Australia's National
Science Agency

Risk adjustment for emergency laparotomy mortality

Results for in-hospital, 30-, 90- and 365-day mortality measures

Marcela Cespedes, Sankalp Khanna, Rajiv Jayasena

Manuscript Number EP2021-1070
26 July 2021

Prepared for Victorian Agency for Health Information

The Australian eHealth Research Centre, Health & Biosecurity, CSIRO

Citation

Cespedes M, Khanna S, Jayasena R (2021) Methodology and risk adjustment for emergency laparotomy measure. EP2021-1070. CSIRO, Australia.

Contents

Figures

Tables

Acknowledgments

This project is funded by the Victorian Agency for Health Information (VAHI) with co-funding support from CSIRO. We thank VAHI and the Expert Advisory Group (EAG) for providing background information and valuable feedback and discussion. We would like to particularly thank Dr. David Watters for providing clinical expertise to guide this project.

Executive summary

Emergency laparotomy (EL) procedures are routinely carried out in hospitals across Australia. Reporting and learning from EL related deaths make an important contribution to understanding and informing the characteristics related to these deaths.

The Victorian Agency for Health Information (VAHI) reports risk adjusted mortality estimates following in-and-out of hospital deaths across a range of medical procedures. As part of the CSIRO advanced statistics and analytic capability uplift partnership with VAHI, the objective of this project was to develop and validate risk adjusted models for in-hospital, 30-, 90- and 365-day mortality following an ED procedure.

Building on previous work initiated by VAHI, and working closely with Prof. David Watters who provided clinical stewardship for this project, the key contributions of this project include:

1. Development of clinically appropriate grouping for laparotomy procedure codes, Elixhauser comorbidity measure and ICD10 family codes for diagnosis grouping.
2. Development and validation of risk adjusted mortality indicators for each of the 4 chosen mortality indicators of interest.

An interim report describing the risk adjusted models for in-patient EL mortality was delivered to VAHI on 28/06/2021. This report represents the final report for this project and presents details of covariate selection, model diagnostics, and the final risk adjusted mortality models. R scripts employed for implementing models and validation will also be delivered to VAHI to support deployment of developed models.

They key findings of this work include:

- For in-hospital up to and including 365-day post-operative outcomes, all models include age, laparotomy procedure and diagnosis groupings, as well as a measure of comorbidity for optimal performance.
- EL risk adjusted models over various post-operation periods, including in and out-hospital care are complex and vary for each outcome.
- Several Elixhauser comorbidities were consistent across all outcomes, suggesting that these specific factors play a large role in survivability of EL procedures.
- All final models presented in this report have a mean predictive performance test set AUC values greater than 0.8

This page has intentionally been left blank.

1 Introduction

The Victorian Agency for Health Information (VAHI) is a division within the Victorian Department of Health. VAHI analyses, monitors, and reports on public and private services that impact on the health, wellbeing, quality, and safety of people who utilise healthcare services within Victoria. Through reporting, VAHI aims to increase transparency and accountability. VAHI has engaged CSIRO to assist with various quality and safety improvement activities. This body of work falls within that scope of work, assisting with the development of risk models for implementation, monitoring and reporting.

Emergency Laparotomies (EL) are often required for life threatening conditions and therefore are associated with substantial risk of mortality. A Victorian study suggests that nearly 1 in 10 patients who underwent emergency laparotomy between 2007/08 to 2015/16, died while in hospital.[1] Adverse patient outcomes following emergency laparotomy vary between hospitals,[2] suggesting opportunities to improve quality of care and postoperative outcomes.

At present, VAHI reports mortality ratios for deaths following hospital episodes associated with a range of conditions. This work pertains to the development and validation of EL risk adjusted models for mortality associated with EL across four specific outcomes (in-hospital mortality, 30-, 90- and 365-day mortality).

1.1 Project background

1.1.1 Preliminary work completed by VAHI

This work builds on initial modelling carried out by a VAHI analyst in collaboration with Prof. David Watters and presented to an Expert Advisory Group (EAG) set up by VAHI to provide expert advice on various projects and initiatives. This previous work was summarised in two reports that were shared with CSIRO by VAHI:

1. Report titled ‘Measuring Victorian Emergency Laparotomy Mortality Rate’
2. Report titled ‘Summary of further work on the Emergency Laparotomies mortality indicator’

The first report delivered definitions, concepts, methodology and issues for further considerations as well as several summaries for in-hospital deaths on a monthly and yearly basis and across hospital clusters. The second reports build upon the first and includes feedback from members of the VAHI Mortality EAG presented in late August 2020. This report provides further details on important potential factors to consider when modelling EL in-hospitals deaths.

1.1.2 Project scope

As a collaborative project between CSIRO and VAHI, this work investigated existing work described in the two aforementioned reports and worked closely under clinical stewardship of Prof. David

Watters to develop and validate models for inpatient, 30-, 90- and 365-day post-operative mortality measures.

Specifically, the scope for this work carried out by CSIRO included the following steps:

1. Development of clinically appropriate grouping for laparotomy procedure codes, Elixhauser comorbidity measure and ICD10 family codes for diagnosis grouping in consultation with VAHI and Prof. David Watters.
2. Development and validation of risk adjusted mortality indicators for
    a. In-hospital deaths,
    b. 30-day post-operative deaths,
    c. 90-day post-operative deaths, and
    d. 365-day post-operative deaths

1.1.3 Project deliverables

The deliverables for this project include:

1. An interim report describing the risk adjusted models for in-patient EL mortality. This was delivered on 28/06/2021.
2. A final report on EL risk adjusted mortality models for all four outcomes described above, including details of covariate selection and model diagnostics.
3. R scripts employed for implementing models and validation for use by VAHI.

2 Methods

Details of the approach for addressing the project scope is presented in this section. This includes relevant approvals required, details of factors considered for EL risk adjusted modelling and derivation of clinically relevant factors, as well as statistical methodological considerations and framework to implement the EL risk adjusted modelling.

2.1 Project and regulatory approvals

This project is contracted under the State of Victoria through the Department of Health and CSIRO Advanced Statistics and Analytic Capability Uplift Partnership Agreement (C9467). Ethics approval as a low-risk project (application 2021_031_LR) was obtained from the CSIRO Health and Medical Human Research Ethics Committee.

2.2 Data extract

VAHI provided all data in a post-prepared state, whereby all outcomes and majority of variables were already processed in a ready-to-use format. The data included details of EL episodes across 64 surgical campuses of public and private Victorian hospitals between July 2016 and May 2020.

The initial dataset was received on 9th April 2021. Throughout the project timeframe, additional data and information was requested. This included:

- Data dictionary to better inform variable measure and definition (Received 23 April 2021)
- Date of hospital discharge, to determine their period of in-hospital care (Received 26 April 2021)
- Charlson raw score for each individual (Received 10 May 2021)
- ICD10 codes to explore the diagnosis grouping variable (Received 1 June 2021)

Moreover, with clinical expertise from Prof David Watters, laparotomy procedure codes were analysed to define a more clinically meaningful procedure grouping (6 May 2021) as well as ICD10 family codes for Diagnosis grouping (24 June 2021).

2.3 Covariates considered for risk adjusted EL mortality modelling

After the data preparation and finalising the groupings across covariates, Table 1 shows the final list of covariates across all outcomes for this project. Alternate representations were also explored for various covariates (e.g. raw Charlson scores, ICD10 Chapter grouping, etc) as described in the following sections.

Table 1 List of final covariates explored for EL risk adjusted modelling.

COVARIATE	DESCRIPTION
Age	18 – 102 years
Sex	Male/ Female
Laparotomy procedure	All other laparotomy, Colonic resection anastomosis, Colonic resection with stoma, Gastroduodenal emergencies, Peritonitis and inter-abdominal sepsis, Small bowel obstruction without resection, Small bowel resection
Transfer from another hospital	Yes/ No
Marital status	Partnered (married or de-facto), Previously partnered (divorced, separated, or widowed), Other (Never married or not stated)
Prefer to speak English at home	Yes/ No
Diagnosis	Small bowel obstruction and hernia, Large bowel emergencies, Upper GI emergencies, Peritonitis, Disorders of the female genital tract, Acute vascular disorder of the intestine, Metastatic disease, Other
Elixhauser comorbidities	31 comorbidity indicators, each Yes/ No
Charlson Comorbidity Index (grouped)	Group 1: Charlson raw value of 0 Group 2: Charlson raw values 1-2 inclusive Group 3: Charlson raw values 3-7 inclusive Group 4: Charlson raw values 8+ inclusive

2.3.1 Age

The age at which a patient underwent an EL procedure and can take discreet numerical values with a range from 18 to 102.

In this work, all outcomes are binary and had values of zero or one. The predictive probabilities from the logistic regression models also range between these values. As the raw age range is of a much larger scale, to avoid numerical warnings, maintain model stability age and preserve the relationship between age the outcome and covariates, age was standardised by subtracting the empirical mean from the raw age, and divided by the empirical standard error. Henceforth in this report Age denotes standardised age.

A squared version of age was also explored to account for non-linear effects.

2.3.2 Laparotomy Procedure

Following meeting with Prof Watters on Friday 7th May, levels for this variable represent selected laparotomy procedure codes as shown on Table 2.

Table 2 Emergency laparotomy procedure code and groupings

GROUPING	PROCEDURE CODES
All other laparotomy	3037300, 3037504, 3037517, 3037510, 3039200
Colonic resection anastomosis	3200301, 3037525, 3202400, 3200600, 3051503, 3200500, 3200501, 9220800, 3200300, 3051504, 3201201, 3200502 3200602, 3200503
Colonic resection with stoma	3200901, 3051505, 3203000, 3200601, 3200400, 3200000, 3200001, 3200002, 3200900, 3200402, 3051506, 3200003, 3200401, 3200403, 3200603
Gastroduodenal emergencies	3051800, 3051500, 3051801, 3050900 3050500, 3037515
Peritonitis and inter-abdominal sepsis	3039401, 3039400, 3039600, 3040200
Small bowel obstruction without resection	3037800, 3056302, 3037518, 3037508
Small bowel resection	3040505, 3056600, 3051502, 3037509, 3037519, 3056500, 3037501, 3037503, 3040502, 3037524, 3051501, 3056400

Refer to Table 15 for tabulated summaries of the incidence of death across each outcome for each of the laparotomy procedure groupings listed above.

2.3.3 Transfer from another hospital

As per Victorian Admitted Episodes (VAED) manual[3] this binary variable is denoted as yes/ no indicating that this episode included a hospital transfer before or after the procedure.

