incidents had occurred during afternoon in resident's bedroom including hallway and caused injuries to elbow, head and knee. The most recent FRAT assessment was conducted in April 2021. Recommendations to prevent future falls: According to the recent FRAT, the identified strategies in managing falls risk were displayed along with prescriptive recommendations such as "regular monitoring", "assessing environmental risk in toilet/bathroom and bedroom" and "assessing FRIDs use".

For further detail view of medication use, resident's *medications in detail* view (Figure 7) can be assessed. Moreover, carers can utilise the information provided in the *recommendation panel* when assessing the falls risk for the resident, based on the resident level risk factors (e.g., dementia) and environmental risk factors (i.e., bedroom) etc.

Discussion

Our dashboard adapted and refined the dashboard development process outlined by Staron [10], with an emphasis on understanding the specific domain of residential aged care and their current work practices around falls prevention and management. This was achieved through continuous stakeholder discussions (i.e. Stage A and Stage B), quantitative data analysis on the extracted data sets and reviewing the published literature. This work produces important new resources for the current state of falls prevention in RACFs along with the extent of evidence-based prevention strategies. The dashboard design stage was an iterative process which required close collaboration with the users and its stakeholders (i.e. Stage B). This was the most important stage of the dashboard development as it identified the data presentation for dashboard views along with the quantitative measures to be included for falls prevention. To enhance the technology implementation process within the context of falls prevention and management the four constructs of i-PARIHS framework was followed throughout the dashboard development process.

The core innovation of this study comes from several novel aspects. The Royal Commission into Aged Care Quality and Safety has noted that the residential aged care sector has lagged behind other healthcare sectors in adopting and implementing technology [32]. It is also found that information systems and processes in these settings are both underdeveloped and inadequately integrated [33]. Furthermore, successfully connecting multiple disparate data sources in aged care is uncommon. This may be due to various factors, such as data being collected by different systems and third-party software vendors being inflexible in incorporating unique identifiers (i.e., resident identifiers) across systems. Therefore, this study emphasises the value of linking existing datasets and visualising the linked information to support falls prevention. The *resident falls* view in the dashboard, presents the

linked data from four data sources and support to identify resident-level risk factors, fall incident characteristics, and personalised recommendations for fall prevention. This allows users to access crucial information at a glance, rather than navigating across different systems, thus demonstrating significant added value in preventing falls.

The dashboard provides staff with easy access to synthesised, evidence-based recommendations for effective fall prevention strategies. In the dashboard, external evidence on fall prevention and management (e.g., published prevention recommendations) has been aligned with current priorities and practices at RACFs (such as PH-FRATs). Current practices, such as the falls prevention strategies identified through PH-FRATs, was embedded, along with rule-based recommendations. Additionally, a separate recommendation panel was established to support decision-making around falls risk assessments.

Another novel aspect in the dashboard is the embedded predictive model. Predicting falls risk is challenging because of the numerous contributing factors [34, 35], including medical conditions, medications, functional status, behavior, physiological aspects, and environmental conditions. Many of these factors, such as medication use, can vary over time [36]. The dynamic predictive model embedded in the dashboard is therefore an important part of the dashboard. It utilises near real time data and helps to classify the resident risk of fall on daily basis. The incorporation of the predictive algorithm in the dashboard goes beyond what has been possible with existing falls risk assessments as it dynamically predicts the risk and link it to resident's falls risk factors and personalised strategies. This provides timely and meaningful risk prediction along with evidence-based recommendations based on resident profile, to the caring staff to facilitate person-centered fall prevention and improve outcomes.

Finally, the dashboard is innovative because it adopts a holistic approach to managing falls in aged care residents by integrating multiple data sources and making this information easily accessible to different stakeholders including managers and carers. The granular resident-level data is aggregated to facility and organisational levels, allowing users to navigate seamlessly between these levels with just a few clicks. This structure enables users to drill down from the organisational level to individual residents or vice versa, providing a comprehensive and detailed view of fall risk and prevention strategies.