2.3.4 Marital status

The VAED manual reports nine levels for marital status. Due to the low counts for some levels and for brevity, in this work this variable was reduced from the nine levels to the three-level categorical variable.

Table 3: Marital status mapped from VAED to categorical variable for this work.

VAED MARITAL STATUS CODE	VAED MARITAL STATUS DESCRIPTOR	FINAL MARITAL GROUPING
1	Never married	Other
2	Widowed	Previously partnered
3	Divorced	
4	Separated	
5	Married	Partnered
6	De facto	
9	Not stated/ inadequately described	Other

2.3.5 Prefer to speak English at home

Binary variable Yes/ No denoting the language (including sign language) most preferred by the patient for communication.

2.3.6 Diagnosis

In the preliminary VAHI analysis, ICD-10 diagnosis codes were grouped into eight levels. This led to a large proportion of the data (63%) being classified under a single ('other digestive') grouping. Consultation with Prof. Watters determined the need for a new, a more clinically meaningful grouping.

Initial regrouping in consultation with Prof Watters and VAHI produced 19 and 16 level groupings which resulted in unstable and non-convergent models. Subsequent consultations produced a clinically and statistically appropriate 9 level grouping (see Table 4) that was employed for final model development and validation.

Table 4: Diagnosis levels and corresponding ICD10 family codes.

GROUPING	ICD10 FAMILY CODES
Small bowel obstruction and hernia	K43, K41, K56, K40, K45, Q43, C83, K4, K44, K92, K46, C17, C82
Large bowel emergencies	K51, K50, K57, C18, A09, C19, N82, D12, C20, K62, K38, K52
Upper GI emergencies	K25, K27, C16, K26, K22, K28, C25, K86, K85, K31, D73
Peritonitis	K66, K65, K63, A41, A40
Disorders of the female genital tract	O00, N70, N73, N83, N92, N74, N80, N94, O82, O99, D27
Post-op and inter-op complication	K91
Acute vascular disorder of the intestine	K55, I71, I48, I72
Metastatic disease	C79, C78
Other	All other ICD10 codes (N = 254)

Refer to Table 14 for tabulated summaries of the incidence of death across each outcome for each of the Diagnosis groupings listed above.

Grouping of diagnosis codes by ICD-10 chapters was also explored but offered poor predictive performance when compared to the grouping described in Table 4.

2.3.7 Elixhauser categories

In some studies, a direct comparison between Elixhauser and Charlson comorbidity measures have found the Elixhauser classification to be superior to the Charlson comorbidity measure at adjusting for comorbidity in predicting mortality.[4] For a robust analyses of each outcome, in this work both measures were explored independently for each outcome.

Elixhauser comorbidities comprises of 31 categories. Initially derived from the much older ICD-9-CM codes,[5] in this work, Elixhauser comorbidity categories were derived by VAHI from ICD-10 codes[6] and provided to CSIRO.

To avoid the inclusion of 30 binary Elixhauser variables in the models yet incorporate the information across the 31 categories, we explored the transformation of the Elixhauser data into a single measure as described by Walraven et. al. 2009,[4] and this was investigated as a covariate for the in-hospital outcome (results not included in report). Unfortunately, this transformation was found to perform poorly in terms of the models predictive capability when compared to similar models which quantified comorbidity by selected Elixhauser comorbidities (< 12 Chapters) or the Charlson index grouped into four categories or as a raw value.

For this reason in this work, the Elixhauser comorbidities were explored independently for each outcome using variable ranking by order of importance from a Random Forest algorithm[7] (which incorporated all covariates listed in Table 1), as well as the mean p-value from the Chi-squared test applied to bootstrapped two-way tables (Outcome vs specific Elixhauser comorbidity). Selected Elixhauser comorbidities for each outcome were chosen based on the concordance of these two approaches and generally reduced the 31 categories down to 11 or less.

We also investigated the inclusion of full 31 Elixhauser comorbidities as a covariate in the models across all outcomes. These models were compared with similar models which had the selected categories, and the latter were found to be equal to or superior in predictive performance.

2.3.8 Charlson Comorbidity Index

The initial data supplied for this project comprised of the Charlson Comorbidity Index values categorised into four groups (as listed in Table 1). This grouping was explored across all outcomes and compared for performance alongside Elixhauser comorbidities.

The use of raw Charlson scores, as a numeric predictor with values ranging from 0-15 inclusive, was also explored but offered poor predictive performance when compared to grouping employed.

2.4 Notes on implementation of EL risk adjusted mortality models

The sub-sections below pertain to specific details relevant to all EL risk adjusted models in this report which are generalised across specific cohort populations. Should the reader replicate this methodology to other similar independent data sets; care needs to be taken to consider implications of specific data related aspects, such as low or zero counts of mortality in levels within a categorical covariate as was the case in this work.

2.4.1 Statistical methodology employed

In line with the previous work described in Section 1.1.1 and following the recommendations described in Ben-Tomin et. al. 2009,[8] in this work, random intercept logistic regression models were used to model risk adjusted EL mortality. This type of model is derived from a broader class of statistical models referred to as generalised linear mixed models or generalised hierarchical models.[9] Specifically for this work, to take into account patient level differences between institutions, a random intercept logistic regression was fitted across all outcomes to factor in hospital clusters.

Goodness-of fit and predictive performance of each model was visually assessed via 10-quantile calibration plots, and binned Pearson residuals.[9] Calibration plots allow for the comparison of the predicted mean of each quantile versus the observed mean and corresponding 95% confidence intervals (CI). Calibration plots whereby each quantile and corresponding 95% CI approximately align with the diagonal $x = y$ line denote adequate prediction of the binary response with respect to the observed value. Binned residual plots which show an approximate random scatter above and below the horizontal $x = 0$ line denote that the model chosen was appropriate for the data.

To assess the capacity of each model explored to be generalised across the population of interest and to avoid the model overfitting the data, repeated random resample was used for validating each of the models explored. Validation consisted of randomly splitting the data 100 times into train/ test sets, whereby in each iteration the whole data was partitioned into a train/test set comprising of 65% and 35% of the data respectively. The mean test area under the curve (AUC) and 95% CI are reported for each model. Higher AUC values denote superior predictive performance compared to lower values.

For further explanation on the choice of model for this work, models assessment, and validation methodology, refer to Louise et. al. 2019.[10]

All analyses and models were implemented using R software[11] (version 4.0.2). Script files for the replication of the analyses presented in this report will be delivered to VAHI.

2.4.2 Baseline levels for each outcome

For consistency and clinical relevance, the baseline levels for Diagnosis and Laparotomy procedure was set to ‘Small bowel obstruction and hernia’ and ‘All other laparotomy’ respectively across all outcomes. Theoretically, the models predictive and goodness-of-fit performances are unaffected by the selection of baseline levels for each categorical variable, but for reasons mentioned in Section 2.4.3, due to the nature of the data, it was necessary to avoid the Diagnosis level ‘Disorders of the female genital tract’ as a baseline level.

The binary Elixhauser categorical variables had baseline set as the presence of said comorbidity, and the corresponding coefficient is for the absence of said Elixhauser comorbidity.

2.4.3 Convergence issues due to zero counts in specific Diagnosis category

The diagnosis category ‘Disorders of the female genital tract’ includes various disorders specific to females such as disorders of the ovary, fallopian tube and broad ligament, endometriosis, excessive, frequent and irregular menstruation, among others.

While the diagnosis grouping is clinically relevant, it proved to be problematic in fitting the models due to the low counts in deaths across most outcomes as shown in Table 5.

Table 5: Mortality summaries for Diagnosis level 'Disorder of the female genital tract' across all outcomes

OUTCOME	NO. DEATHS	NO. OBSERVATIONS	PERCENTAGE OF DEATHS (%)
In-hospital	0	651	0
30-day	0	651	0
90-day	0	651	0

365-day	2	651	0.31

For this reason, some of the model's coefficient estimates for this category show unusually large standard errors and some models had numerical warnings in terms of the model converging; due to the zero or low counts of deaths. Hence, this level does not meaningfully contribute to the risk adjusted mortality estimates and predicted probabilities.

It is important to note, that to estimate the model parameters for a simple logistic regression model, solutions generally have no closed form, and iterative numerical procedure need to be used.[12] In this case, for a more complex random intercept logistic regression model, numerical approaches are always used and coupled with covariates with zero or low counts, make model estimation and convergence sometimes difficult to achieve. Nonetheless, all models presented in this report were successfully implemented and validated for generalisability for each specific population investigated.

3 Results

This report delivers risk adjusted EL mortality indicators across four specific outcomes:

1. In-hospital death
2. 30-day post-operative death
3. 90-day post-operative death
4. 365-day post-operative death

Each outcome was analysed independently from each other, despite possible associations which may be related across each outcome. Refer to Section 5 for further discussion on this issue.

In-hospital EL mortality pertains to in-hospital factors and in-hospital level of care related deaths. Post-operative mortality (30/90/365 days) are in part associated with in-hospital level of care, however for many patients these outcomes relate to hospital discharge processes and at home or outside hospital care.

3.1 Risk adjusted EL in-hospital mortality

The approach described in Section 2.3.7 was used to derive the selected Elixhauser comorbidities for EL in-hospital outcome which are shown on Table 6. The final model for this outcome is summarised in Table 7, which was also presented in the interim report delivered on 28/6/2021.

Table 6: Selected 10 Elixhauser comorbidities used to model in-hospital EL mortality.

INDEX	ELIXHAUSER COMORBIDITY
E1	Congestive Heart Failure
E2	Cardiac arrhythmias
E5	Peripheral vascular disorders
E9	Other neurological disorders
E12	Diabetes complicated
E14	Renal failure
E15	Liver disease
E19	Metastatic cancer
E22	Coagulopathy
E24	Weight loss

A summary of all models explored for this outcome can be found in Appendix C (Table 16). Selection of this final model is a trade-off between choosing the most parsimonious model which is supported by the data, yet have superior predictive performance determined by the mean test set AUC value. The final model for this outcome suggests that the linear combination of age, diagnosis, laparotomy procedure, 10 Elixhauser comorbidities listed in Table 6 as well as the interaction between these Elixhauser comorbidities with age delivers the best overall performance.

Table 7: Logistic regression summaries for in-hospital EI risk adjusted mortality modelling. Variable level in blue, shows unusually large standard error for reasons described in Section 2.4.3.