Challenges faced and strategies to overcome

There were many challenges faced when developing this dashboard. Initially the dashboard was developed utilising datasets which were extracted from the provider rather than directly connecting to the database. This leads to the integration process becoming more challenging unless the variables are in standard format as in the database. Moreover, our partner has changed its incident reporting system and daily medication management system within the development process. More robust processes were required to be implemented on the back end of the dashboard to overcome these challenges. The data acquisition layer discussed at dashboard architecture was important in this aspect. This layer act as a data reservoir. Here, the initial data is extracted from original sources, stored as in original format, and then transformed into the data tables that the dashboard requires. This layer enabled the dashboard to be sustainable in the long run amidst the underlying system changes.

Data model in the backend of the dashboard also plays a critical role in facilitating the above process. This is crucial as the measures were developed using the linkages between the tables. Adapting a star schema as much as possible within the dashboard backend has promoted several advantages within the study. Simplicity and ease of use of the data model during various stages of the development

process can be noted. Visualisation and embedding analytical measures within the dashboard were simplified without complex data integration. This has streamlined the dashboard development during co-design stage while accelerating the time of incorporating various views on falls prevention and management. Flexibility and scalability can be noted as another advantage where the schema was helpful in adapting the dashboard design to changing RACF requirements in managing falls while incorporating additional data fields and sources with minimum modifications to the existing structure. Therefore overall, adapting the star schema as much as possible within the dashboard development process was an excellent choice due to its ability of incorporating changing user requirements in the context of falls management at RACFs.

Furthermore, for the daily calculation of *changes* in falls risk, the current study employs R programming. This decision stems from PBI's inability to retain and save daily risk calculations. To address this limitation, the designers have integrated R programming code into the Power Query Editor, enabling the storage of these risk calculations on a shared drive. The code automatically saves these calculations on a daily basis during the data refresh cycle, occurring every 24 hours. Subsequently, on daily basis, these stored files (i.e. previous day risk calculations) are retrieved into the PBI backend to calculate the difference between current and previous risks at the resident level.

The integration of R programming into the dashboard backend has introduced a technical skills gap between the partner organisation and the dashboard designers. Consequently, workshops were organised with the partner organisation's IT teams to provide training on R programming, bridging the gap in statistical analysis using R programming. Additionally, line-by-line code interpretation was incorporated into the embedded codes to facilitate a seamless transition during dashboard implementation.

Implications for policy, practice, and future research

Our study highlights the potential of using a falls prevention and management dashboard to enhance resident outcomes in aged care through effective use of information systems. Health dashboards facilitate decision-making and required to be used in conjunction with clinical judgment, staff education, training, and individualised tailored responses. Future policy and practice must ensure interoperability of information systems in aged care, involve key stakeholders in development and implementation, and allocate appropriate funding for these processes. Future research should also focus on expanding the fall prediction dashboard and incorporating other care needs in residential aged care facilities, such as hospitalisation and wound management.

Conclusion

In this study, a comprehensive process for developing a falls prevention and management dashboard with descriptive, predictive, and prescriptive analytics for RACFs was thoroughly discussed along with a sustainable architecture. The key focus was to provide a holistic approach in managing falls by linking existing data sources at provider level. This highly applied and translational research demonstrated how EHRs can be utilised along with technology to deliver evidence-based information to aged care allied health workers and managers, to drive better aged care quality and safety.

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Data availability

The data underlying this study cannot be shared publicly to protect the privacy of the individuals who participated in the study. However, the data can be shared upon a reasonable request to the corresponding author. Researchers interested in implementing a similar prescriptive dashboard or requiring additional information, including details on the backend data model schema, can contact the authors for further information.

Conflicts of Interest

None declared. The authors declare that they have no competing interests.

Abbreviations

ATC: Anatomical Therapeutic Chemical codes

DAX: Data Analysis Expression

EHR: electronic health record

FRATs: falls risk assessment tools

FRIDs: fall-risk-increasing drugs

i-PARIHS: integrated-Promoting Action on Research Implementation in Health Services

NPSD: Network of Patient Safety Databases

PBI: Power BI

PH-FRAT: Peninsula Health Falls Risk Assessment Tool

RACFs: residential aged care facilities

Author Contributions

The dashboard was technically designed by S.S.M.S. The co-design process of the dashboard involved S.S.M.S., N.W., A.D.N., K.S., L.D., I.M., C.M., and G.H. The manuscript was drafted by S.S.M.S. and revised by N.W., A.D.N., K.S., G.H., and I.M. Both manuscript draft and system were reviewed by J.I.W.

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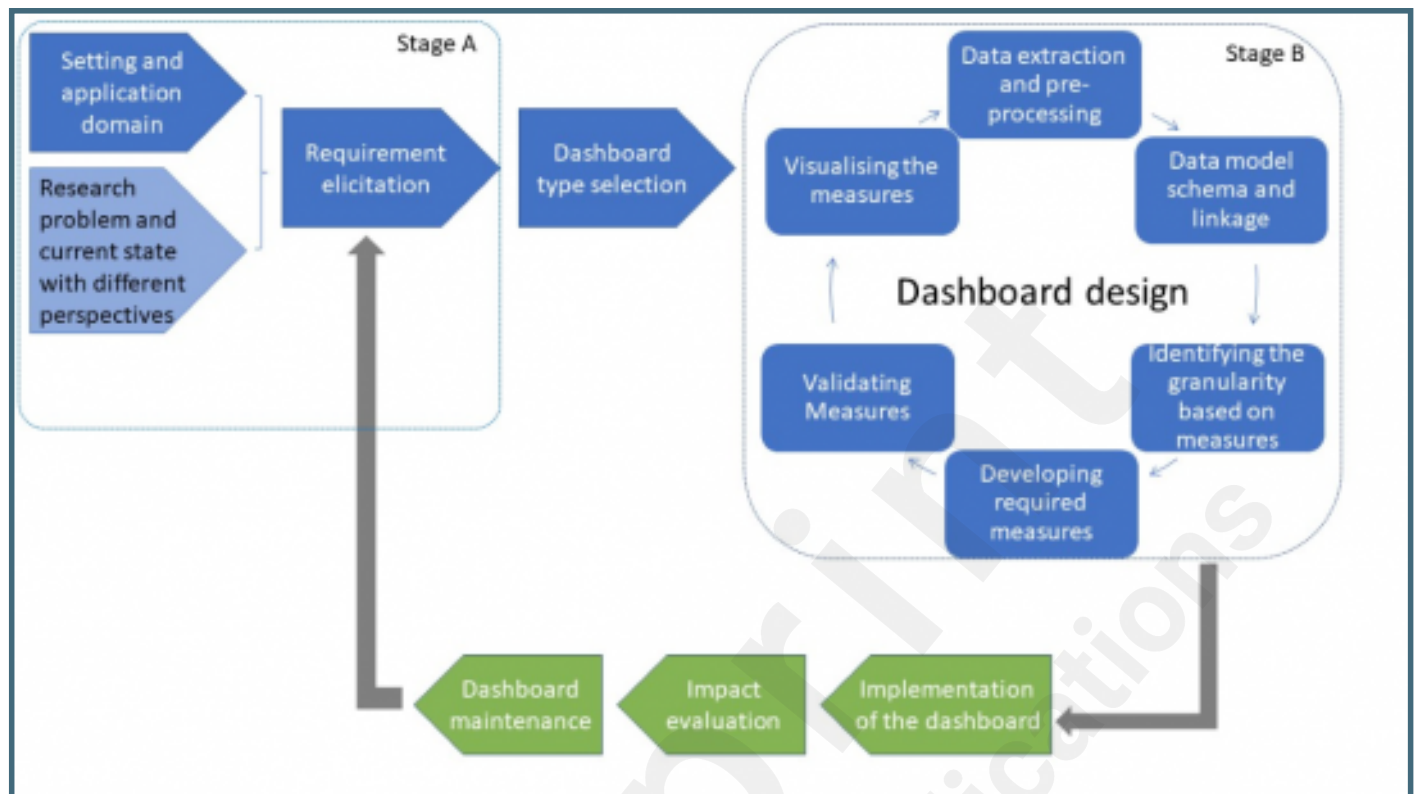
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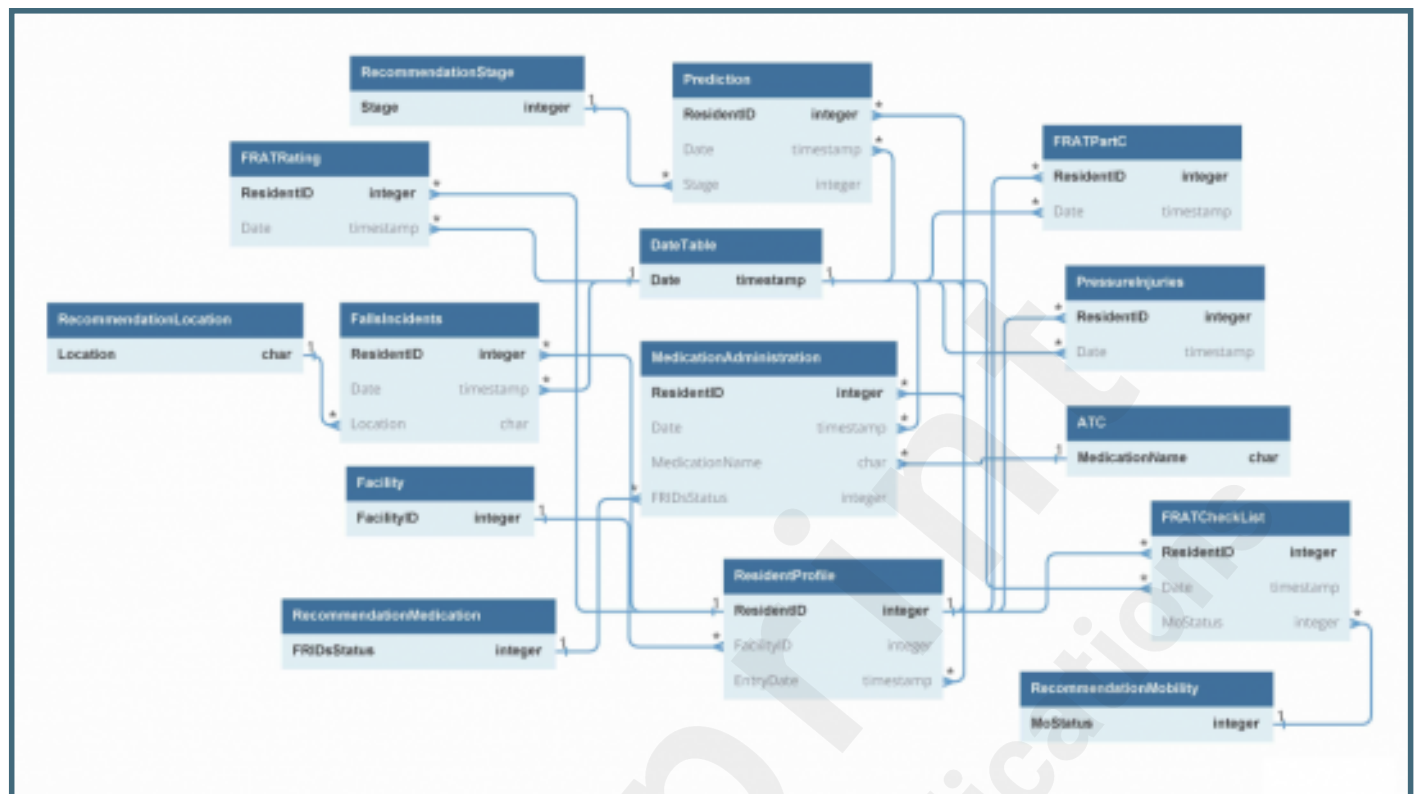
Supplementary Files