VARIABLE	VARIABLE LEVEL	COEFFICIENT VALUE	STANDARD ERROR	ODDS RATIO	P-VALUE
Intercept		0.4409	0.3104	1.5541	0.1555
Age		-0.1855	0.308	0.8307	0.5469
Diagnosis	Small bowel obstruction and hernia (baseline)				
	Large bowel emergencies	-0.0615	0.1349	0.9404	0.6481
	Other	1.0191	0.1269	2.7707	< 0.0001
	Upper GI emergencies	0.5765	0.1494	1.7798	0.0001
	Peritonitis	1.2071	0.1369	3.3438	< 0.0001
	Disorders of the female genital tract	-12.9533	43.911	0	0.768
	Post-op and inter-op complication	-0.3978	0.26	0.6718	0.126
	Acute vascular disorder of the intestine	1.3353	0.1329	3.8011	< 0.0001
	Metastatic disease	1.6326	0.2252	5.1172	< 0.0001
Laparotomy procedure	All other laparotomy procedure (baseline)				
	Gastroduodenal emergencies	-0.2755	0.2198	0.7592	0.21
	Colonic resection with stoma	-0.4208	0.153	0.6565	0.0059
	Small bowel resection	-0.5895	0.1351	0.5546	< 0.0001
	Colonic resection anastomosis	-0.7765	0.1611	0.46	< 0.0001
	Small bowel obstruction without resection	-0.6462	0.1395	0.524	< 0.0001
	Peritonitis and inter-abdominal sepsis	-0.7517	0.1732	0.4716	< 0.0001
Congestive heart failure		-0.1888	0.147	0.828	0.1991
Cardiac arrhythmias		-0.2679	0.1038	0.765	0.0098
Peripheral vascular disorders		-0.9166	0.1244	0.3999	< 0.0001
Other neurological disorders		-0.0246	0.1699	0.9757	0.885
Diabetes complicated		-0.0495	0.1285	0.9517	0.7002
Renal failures		-0.038	0.1538	0.9627	0.8047
Liver disease		-0.8472	0.1225	0.4286	< 0.0001
Metastatic cancer		-0.7969	0.121	0.4507	< 0.0001
Coagulopathy		-0.9573	0.1139	0.3839	< 0.0001
Weight loss		0.1729	0.1031	1.1887	0.0934
Age * Congestive heart failure		0.3515	0.1513	1.4212	0.0201
Age * Cardiac arrhythmias		-0.1851	0.1125	0.831	0.0998
Age * Peripheral vascular disorders		0.4584	0.1292	1.5815	0.0004
Age * Other neurological disorders		-0.0857	0.1912	0.9179	0.6541
Age * Diabetes complicated		0.1833	0.1492	1.2012	0.2193
Age * Renal failures		-0.3947	0.1587	0.6739	0.0129
Age * Liver disease		0.1239	0.1565	1.1319	0.4284
Age * Metastatic cancer		0.2798	0.1335	1.3229	0.036
Age * Coagulopathy		0.471	0.1329	1.6016	0.0004
Age * Weight loss		0.1592	0.1119	1.1726	0.1548

Despite the large standard error for the Diagnosis level 'Disorders of the female genital tract' and convergence warning when implementing this model, the result was successfully computed.

The plots in Figure 1 correspond to the final model applied to the whole data set and demonstrate good performance under the receiver operating curve (ROC), good calibration performance and a general random scatter of the residuals above and below the horizontal line which indicate goodness of fit.

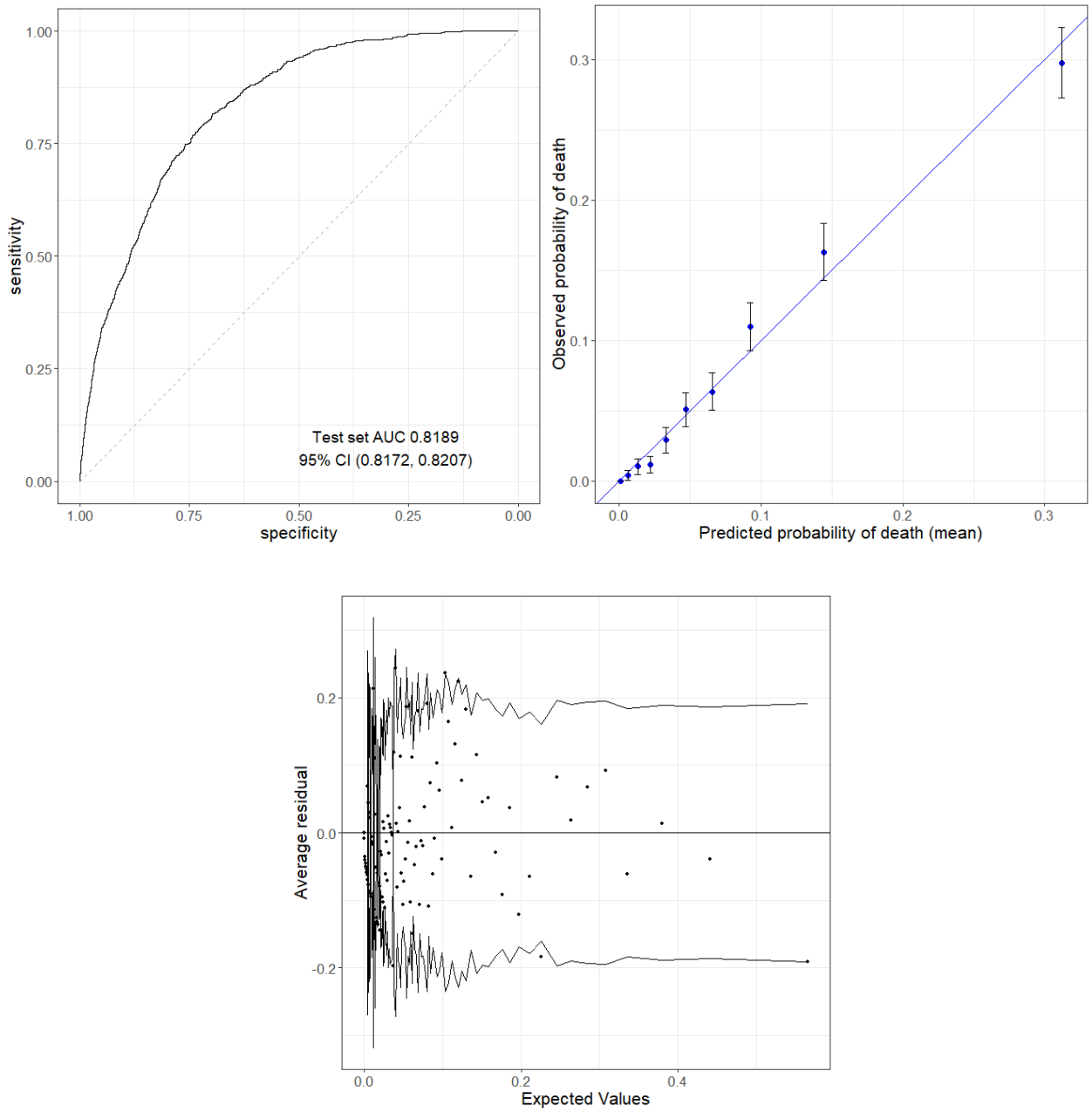


Figure 1: Predictive performance and goodness-of-fit plots. Top left: Receiver operating (ROC) plot with mean area under the curve (AUC) value of 0.8189 on the test set and 95% confidence interval (CI) in parenthesis. Top right: 10-quantile calibration plot with 95% confidence interval for the observed mortality ratios. Bottom left: Binned Pearson residual plot with 95% CI bands.

3.2 Risk adjusted EL 30-day post-operation mortality

Selected Elixhauser comorbidities for EL 30-day post-operation mortality outcome are shown on Table 8. For this outcome, models which included selected Elixhauser comorbidities were shown to have superior predictive performance in terms of AUC values, compared to Charlson variables.

The final model for this outcome (see Table 9) suggest that the linear combination of age, Diagnosis, laparotomy procedure and the 11 Elixhauser comorbidities listed in Table 8 delivers the best overall performance.

Table 8: Selected 11 Elixhauser comorbidities used to model for 30-day post-operative EL mortality.

INDEX	ELIXHAUSER COMORBIDITY
E1	Congestive Heart Failure
E2	Cardiac arrhythmias
E5	Peripheral vascular disorders
E9	Other neurological disorders
E12	Diabetes complicated
E14	Renal failure
E15	Liver disease
E19	Metastatic cancer
E22	Coagulopathy
E24	Weight loss
E25	Fluid and electrolyte disorders

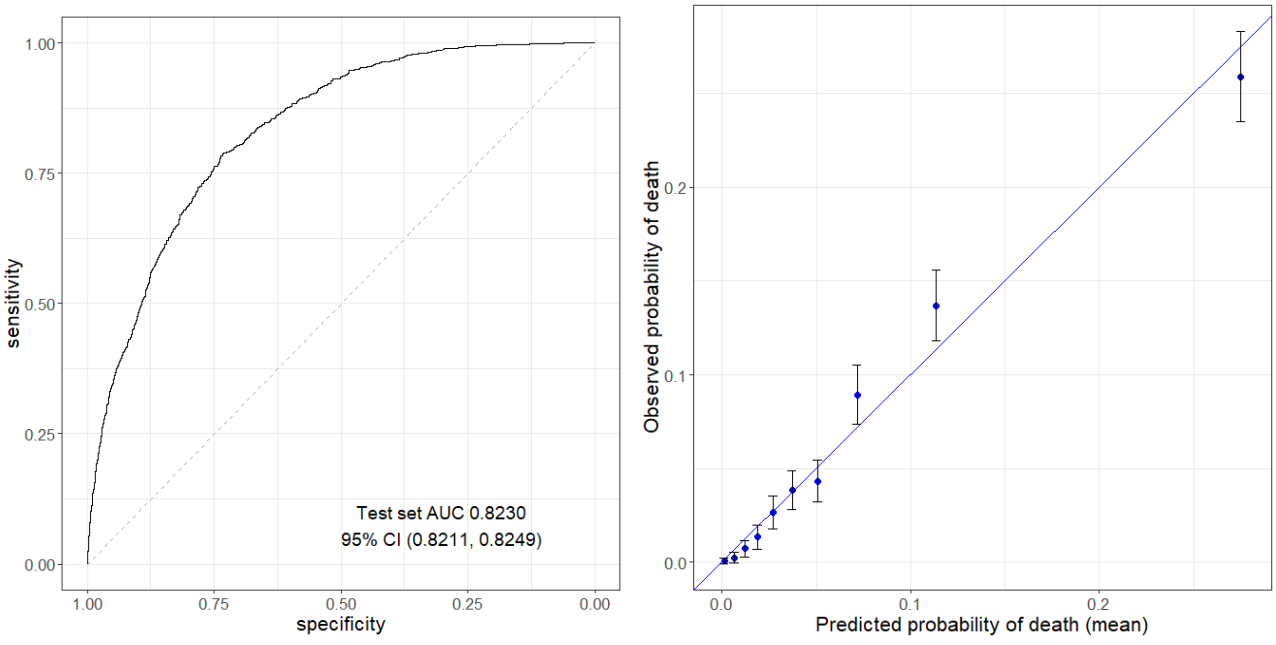
Various interaction terms were explored (see Table 17 for a full list of models considered for this outcome). Despite the additional model complexity any interaction term adds to the model, they did not significantly improve the predictive capability of the final model, and thus the simpler linear model was selected as the final model.