Figures

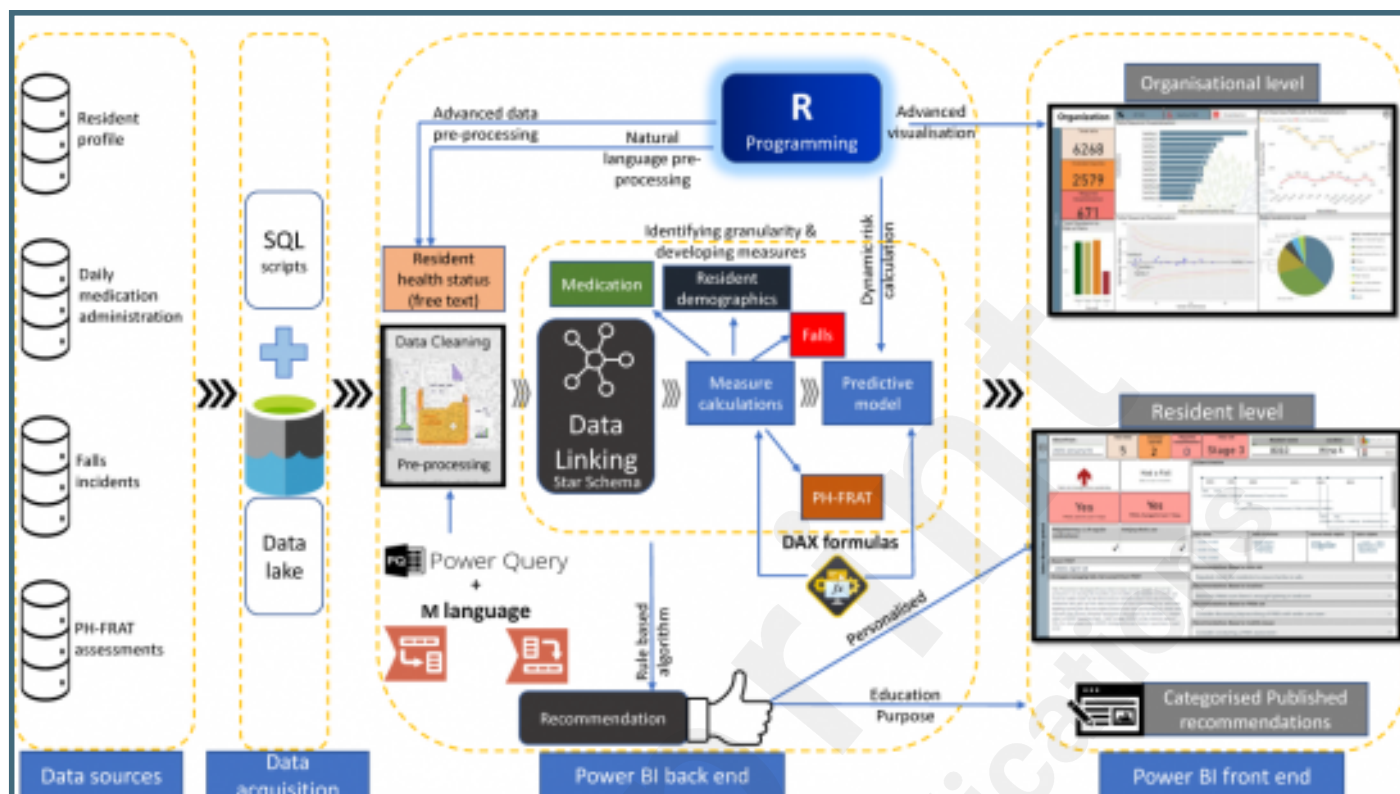
The dashboard development process.