Table 9: Logistic regression summaries for 30-day post-operative EL risk adjusted mortality modelling. Variable level in blue, shows unusually large standard error for reasons described in Section 2.4.3.

VARIABLE	VARIABLE LEVEL	COEFFICIENT VALUE	STANDARD ERROR	ODDS RATIO	P-VALUE
(Intercept)		-0.2604	0.2903	0.7707	0.3698
Age		0.9606	0.0633	2.6133	< 0.0001
Laparotomy procedure	All other laparotomy (baseline)				
	Colonic resection anastomosis	-1.0354	0.1688	0.3551	< 0.0001
	Colonic resection with stoma	-0.7349	0.161	0.4796	< 0.0001
	Gastroduodenal emergencies	-0.4811	0.2438	0.6181	0.0485
	Peritonitis and inter-abdominal sepsis	-1.0116	0.1843	0.3636	< 0.0001
	Small bowel obstruction without resection	-0.9319	0.1448	0.3938	< 0.0001
	Small bowel resection	-0.902	0.1404	0.4058	< 0.0001
Diagnosis	Small bowel obstruction and hernia (baseline)				

	Large bowel emergencies	-0.2509	0.1505	0.7781	0.0954
	Upper GI emergencies	0.2029	0.1673	1.2249	0.2252
	Peritonitis	1.2282	0.1443	3.4151	< 0.0001
	Disorders of the female genital tract	-13.2146	64.0063	0	0.8364
	post-op and inter-op complication	-0.2467	0.2604	0.7814	0.3435
	Acute vascular disorder of the intestine	1.3133	0.1389	3.7184	< 0.0001
	Metastatic disease	1.5391	0.2468	4.6604	< 0.0001
	Other	0.8267	0.1393	2.2858	< 0.0001
Congestive heart failure		0.2209	0.1115	1.2472	0.0476
Cardiac arrhythmias		-0.3067	0.085	0.7359	0.0003
Peripheral vascular disorders		-0.7354	0.1065	0.4793	< 0.0001
Other neurological disorders		0.0358	0.1553	1.0364	0.8175
Diabetes complicated		0.1436	0.1037	1.1544	0.1661
Renal failure		-0.3208	0.1051	0.7256	0.0023
Liver disease		-1.0444	0.1219	0.3519	< 0.0001
Metastatic cancer		-0.5817	0.1056	0.5589	< 0.0001
Coagulopathy		-0.6359	0.1074	0.5295	< 0.0001
Weight loss		0.5285	0.0876	1.6964	< 0.0001
Fluid and electrolyte disorders		-0.2502	0.0954	0.7786	0.0088

Despite the large standard error for the Diagnosis level ‘Disorders of the female genital tract’ and convergence warning when implementing this model, the result was successfully computed. The final model presented in Table 9 was applied to the whole data set to assess the goodness-of-fit, predictive performance and calibration performance. Figure 2 shows this final model to have a test set AUC value of 0.8230, and acceptable calibration and residual plots.



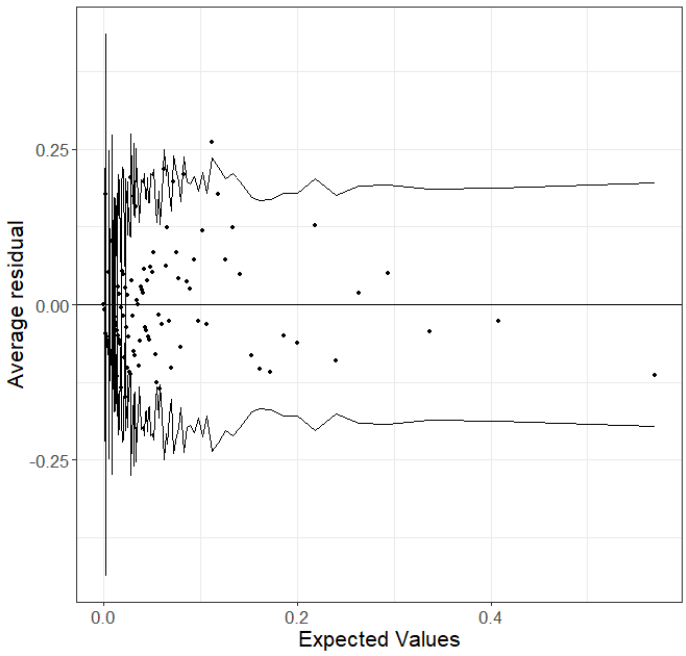


Figure 2: Predictive performance and goodness-of-fit plots. Top left: Receiver operating (ROC) plot with mean area under the curve (AUC) value of 0.8230 on the test set and 95% confidence interval (CI) in parenthesis. Top right: 10-quantile calibration plot with 95% confidence interval for the observed mortality ratios. Bottom left: Binned Pearson residual plot with 95% CI bands.

3.3 Risk adjusted EL 90-day post-operation mortality

Despite the careful selection of selected Elixhauser comorbidity measures for this outcome, the model which included the Charlson 4-level group was found to have superior predictive performance and was hence selected as the final model. Nonetheless, for consistency selected Elixhauser comorbidities for EL 90-day post-operation mortality outcome are shown on Table 10.

Table 10: Selected 11 Elixhauser comorbidities used to model for 90-day post-operative EL mortality.

INDEX	ELIXHAUSER COMORBIDITY
E2	Cardiac arrhythmias
E5	Peripheral vascular disorders
E6	Hypertension uncomplicated
E9	Other neurological disorders
E12	Diabetes complicated
E14	Renal failure
E20	Solid tumor without metastatis
E22	Coagulopathy
E24	Weight loss
E25	Fluid and electrolyte disorders
E27	Deficiency anemia

As in all outcomes, 40 models were explored for the EL 90-day post-operation outcome; see Table 18 for AUC values and summaries for all models explored. Summaries of the final model are presented in Table 11. This model includes age, laparotomy procedure, Diagnosis, Charlson index grouped into the four levels, as well as the interaction between Charlson groups with age.

Table 11: Logistic regression summaries for 90-day post-operative EL risk adjusted mortality modelling. Variable level in blue, shows unusually large standard error for reasons described in Section 2.4.3.

VARIABLE	VARIABLE LEVEL	COEFFICIENT VALUE	STANDARD ERROR	ODDS RATIO	P-VALUE
Intercept		-0.6069	0.2096	0.545	0.0038
Age		0.3498	0.2098	1.4188	0.0955
Laparotomy procedure	All other laparotomy procedure (baseline)				
	Colonic resection anastomosis	-0.8502	0.144	0.4273	< 0.0001
	Colonic resection with stoma	-0.5727	0.139	0.564	< 0.0001
	Gastroduodenal emergencies	-0.2098	0.1918	0.8107	0.2741
	Peritonitis and inter-abdominal sepsis	-0.7526	0.1588	0.4711	< 0.0001
	Small bowel obstruction without resection	-0.7494	0.1262	0.4727	< 0.0001
	Small bowel resection	-0.6263	0.1232	0.5346	< 0.0001
Diagnosis	Small bowel obstruction and hernia (baseline)				
	Large bowel emergencies	-0.2968	0.115	0.7432	0.0099
	Upper GI emergencies	0.0718	0.137	1.0744	0.6005
	Peritonitis	0.9383	0.1252	2.5556	< 0.0001
	Disorders of the female genital tract	-13.3835	52.2573	0	0.7979
	post-op and inter-op complication	-0.5549	0.2263	0.5741	0.0142
	Acute vascular disorder of the intestine	1.4434	0.1167	4.2351	< 0.0001
	Metastatic disease	1.1082	0.1914	3.0289	< 0.0001
	Other	0.7264	0.1139	2.0676	< 0.0001
Charlson group 1		-2.5707	0.1956	0.0765	< 0.0001
Charlson group 2		-1.8455	0.189	0.1579	< 0.0001
Charlson group 3		-0.6885	0.1753	0.5023	0.0004
Age * Charlson group 1		0.7619	0.2337	2.1423	0.0011
Age * Charlson group 2		0.4914	0.2296	1.6346	0.0324
Age * Charlson group 3		0.1181	0.22	1.1254	0.5914

In a similar manner as the in-hospital and 30-day post-operative outcomes, the model results for 90-day post-operation outcome also had a large standard error for the Diagnosis level 'Disorders of the female genital tract' and convergence warning when the model was implemented. Despite these numerical issues, the model results were successfully computed.

Figure 3 shows the final model for EL 90-day post-operation mortality had a test AUC of 0.8101, acceptable calibration and residual plots when applied to the whole data set.