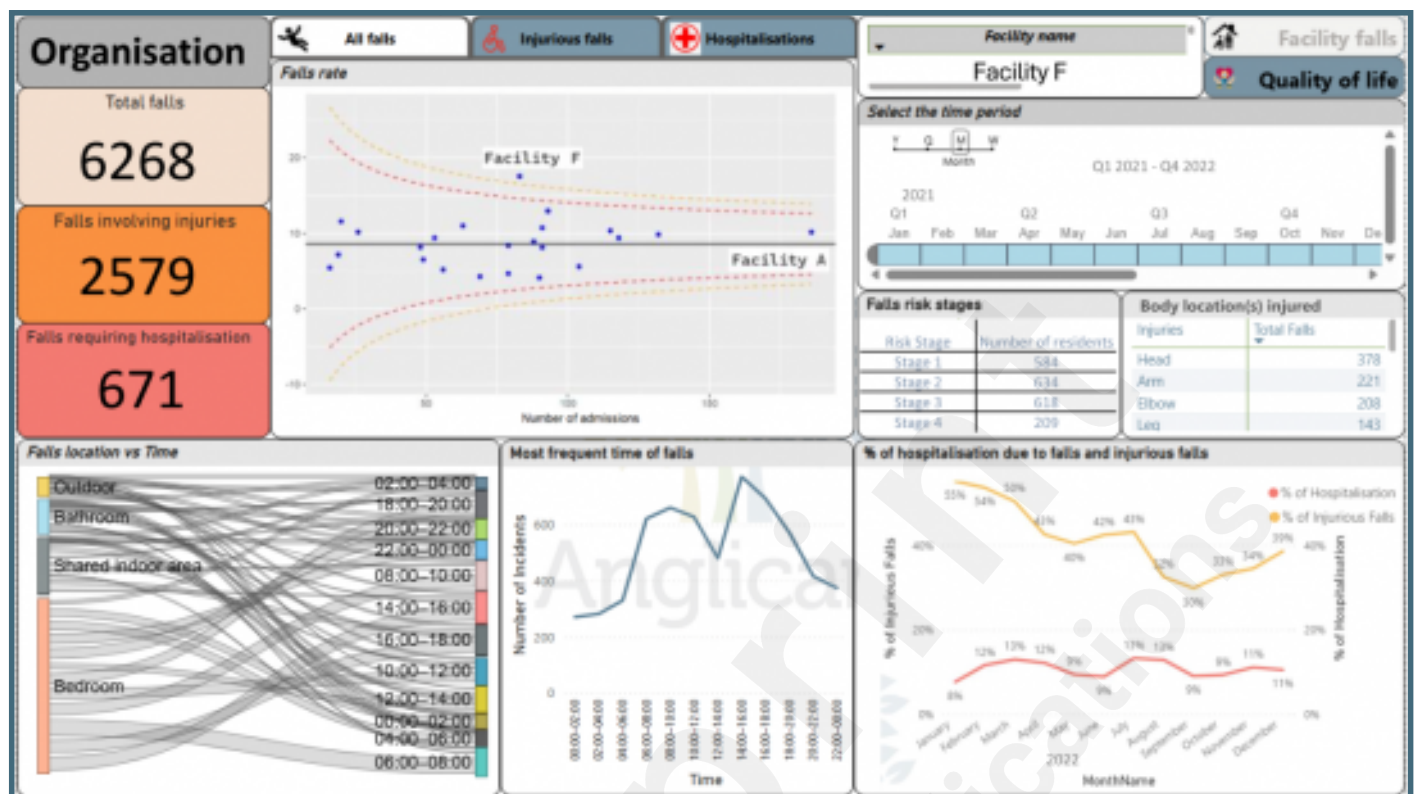
Simplified view of the data model schema.



The dashboard architecture with four layers.



Organisational falls view.



Facility falls view.

Risk Stage

All

Resident name

Search

To

2021/01/01

From

2021/12/31

17.55

Falls rate (per 1000 resident days)