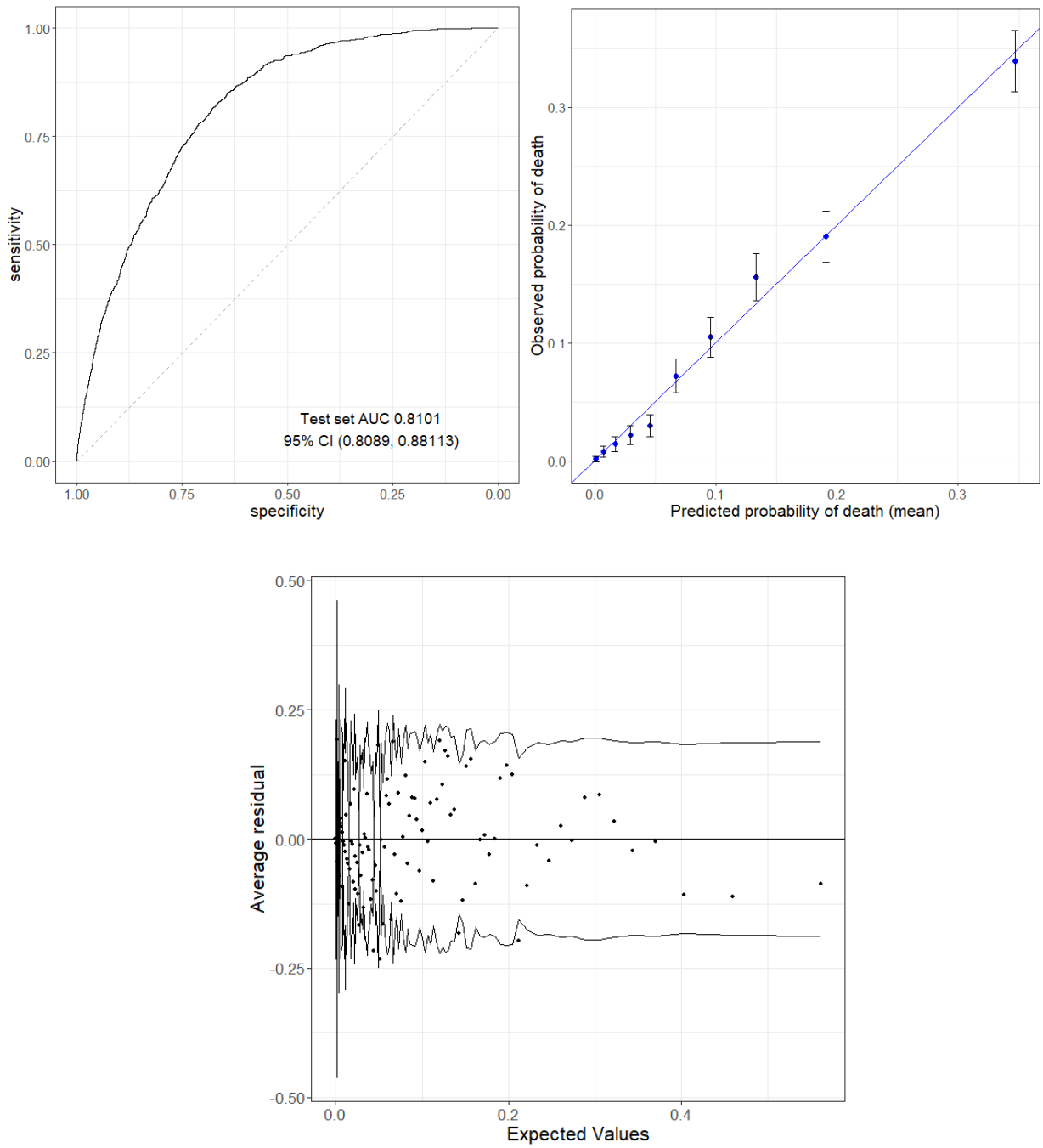


Figure 3: Predictive performance and goodness-of-fit plots. Top left: Receiver operating (ROC) plot with mean area under the curve (AUC) value of 0.8101 on the test set and 95% confidence interval (CI) in parenthesis. Top right: 10-quantile calibration plot with 95% confidence interval for the observed mortality ratios. Bottom left: Binned Pearson residual plot with 95% CI bands.

3.4 Risk adjusted EL 365-day post-operation mortality

Similar to in-hospital and 30-day post-operation outcomes, the model for the 365-day post-operation outcome supported selected Elixhauser comorbidities as the model with superior predictive performance when compared with Charlson variables. Selected Elixhauser comorbidities for EL 365-day post-operation mortality outcome are shown in Table 12.

Table 12: Selected 11 Elixhauser comorbidities used to model for 365-day post-operative EL mortality.

INDEX	ELIXHAUSER COMORBIDITY
E1	Congestive heart failure
E2	Cardiac arrhythmias
E5	Peripheral vascular disorders
E9	Other neurological disorders
E12	Diabetes complicated
E15	Liver disease
E19	Metastatic cancer
E20	Solid tumor without metastatis
E22	Coagulopathy
E25	Fluid and electrolyte disorders
E27	Deficiency anemia

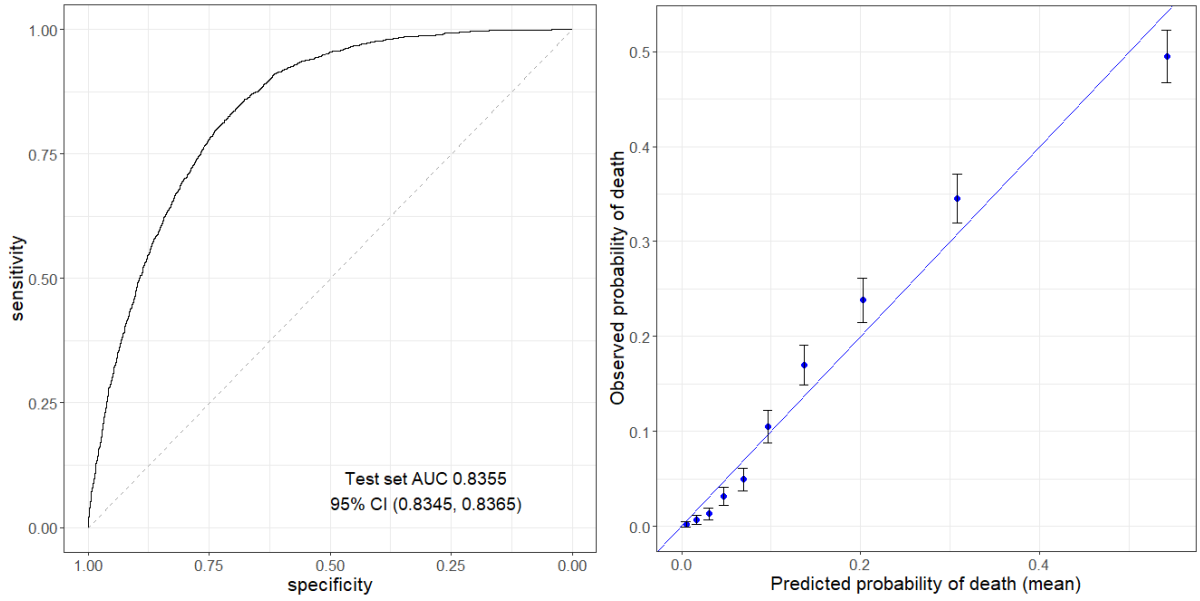
This final model comprises of age, laparotomy procedure, Diagnosis and the 11 selected Elixhauser comorbidities as shown in Table 13. While interaction terms were also considered for this outcome, the added complexity did not significantly improve the predictive performance of the model, and hence the simpler parsimonious model was selected.

Table 13: Logistic regression summaries for 365-day post-operative EL risk adjusted mortality modelling.

VARIABLE	VARIABLE LEVEL	COEFFICIENT VALUE	STANDARD ERROR	ODDS RATIO	P-VALUE
Intercept		2.0696	0.2244	7.9217	< 0.0001
Age		0.7784	0.0428	2.178	< 0.0001
Laparotomy procedure	All other laparotomy procedure (baseline)				
	Colonic resection anastomosis	-0.7654	0.1274	0.4651	< 0.0001
	Colonic resection without stoma	-0.5955	0.1258	0.5513	< 0.0001
	Gastroduodenal emergencies	0.1561	0.1745	1.1689	0.3708
	Peritonitis and inter-abdominal sepsis	-0.7065	0.1415	0.4934	< 0.0001
	Small bowel obstruction wo resection	-0.7689	0.1143	0.4635	< 0.0001
	Small bowel resection	-0.6712	0.1128	0.5111	< 0.0001
Diagnosis	Small bowel obstruction and hernia (baseline)				
	Large bowel emergencies	-0.1339	0.0954	0.8747	0.1608
	Upper GI emergencies	0.2558	0.1183	1.2915	0.0305
	Peritonitis	0.7261	0.1144	2.067	< 0.0001
	Disorders of the female genital tract	-1.5656	0.7226	0.209	0.0302
	post-op and inter-op complication	-0.5786	0.187	0.5607	0.002
	Acute vascular disorder of the intestine	1.0203	0.118	2.774	< 0.0001
	Metastatic disease	1.3968	0.1947	4.0422	< 0.0001

Other	0.7084	0.1023	2.0307	< 0.0001
Congestive heart failure	-0.2034	0.0797	0.816	0.0107
Cardiac arrhythmias	-0.2483	0.0612	0.7801	< 0.0001
Peripheral vascular disorders	-0.5024	0.0866	0.6051	< 0.0001
Other neurological disorders	-0.4181	0.1079	0.6583	0.0004
Diabetes complicated	-0.1394	0.0726	0.8699	0.0549
Liver disease	-0.6456	0.097	0.5243	< 0.0001
Metastatic cancer	-1.7425	0.0708	0.1751	< 0.0001
Solid tumor without metastatis	-0.0617	0.072	0.9402	0.392
Coagulopathy	-0.6871	0.0821	0.503	< 0.0001
Fluid and electrolyte disorders	-0.5313	0.0682	0.5878	< 0.0001
Deficiency anemia	0.3222	0.081	1.3802	0.0001

The data for this outcome included two deaths for Diagnosis level 'Disorders of the female genital tract', and for this reason, the model was able to successfully compute the appropriate standard error, and hence there were no numerical warnings when implementing this final model. Figure 4 shows this final model had the highest test set AUC value of 0.8355, compared to all the outcomes. Goodness-of-fit and calibration plots show acceptable model performance in terms of random scatter of residuals and prediction of binary response with respect to the observed value.



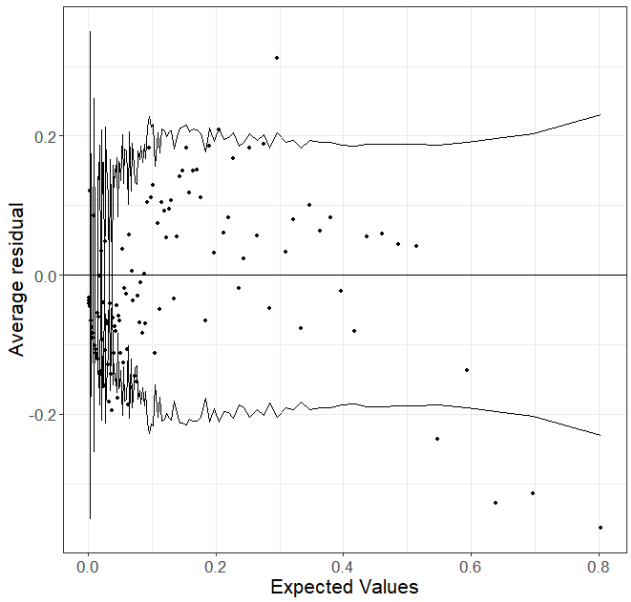


Figure 4: Predictive performance and goodness-of-fit plots. Top left: Receiver operating (ROC) plot with mean area under the curve (AUC) value of 0.8355 on the test set and 95% confidence interval (CI) in parenthesis. Top right: 10-quantile calibration plot with 95% confidence interval for the observed mortality ratios. Bottom left: Binned Pearson residual plot with 95% CI bands.

3.5 Summary of EL risk adjusted mortality across all outcomes

While risk adjusted mortality is typically reported up to 30-day post procedure,[13] literature suggests there is utility in reporting longer term mortality for EL.[14] Longer term post-operative EL mortality studies such as 90- and 365-day provide further insight and potential factors regarding the level of care within and out of hospital post EL operation.

Across all outcomes, age, diagnosis, laparotomy procedure and a comorbidity measure were found to significantly contribute to overall fit and improve predictive performance for EL risk adjusted mortality estimates.

Except for 90-day EL post-operative mortality outcome, all other outcomes showed that a selection of Elixhauser comorbidities provided superior predictive performance in terms of higher AUC value. There was some slight variation across outcomes in the selection of the Elixhauser comorbidities, however, across all outcomes the following Elixhauser comorbidities were found to strongly contribute to EL risk adjusted mortality estimates:

- Cardiac arrhythmias,
- Peripheral vascular disorder,
- Other neurological disorders,
- Diabetes complicated, and
- Coagulopathy.

In addition to selected Elixhauser comorbidities, Charlson Comorbidity Index (4-level grouping and raw values) was investigated as an alternative measure of comorbidity. This variable was investigated in conjunction with other covariates as a suitable comorbidity measure across each outcome.

While the Charlson 4-level group variable was the preferred comorbidity measure for the 90-day postoperative final model with a Test mean AUC of 0.8101, Model 24 in Supplementary Table 18 shows comparable predictive performance with a mean test AUC of 0.7907 and 95% CI of (0.7893, 0.7922). Model 24 comprises of the linear combination of age, diagnosis, laparotomy procedure and 11 Elixhauser comorbidities.

Important factors for risk adjusted EL mortality models

- For in-hospital up to and including 365-day post-operative outcomes, all models include age, laparotomy procedure and diagnosis groupings, as well as a measure of comorbidity for optimal performance.
- EL risk adjusted models over various post-operation periods are unique across each outcome, with differences primarily being in the selection of comorbidity measures.
- Several Elixhauser comorbidities were significant across all outcomes modelled. Further investigation is recommended to better understand the clinical significance of their impact on post-EL survival.
- All final models presented in this report have predictive performance test set AUC values greater than 0.8.

4 Model caveats

The following caveats pertain to the analyses presented in this report:

- Models are intended for patients aged 18 years or older. These models have not been validated for younger patients.
- The models are intended for in and out of hospital deaths following a Victorian public or private hospital EL episode. Models have not been validated following episodes in non-Victorian hospitals.
- Current modelling employs Random Forest and bootstrapped Chi-squared tables to identify Elixhauser comorbidities for each outcome. Given differences in the selected comorbidities across various outcomes, particularly for the 90-day post-operative outcome, further investigation of Elixhauser comorbidities is recommended. As the focus of this work was to validate and deliver EL risk adjusted models which incorporate a range of clinical factors, including comorbidity measures; investigating the intricate effects of Elixhauser comorbidities across each outcome, as well as their effect with the addition of other clinical factors falls outside the scope of work and further investigation is warranted due to the final results.
- Model results depend on the coding of covariates in the models. A change to coding practise may affect performance of models.
- Death out of hospital relies on the date of death as reported and linked from the Victorian Death Index. Deaths occurring outside Victoria within 30-, 90 or 365-days of a Victorian hospital admission may not be included.

5 Future work suggestions

Motivated by the analyses presented in this report, and the insights gained into the complexities of modelling EL in Victorian hospitals, CSIRO recommends several areas for potential future work.

5.1 Joint modelling of 30-, 90- and 365-day post operation EL mortalities

Joint modelling of 30, 90 and 365-day post-operative mortality as a single outcome. Based on this work, we could expand the analyses presented in this report from separate and independent univariate analyses of each outcome to a joint ordinal category outcome, as there is inter-dependence across these outcomes. The dependence is clear, because if an instance of death following an EL procedure did occur for a patient, then they must be in one of the three categories, and no patient can be in more than one category. That is no patient can be in a 30-day *and* 90-day post-operative death. Such a modelling approach will capture time-dependent factors in relation to an incidence of death, enabling a broader and more complete understanding of EL mortality over time. Such a model and may provide further insights in relation to the level of care prior to and post hospital discharge, as well as estimate the effects of age, laparotomy procedure undertaken, diagnosis and comorbidity measures and how they affect how a patient transitions in survival post 30-, 90- or 365-day EL post-operation. Such insights would benefit clinicians and decision makers in terms of identifying which factors or patient profiles lead to a higher rate of survival over time.

5.2 Spatial EL mortality modelling

To better understand factors related to out of hospital care that may be contributing to longer term (30/90 and 365-day post-operation) mortality following procedures such as EL, we recommend analysis that captures the spatial aspect of mortality estimates and includes additional region-specific information (attained from publicly available sources such as the ABS) such as socio-economic aspects and household income for specific geographical regions. Such an analyses will have the capability to capture geographical and socioeconomic spatial features[15] and help identify previously unaccounted factors that influence patient outcomes outside the hospital setting. For example, patients from a lower socio-economic regions (generally at a higher risk of poor health) may have a higher incidence of post-EL deaths compared to those from higher groups.

Similar analyses have already been carried out by the Cancer Council and information on cancer related deaths is publicly accessible via the Australian Cancer Atlas. Figure 5 shows the snapshot of this dashboard for the state of Victoria, as well as general summary statistics (panel on the right) pertaining to all cancers.

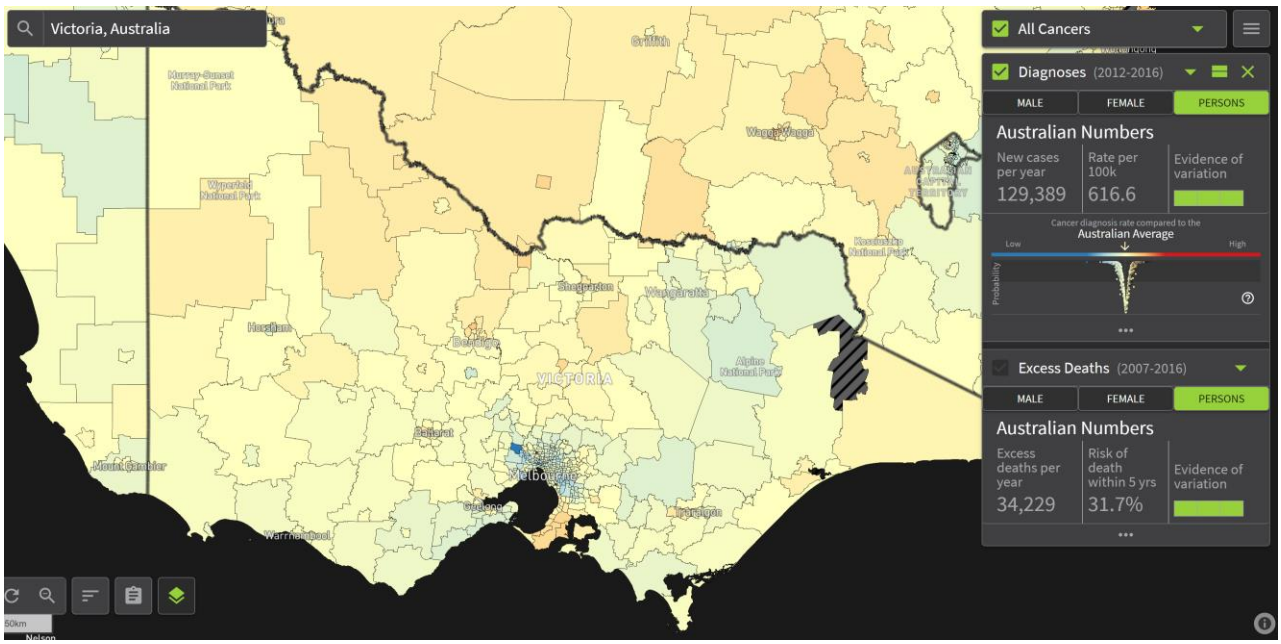


Figure 5: Snapshot of the Australian Cancer Atlas dashboard for Victoria.

Appendix A Summaries for EL mortality across diagnosis and laparotomy procedure levels on all outcomes

Table 14: Summary of deaths and observations across diagnosis levels for each outcome.

DIAGNOSIS		IN-HOSPITAL		30-DAY		90-DAY		365-DAY	
	NO.	DEATHS	%	DEATHS	%	DEATHS	%	DEATHS	%
Small bowel obstruction and hernia	5136	262	5.1	234	4.56	368	7.17	588	11.45
Large bowel emergencies	2556	120	4.69	87	3.4	170	6.65	339	13.26
Upper GI emergencies	1039	97	9.34	69	6.64	120	11.55	196	18.86
Peritonitis	856	113	13.2	100	11.68	134	15.65	176	20.56
Disorders of the female genital tract	651	0	0	0	0	0	0	2	0.31
Post-op and inter-op complication	645	17	2.64	17	2.64	23	3.57	37	5.74
Acute vascular disorder of the intestine	585	155	26.5	144	24.62	163	27.86	191	32.65
Metastatic disease	148	38	25.68	30	20.27	53	35.81	92	62.16
Other	1151	142	12.34	107	9.3	166	14.42	239	20.76

Table 15: Summary of deaths and observations across laparotomy levels for each outcome.