Resident	Change in Falls risk	Falls Risk Stage	Dementia Status (At admission)	Fall incident within last 6 months	Recent FRDs Use	Frequent Falls Location	Frequent Falls Time	Infection	Psychological Status (FRAT)	Mobility Issue (FRAT)	Antipsychotics	Anti-Parkinson drugs	Corticosteroids	Opioids	Analgesics	Anxiolytics /Hypnotics /Sedatives
1240	⬆	Stage 4	✓	✓	✓	Lounge room	18:00-20:00	✓	●						●	●
2365	⬆	Stage 4		✓		Bedroom	18:00-20:00		●	✓			●		●	
4589	⬆	Stage 4		✓	✓	Bedroom	22:00-00:00	✓	●	✓					●	●
8010	⬆	Stage 3	✓	✓	✓	Corridor / Hallway	18:00-20:00		●		●				●	●
4896	⬆	Stage 3	✓	✓	✓	Bedroom	08:00-10:00		●		●				●	●
7895	⬆	Stage 3							●			✓				
7859	⬆	Stage 3	✓	✓	✓	Courtyard	20:00-22:00		●			✓				
1547	⬆	Stage 3	✓	✓		Bedroom	20:00-22:00		●						●	
3259	⬆	Stage 3	✓	✓		Bedroom	22:00-00:00		●			✓				
5694	⬆	Stage 3		✓		Bedroom	20:00-22:00		●						●	
8942	⬆	Stage 3			✓			✓	●					●	●	
0229	⬆	Stage 3		✓	✓	Bedroom	20:00-22:00		●					●	●	
0981	⬆	Stage 3		✓	✓	Bedroom	22:00-00:00		●					●		
36459	⬆	Stage 3				Lounge room	08:00-10:00		●	✓						
1582	⬆	Stage 3			✓	Bedroom	22:00-00:00	✓	●						●	

Falls, Polypharmacy and Antipsychotic Use (for the above time period)

Facility Name	Year	QuarterOf Year	MonthName	Head Count	Total Falls	Falls Involved Injuries	Required Hospitalisation	Polypharmacy (≥9 regular medications)	On Antipsychotic	Colour	Risk level
Facility F	2021	3	July	69	40	11	3	56	16	●	High
Facility F	2021	3	August	71	34	10	1	53	15	●	Moderate
Facility F	2021	3	September	70	35	12	2	54	13	●	Mild

Resident falls view.

Since from 2021 January 01		Total falls 5	Involved injuries 2	Required hospitalisation 0	Falls risk Stage 3	Resident name 8010	Location Wing A	Medication 	QoL
Falls risk change since yesterday 		Had a Fall Falls in last 6 months		Incident timeline					
Yes FRIDs used in Last 7 Days		Yes FRIDs changed in last 7 days							
Polypharmacy (≥9 regular medications) ☒		Antipsychotic use ☒		Falls time		Falls locations		Injured body region	
				12:00–14:00 14:00–16:00 16:00–18:00		Bedroom Corridor Hallway		Elbow (cut, abrasion, laceration, puncture)	
Recent FRAT 2021 April 14				Recommendations: Based on falls risk Regularly check the residents to ensure he/she is safe.					
Strategies managing falls risk overall (from FRAT) Falls Prevention Strategies: Ensure bed is kept at knee height. Ensure hip protector is on during the transfers and mobility. Call ZZZZZ & mobility aid must be within reach at all times. Ensure resident wears non-slip footwear whenever she gets up from bed. Ensure room and surrounding has adequate lighting during the day and night. Ensure room and surrounding is clutter and obstacle free. Ensure required assistance is provided for all transfers // please refer to ZZZZZ handling chart. Staff to keep ZZZZZ in the common area of DSU for close supervision ZZZZZ strategy informed family to purchase a head saver				Recommendations: Based on locations Bedroom: Make sure there is enough lighting in bedroom					
				Recommendations: Based on FRIDs use Consider discussing deprescribing of FRIDs with wider care team					
				Recommendations: Based on mobility issues Consider conducting a FRAT assessment					

Medicines in detail.