LAPAROTOMY PROCEDURE		IN-HOSPITAL		30-DAY		90-DAY		365-DAY	
	NO.	DEATHS	%	DEATHS	%	DEATHS	%	DEATHS	%
All other laparotomy	930	127	13.66	125	13.44	157	16.88	208	22.37
Colonic resection anastomosis	1885	113	5.99	93	4.93	153	8.12	288	15.28
Colonic resection with stoma	1836	161	8.77	128	6.97	195	10.62	312	16.99
Gastroduodenal emergencies	283	38	13.43	28	9.89	55	19.43	104	36.75
Peritonitis and inter-abdominal sepsis	1691	76	4.49	61	3.61	94	5.56	145	8.57
Small bowel obstruction wo resection	3294	195	5.92	161	4.89	256	7.77	385	11.69
Small bowel resection	2848	234	8.22	192	6.74	287	10.08	418	14.68

Appendix B Models explored for in-hospital mortality

Summaries for additional models investigated for in-hospital mortality are included in the table below. For completeness this table includes the model results presented in the interim report titled 'Emergency laparotomy in-hospital mortality', delivered to VAHI on 28/06/2021.

Table 16: List of 40 models explored for in-hospital EL risk adjusted mortality. Final model shown highlighted.

NO.	COVARIATES IN MODEL	FULL DATA AUC	MEAN TEST AUC	TEST AUC 95% CI
31	lap_type2, diagnosis, transfer, marital, prefEng, Age, Elix (10), Age*ELix(10)	0.8335	0.8214	(0.8195, 0.8232)
25	Age, Elix (10), diagnosis, lap_type2, marita2, Age*Elix(10)	0.8335	0.8203	(0.8189, 0.8218)
27	Age, lap_type2, diagnosis, marital2, Elix (7), Elix (7) * Age		0.8196	(0.8178, 0.8214)
24	**Age*Elix (10), diagnosis, lap_type2**	**0.8322**	**0.8189**	**(0.8172, 0.8207)**
40	Age, Age^2, lap_type2, diagnosis, Elix (10), Elix (10) * Age		0.8187	(0.8169, 0.8205)
26	Age, lap_type2, diagnosis, Transfer, Elix (10), Elix(10) * Age		0.8177	(0.8162, 0.8193)
38	Charlson, Age, charlson * Age, diagnosis		0.8175	(0.8158, 0.8193)
23	Age, lap_type2, diagnosis, Elix (10)		0.8161	(0.7080, 0.7120)
13	Age, diagnosis, Elix (10)		0.8152	(0.8134, 0.8170)
30	Age, lap_type2, diagnosis, Age * charlson_grp		0.8142	(0.8127, 0.8158)
39	charlson_grp, Age, charlson_grp * Age, diagnosis, lap_type2		0.8132	(0.8119, 0.8144)
9	Age, lap_type2, Elix (10)	0.8041	0.8051	(0.8042, 0.8061)
20	Age, lap_type2, marital2, Transfer, prefEng, Elix (10)		0.7948	(0.7569, 0.7616)
10	Age, lap_type2, marital2, Elix (10)		0.7945	(0.7928, 0.7962)
19	Age, lap_type2, Elix (10), Elix(10) * Age		0.7932	(0.7929, 0.7967)
11	Age, lap_type2, Transfer, Elix (10)		0.7925	(0.7906, 0.7944)
12	Age, lap_type2, prefEng, Elix (10)		0.7918	(0.7902, 0.7935)
14	Age, Elix (10), Elix (10) * Age		0.7892	(0.7874, 0.7909)
8	Age, Elix(10)		0.7869	(0.7850, 0.7888)
29	Age, lap_type2, diagnosis, Age*lap_type2	0.7958	0.7850	(0.7805, 0.7845)
22	Age, lap_type2, diagnosis		0.7826	(0.8143, 0.8179)
28	Age, lap_type2, diagnosis * Age		0.7813	(0.7793, 0.7834)
18	Age, diagnosis, Age*diagnosis		0.7804	(0.7782, 0.7826)
33	charlson_grp, Age		0.7665	(0.7646, 0.7684)
34	charlson_grp, Age, charlson_grp * Age		0.7653	(0.7635, 0.7672)
36	Charlson, Age		0.7634	(0.7616, 0.7653)
21	Elix (31)		0.7592	(0.7809, 0.7843)
7	Elix (10)		0.7496	(0.7474, 0.7518)
16	Age, lap_type2, Age*lap_type2	0.7387	0.7221	(0.7914, 0.7950)
32	charlson_grp		0.7184	(0.7162, 0.7207)
35	Charlson		0.7148	(0.7125, 0.7172)
15	Age, Transfer, Age*Transfer		0.7143	(0.7123, 0.7164)
17	Age, marital2, Age*marital2		0.7100	(0.7080, 0.7120)
1	Age		0.7078	(0.7057, 0.7100)
37	Age, Age^2		0.7077	(0.7058, 0.7097)
5	diagnosis		0.6971	(0.6945, 0.6997)
2	lap_type2		0.6050	(0.6025, 0.6074)
3	marital2		0.5968	(0.5947, 0.5989)
4	Transfer		0.5718	(0.5693, 0.5742)
6	prefEng		0.5653	(0.5629, 0.5677)

Appendix C Models explored for 30-day post-operative mortality

Summaries for additional models investigated for EL 30-day post-operative mortality are included in the table below.

Table 17: List of 40 models explored for 30-day EL post-operation risk adjusted mortality. Final model shown highlighted.

NO.	COVARIATES IN MODEL	FULL DATA AUC	MEAN TEST AUC	TEST AUC 95% CI
31	Age, lap_type2, diagnosis, marital2, Transfer, prefEng, Elix (11), Elix (11) * Age		0.8273	(0.8255, 0.8292)
26	Age, lap_type2, diagnosis, Transfer, Elix (11), Elix (11) * Age		0.8272	(0.8254, 0.8291)
24	Age, lap_type2, diagnosis, Elix (11), Elix (11) * Age		0.8241	(0.8224, 0.8258)
23	**Age, lap_type2, diagnosis, Elix (11)**	**0.8340**	**0.8230**	**(0.8211, 0.8249)**
27	Age, lap_type2, diagnosis, marital2, Elix (11), Elix (11) * Age		0.8223	(0.8205, 0.8241)
25	Age, lap_type2, marital2, diagnosis, Elix (11), Elix (11) * Age		0.8212	(0.8195, 0.8230)
13	Age, diagnosis, Elix (11)		0.8182	(0.8163, 0.8201)
39	charlson_grp, Age, charlson_grp*Age, diagnosis, lap_type2		0.8095	(0.8076, 0.8115)
38	charlson, Age, charlson*Age, diagnosis		0.8092	(0.8074, 0.8111)
30	Age, lap_type2, diagnosis, Age*charlson_grp		0.8084	(0.8064, 0.8103)
11	Age, lap_type2, Transfer, Elix (11), Elix (11) * Age		0.8048	(0.8028, 0.8068)
20	Age, lap_type2, marital2, Transfer, prefEng, Elix (11)		0.8020	(0.7999, 0.8040)
19	Age, lap_type2, Elix (11), Elix (11) * Age		0.8000	(0.7982, 0.8019)
10	Age, lap_type2, marital2, Elix (11)		0.7998	(0.7980, 0.8015)
12	Age, lap_type2, prefEng, Elix (11)		0.7984	(0.7964, 0.8004)
9	Age, lap_type2, Elix (11)		0.7983	(0.7966, 0.8001)
40	Age, Age^2, lap_type2, Elix (11), Elix (11) * Age		0.7974	(0.7955, 0.7993)
8	Age, Elix (11)		0.7907	(0.7886, 0.7929)
14	Age, Elix (11), Elix (11) * Age		0.7895	(0.7875, 0.7914)
28	Age, lap_type2, diagnosis*Age		0.7861	(0.7840, 0.7882)
22	Age, lap_type2, diagnosis		0.7855	(0.7837, 0.7874)
29	Age, lap_type2*Age, diagnosis		0.7826	(0.7805, 0.7847)
18	Age, diagnosis, Age*diagnosis		0.7799	(0.7779, 0.7819)
34	charlson_grp, Age, charlson_grp*Age		0.7526	(0.7506, 0.7547)
33	charlson_grp, Age		0.7517	(0.7498, 0.7536)
21	Elix (31)		0.7515	(0.7489, 0.7542)
36	charlson, Age		0.7509	(0.7485, 0.7532)
7	Elix (11)		0.7394	(0.7371, 0.7417)
16	Age, lap_type2, Age*lap_type2		0.7263	(0.7243, 0.7283)
15	Age, Transfer, Age*Transfer		0.7185	(0.7163, 0.7207)
17	Age, marital2, Age*marital2		0.7122	(0.7100, 0.7143)
1	Age		0.7090	(0.7069, 0.7112)
37	Age, Age^2		0.7061	(0.7040, 0.7081)
5	diagnosis		0.6968	(0.6942, 0.6994)
32	charlson_grp		0.6928	(0.6901, 0.6954)
35	charlson		0.6885	(0.6858, 0.6912)
2	lap_type2		0.6016	(0.5988, 0.6044)
3	marital2		0.5907	(0.5874, 0.5940)
4	Transfer		0.5534	(0.5511, 0.5558)
6	prefEng		0.5473	(0.5451, 0.5495)

Appendix D Models explored for 90-day post-operative mortality

Summaries for additional models investigated for EL 90-day post-operative mortality are included in the table below.

Table 18: List of 40 models explored for 90-day EL post-operation risk adjusted mortality. Final model shown highlighted.

NO.	COVARIATES IN MODEL	**FULL DATA AUC**	MEAN TEST AUC	TEST AUC 95% CI
38	charlson, Age, charlson*Age, diagnosis		0.8124	(0.8109, 0.8138)
30	**Age, lap_type2, diagnosis, charlson_grp, Age*charlson_grp**	**0.8175**	**0.8101**	**(0.8089, 0.8113)**
39	charlson_grp, Age, charlson_grp*Age, diagnosis, lap_type2		0.8094	(0.8079, 0.8108)
25	Age, lap_type2, marital2, diagnosis, Elix (11), Elix (11) * Age		0.7921	(0.7905, 0.7937)
31	Age, lap_type2, diagnosis, marital2, Transfer, prefEng, Elix (11), Elix (11) * Age		0.7914	(0.7896, 0.7932)
27	Age, lap_type2, diagnosis, marital2, Elix (11), Elix (11) * Age		0.7913	(0.7899, 0.7928)
24	Age, lap_type2, diagnosis, Elix (11)		0.7907	(0.7893, 0.7922)
23	Age, lap_type2, diagnosis, Elix (11)		0.7905	(0.7890, 0.7921)
26	Age, lap_type2, diagnosis, Transfer, Elix (11), Elix (11) * Age		0.7905	(0.7887, 0.7922)
13	Age, diagnosis, Elix (11)		0.7875	(0.7851, 0.7891)
34	charlson_grp, Age, charlson_grp*Age		0.7748	(0.7731, 0.7765)
36	charlson, Age		0.7733	(0.7717, 0.7748)
33	charlson_grp, Age		0.7725	(0.7709, 0.7742)
20	Age, lap_type2, marital2, Transfer, prefEng Elix (11)		0.7644	(0.7627, 0.7662)
12	Age, lap_type2, prefEng, Elix (11)		0.7641	(0.7624, 0.7658)
19	Age, lap_type2, Elix (11), Elix (11) * Age		0.7640	(0.7625, 0.7655)
40	Age, Age^2, lap_type2, Elix (11), Elix (11) * Age		0.7635	(0.7617, 0.7652)
29	Age, lap_type2*Age, diagnosis		0.7631	(0.7614, 0.7649)
10	Age, lap_type2, marital2, Elix (11)		0.7628	(0.7609, 0.7647)
21	Elix (31)		0.7624	(0.7607, 0.7642)
11	Age, lap_type2, Transfer, Elix (11)		0.7623	(0.7608, 0.7637)
22	Age, lap_type2, diagnosis		0.7621	(0.7601, 0.7641)
28	Age, lap_type2, diagnosis*Age		0.7607	(0.7589, 0.7625)
9	Age, lap_type2, Elix (11)		0.7592	(0.7575, 0.7609)
18	Age, diagnosis, Age*diagnosis		0.7582	(0.7562, 0.7602)
8	Age , Elix (11)		0.7543	(0.7525, 0.7561)
14	Age, Elix(11), Elix(11) * Age		0.7536	(0.7552, 0.7520)
35	charlson		0.7338	(0.7317, 0.7359)
32	charlson_grp		0.7296	(0.7274, 0.7318)
7	Elix (11)		0.7149	(0.7128, 0.7170)
16	Age, lap_type2, Age*lap_type2		0.7136	(0.7116, 0.7157)
15	Age, Transfer, Age*Transfer		0.7002	(0.6982, 0.7023)
1	Age		0.6979	(0.6960, 0.6999)
37	Age, Age^2		0.6962	(0.6944, 0.6980)
17	Age, marital2, Age*marital2		0.6944	(0.6925, 0.6962)
5	diagnosis		0.6708	(0.6684, 0.6731)
2	lap_type2		0.5924	(0.5900, 0.5947)
3	marital2		0.5866	(0.5846, 0.5886)
4	Transfer		0.5556	(0.5536, 0.5575)
6	prefEng		0.5544	(0.5524, 0.5563)

Appendix E Models explored for 365-day post-operative mortality

Summaries for additional models investigated for EL 365-day post-operative mortality are included in the table below.

Table 19: List of 40 models explored for 365-day EL post-operation risk adjusted mortality. Final model shown highlighted.

NO.	COVARIATES IN MODEL	FULL DATA AUC	MEAN TEST AUC	TEST AUC 95% CI
23	**Age, lap_type2, diagnosis, Elix (11)**	**0.8410**	**0.8355**	**(0.8345, 0.8365)**
31	Age +lap_type2 +diagnosis +marital2 +Transfer +prefEng, Elix (11), Elix (11) * Age		0.8354	(0.8342, 0.8366)
26	Age, lap_type2, diagnosis, Transfer, Elix (11)		0.8349	(0.8337, 0.8361)
27	Age, lap_type2, diagnosis, marital2, Elix (11), Elix (11) * Age		0.8348	(0.8334, 0.8361)
25	Age, lap_type2, marital2, diagnosis, Elix (11), Elix (11) * Age		0.8342	(0.8329, 0.8354)
24	Age, lap_type2, diagnosis, Elix (11), Elix (11) * Age		0.8340	(0.8328, 0.8352)
13	Age, diagnosis, Elix (11)		0.8318	(0.8308, 0.8328)
12	Age, lap_type2, prefEng, Elix (11)		0.8256	(0.8245, 0.8267)
20	Age, lap_type2, marital2, Transfer, prefEng, Elix (11)		0.8251	(0.8239, 0.8264)
10	Age, lap_type2, marital2, Elix (11)		0.8248	(0.8237, 0.8259)
11	Age, lap_type2, Transfer, Elix (11)		0.8247	(0.8235, 0.8259)
38	charlson, Age, charlson*Age, diagnosis		0.8245	(0.8232, 0.8258)
19	Age, lap_type2, Elix (11), Elix (11) * Age		0.8240	(0.8230, 0.8250)
9	Age, lap_type2, Elix (11)		0.8228	(0.8217, 0.8240)
40	Age, Age^2, lap_type2, Elix (11), Elix (11) * Age		0.8228	(0.8215, 0.8241)
39	charlson_grp, Age, charlson_grp*Age, diagnosis, lap_type2		0.8214	(0.8203, 0.8225)
30	Age +lap_type2 +diagnosis, Age*charlson_grp		0.8207	(0.8195, 0.8219)
8	Age , Elix (11)		0.8185	(0.8173, 0.8198)
14	Age, Elix (11), Elix (11) * Age		0.8175	(0.8162, 0.8188)
21	Elix (31)		0.8050	(0.8036, 0.8064)
36	charlson, Age		0.8046	(0.8033, 0.8059)
34	charlson_grp, Age, charlson_grp*Age		0.7994	(0.7982, 0.8006)
33	charlson_grp, Age		0.7977	(0.7964, 0.7990)
7	Elix (11)		0.7966	(0.7953, 0.7979)
35	charlson		0.7725	(0.7709, 0.7741)
32	charlson_grp		0.7629	(0.7615, 0.7643)
29	Age +lap_type2*Age, diagnosis		0.7547	(0.7530, 0.7564)
22	Age, lap_type2, diagnosis		0.7533	(0.7519, 0.7546)
28	Age, lap_type2, diagnosis*Age		0.7533	(0.7516, 0.7551)
18	Age, diagnosis, Age*diagnosis		0.7464	(0.7450, 0.7478)
16	Age, lap_type2, Age*lap_type2		0.7159	(0.7141, 0.7176)
15	Age, Transfer, Age*Transfer		0.6987	(0.6972, 0.7002)
1	Age		0.6958	(0.6941, 0.6976)
37	Age, Age^2		0.6946	(0.6929, 0.6962)
17	Age, marital2, Age*marital2		0.6945	(0.6928, 0.6962)
5	diagnosis		0.6587	(0.6568, 0.6606)
2	lap_type2		0.6095	(0.6077, 0.6113)
3	marital2		0.5901	(0.5882, 0.5921)
4	Transfer		0.5868	(0.5848, 0.5888)
6	prefEng		0.5577	(0.5559, 0.5595)

References

1. Stevens CL, Brown C, Watters DAK. Measuring Outcomes of Clinical Care: Victorian Emergency Laparotomy Audit Using Quality Investigator. *World J Surg*. 2018;42(7):1981-1987. doi:10.1007/s00268-017-4418-4
2. Oliver CM, Bassett MG, Poulton TE, et al. Organisational factors and mortality after an emergency laparotomy: multilevel analysis of 39 903 National Emergency Laparotomy Audit patients. *Br J Anaesth*. 2018;121(6):1346-1356. doi:10.1016/j.bja.2018.07.040
3. Government V. *Victorian Admitted Episodes (VAED) Manual 2020-21: Section 3 Data Definitions*.; 2020. https://www2.health.vic.gov.au/hospitals-and-health-services/data-reporting/health-data-standards-systems
4. Walraven van C, Austin PC, Jennings A, Quan H, Forster AJ. A modification of the Elixhauser comorbidity measures into a single point system for hospital death using administrative data. *Med Care*. 2009;47(6):626-633.
5. Elixhauser A, Steiner A, Harris R, Coffey R. Comorbidity measures for use with administrative data. *Med Care*. 1998;36(1):8-27. doi:10.1097/00005650-199801000-00004
6. Li B, Evans D, Faris P, Dean S, Quan H. Risk adjustment performance of Charlson and Elixhauser comorbidities in ICD-9 and ICD-10 administrative databases. *BMC Health Serv Res*. 2008;8:1-7. doi:10.1186/1472-6963-8-12
7. Breiman L. Random forests. *Mach Learn*. 2001;45:5-32.
8. Ben-Tovim D, Woodman R, Harrison JE, Pointer S, Hakendorf P, Henley G. *Measuring and Reporting Mortality in Hospital Patients*.; 2009. https://www.aihw.gov.au/reports/hospitals/measuring-and-reporting-mortality-in-hospital-pati/contents/table-of-contents
9. Gelman, Andrew; Hill J. *Data Analysis Using Regression and Multilevel/ Hierarchical Models*. Cambridge University Press; 2006. doi:10.1017/CBO9780511790942
10. Louise S, Rolls D, Khanna S, Good N, Jayasena R. *Methodology and Risk Adjustemnt for a New AMI 30-Day Mortality Measure*.; 2019.
11. Team RC. *R: A Language and Environment for Statistical Computing.*; 2020. www.R-project.org
12. Bilder CLT. *Analysis of Categorical Data with R*. CRC Press; 2014.
13. Saunders DI, Murray D, Pichel AC, Varley S, Peden CJ. Variations in mortality after emergency laparotomy: The first report of the UK emergency laparotomy network. *Br J Anaesth*. 2012;109(3):368-375. doi:10.1093/bja/aes165
14. Pedersen T, Watt SK, Tolstrup MB, Gögenur I. 30-Day, 90-day and 1-year mortality after emergency colonic surgery. *Eur J Trauma Emerg Surg*. 2017;43(3):299-305. doi:10.1007/s00068-016-0742-x
15. Moraga P. *Geospatial Health Data: Modeling and Visualisations with R-INLA and Shiny*. Chapman & Hall/ CRC Biostatistics Series; 2019.

This page has intentionally been left blank.

As Australia's national science agency and innovation catalyst, CSIRO is solving the greatest challenges through innovative science and technology.

CSIRO. Unlocking a better future for everyone.

Contact us

1300 363 400
+61 3 9545 2176
csiroenquiries@csiro.au
csiro.au

For further information

Health and Biosecurity
Rajiv Jayasena
+61 3 9662 7383
Rajiv.Jayasena@csiro.au
www.aehrc.com

Health and Biosecurity
Sankalp Khanna
+61 7 3253 3629
Sankalp.Khanna@csiro.au
www.aehrc.com