Medicines in detail		Resident name		Location		FRIDs used within last 7 days			
		8010		Wing A		Yes			
Change in FRIDs									
Date	Change in Daily FRIDs	Change in Opioids	Change in Vasodilators	Change in Sedatives-hypnotics	Change in Beta blocking agents	Change in Anxiolytics	Change in Antidepressants		
2021 December 31									
2021 December 30									
2021 December 29	✓						✓		
2021 December 28							✓		
2021 December 27							✓		
2021 December 26							✓		
2021 December 25							✓		
Medication administered									
Date	2021 December 31					2021 December 30		2021 December 29	
Brand Name	6:22:00 AM	8:55:00 AM	12:14:00 PM	4:01:00 PM	7:07:00 PM	9:08:00 AM	12:05:00 PM	4:16:00 PM	7:19:00 PM
CO LAXATIVE WITH SENNA 90		✓							
DULOSE		✓		✓				✓	
EGO QV CREAM 1KG		✓				✓			✓
ENSURE TWO CAL 280ML		✓	✓	✓		✓	✓	✓	✓
EPI LIM		✓			✓			✓	✓
FLAVOUR CREATIONS NUTRITIONAL POWDER		✓				✓		✓	✓
Special needs (at admission)					Recommendations based on FRIDs use				
DEMENTIA (DIAGNOSED IN NOVEMBER 2015), MIXED ALZHEIMER'S DISEASE AND LEWY BODY DEMENTIA (AS PER BRAIN SCAN IN 2017) BPSD, URINARY AND BOWEL INCONTINENCE, OA, CHRONIC BACK PAIN AND HIP, RECURRENT UTIs, COGNITIVE IMPAIRMENT, HALLUCINATION, DEPRESSION AND ANXIETY					Consider discussing deprescribing of FRIDs with wider care team Consider requesting a medication review Double-check FRIDs and their effects on the resident Make sure resident is receiving correct dose, frequency and type of FRIDs Monitor effect of FRIDs				

Recommendation panel.

Level, Category, Sub Category	Recommendations
☐ A). Environment ☐ 1. Reduce fall risk in Bedroom ☐ 2. Reduce fall risk in Shared indoor area ☐ 3. Reduce fall risk in Bathroom/toilet ☐ 4. Reduce fall risk in Garden/outdoor area	☐ Have residents' eyesight and glasses assessed by an optometrist ≥ 1 time per 2 years and yearly by your doctor. ☐ Keep residents' glasses clean, within reach and placed in consistent place. ☐ Take extra care on steps if residents wear bifocals or multi-focals. ☐ Wear sunglasses and a hat outside.
☒ B). Residents ☐ 10. Footwear and Clothing ☐ (10-1) Recommendations of safe shoes ☐ (10-2) Consult a podiatrist for podiatry assessment, particularly if residents experien... ☐ (10-3) Avoid long, baggy clothing. ☐ 11. Leisure activities & lifestyle ☐ 5. Fall assessment ☐ 6. Medication ☒ 7. Eyesight ☐ 8. Nutrition ☐ (8-1) Recommendations to improve nutrition taking and avoid falls due to thisty an... ☐ 9. Mobility devices and protectors	
☐ C). Others ☐ 12. Fall education ☐ (12-1) Regularly explain to residents about the falls risk. ☐ (12-2) Help residents familiarise with the location of emergency call system in their ... ☐ (12-3) Educate residents how to properly get up when a fall happens. ☐ (12-4) Encourage/remind residents to use staff assistance and device ☐ 13. For residents requiring intensive care and falling frequently ☐ 14. For resident to be transferred to hospital ☐ 15. Specific for residents with dementia/Parkinson's ☐ 16. Specific for residents with cognitive impairment	

Multimedia Appendixes

Datasets utilised in design stage of the dashboard.

URL: <http://asset.jmir.pub/assets/ce11db78fdf24ef5672c013597de7b09.docx>

Admission related information from resident profile dataset.

URL: <http://asset.jmir.pub/assets/4ac3773359cb611b53992ffdbbf44322.docx>

Resident characteristics from resident profile dataset, FRAT dataset and daily medication administration data.

URL: <http://asset.jmir.pub/assets/cbd6a332605177b90e325f1251a94366.docx>

Rule-based recommendations included in the resident falls view.

URL: <http://asset.jmir.pub/assets/799947d5523bef0d2afab44990c4cfb8.docx>

Dashboard evolution within the design stage.

URL: <http://asset.jmir.pub/assets/588ad34f1e8aeb4fa02b781678a0b90c.png>