

A Continuous Life-years Gained Priority Score for Ventilator Allocation

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1 Theory

2 Simulation using CDC data

Theory

Military triage- save as many soldiers as possible

In military triage situations, a utilitarian framework is employed to save the greatest number of wounded soldiers in a mass casualty event

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- 3 Rank order patients who will die without critical care by $P(ICU\text{Survival})$ (Red > Yellow)

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- 2 Exclude patients who obviously will not survive with critical care (Blue)
- 3 Rank order patients who will die without critical care by $P(ICU\text{Survival})$ (Red > Yellow)
- 4 Treat as many patients as possible in order of $P(ICU\text{Survival})$

Problems with military triage approach in the COVID-19 Pandemic

Three patients with COVID-19



28 year old female

- SOFA: 30% survival



80 year old male

- SOFA: 75% survival



60 year old male

- SOFA: 50% survival

Who gets the one remaining ventilator?

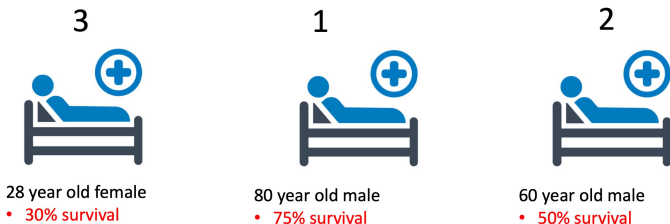
New York ventilator allocation policy

Step 2 – Mortality Risk Assessment Using SOFA ¹	
Color Code and Level of Access	Assessment of Mortality Risk/ Organ Failure
<p>Blue</p> <p>No ventilator provided. Use alternative forms of medical intervention and/or palliative care or discharge.</p> <p>Reassess if ventilators become available.</p>	<p>Exclusion criterion</p> <p>OR</p> <p>SOFA > 11</p>
<p>Red</p> <p>Highest</p> <p>Use ventilators as available</p>	<p>SOFA < 7</p> <p>OR</p> <p>Single organ failure²</p>
<p>Yellow</p> <p>Intermediate</p> <p>Use ventilators as available</p>	<p>SOFA 8 – 11</p>
<p>Green</p> <p>Use alternative forms of medical intervention or defer or discharge.</p> <p>Reassess as needed.</p>	<p>No significant organ failure</p> <p>AND/OR</p> <p>No requirement for lifesaving resources</p>

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Priority rankings under NY triage system



Goes against “youngest first” allocation principles and does not maximize life-years saved

Multiprinciple approach

Table 3. Illustration of a Multiprinciple Strategy to Allocate Ventilators During a Public Health Emergency

Principle	Specification	Point System*			
		1	2	3	4
Save the most lives	Prognosis for short-term survival (SOFA score)	SOFA score <6	SOFA score, 6–9	SOFA score, 10–12	SOFA score >12
Save the most life-years	Prognosis for long-term survival (medical assessment of comorbid conditions)	No comorbid conditions that limit long-term survival	Minor comorbid conditions with small impact on long-term survival	Major comorbid conditions with substantial impact on long-term survival	Severe comorbid conditions; death likely within 1 year
Life-cycle principl [†]	Prioritize those who have had the least chance to live through life's stages (age in years)	Age 12–40 y	Age 41–60 y	Age 61–74 y	Age ≥75 y

SOFA = Sequential Organ Failure Assessment.

* Persons with the lowest cumulative score would be given the highest priority to receive mechanical ventilation and critical care services.

† Pediatric patients may need to be considered separately, because their small size may require the use of different mechanical ventilators and personnel.

White

et al, Ann Internal Medicine, 2009 **What justification for relative weight of each category? Why categorical?**

Maximizing life-years gained

An alternative **utilitarian** approach is to maximize life-years gained

Priority Score that maximizes life-years gained

$$PriorityScore = P(ICUSurvival) * (100 - age)$$

Example: Maximizing life-years

Life-years gained allocation



28 year old female

- SOFA: 30% survival
- $100 - 28 = 72$ years of life left
- **22 life-years gained with vent**

1



80 year old male

- SOFA: 75% survival
- $100 - 80 = 20$ years of life left
- **15 life-years gained with vent**

2

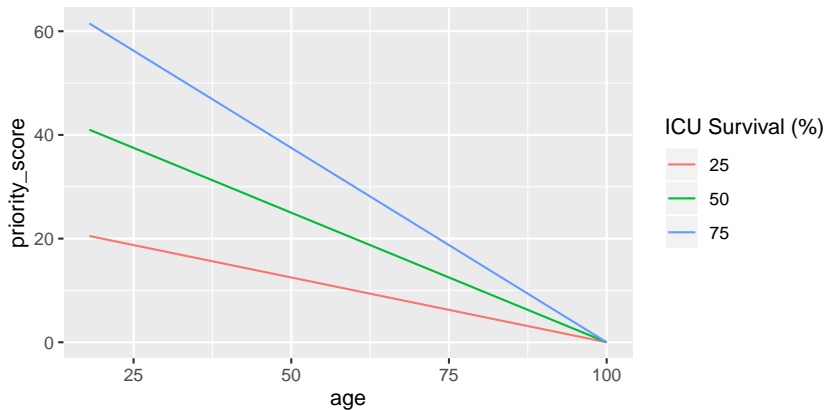


60 year old male

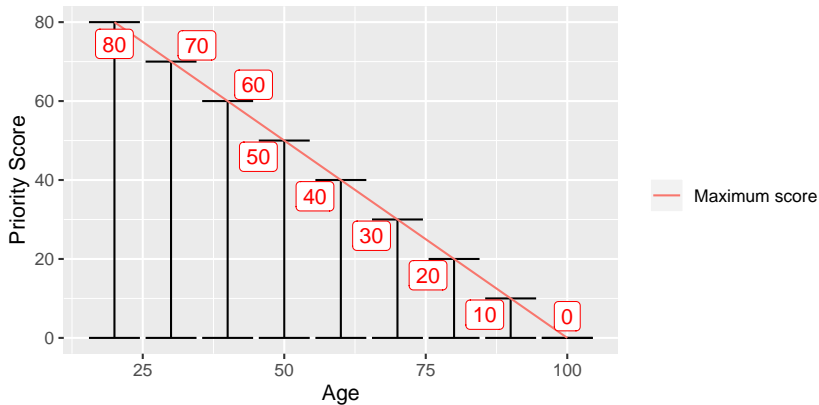
- SOFA: 50% survival
- $100 - 60 = 40$ years of life left
- **20 life-years gained with vent**

3

Priority Score vs. Patient Age, by Probability of ICU Survival



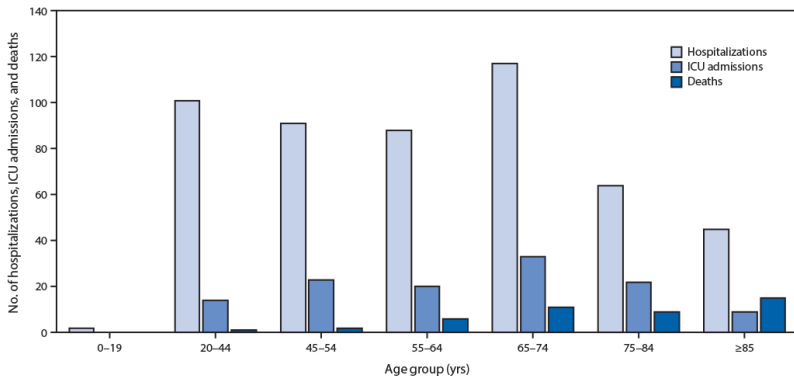
Range of possible priority scores by patient age



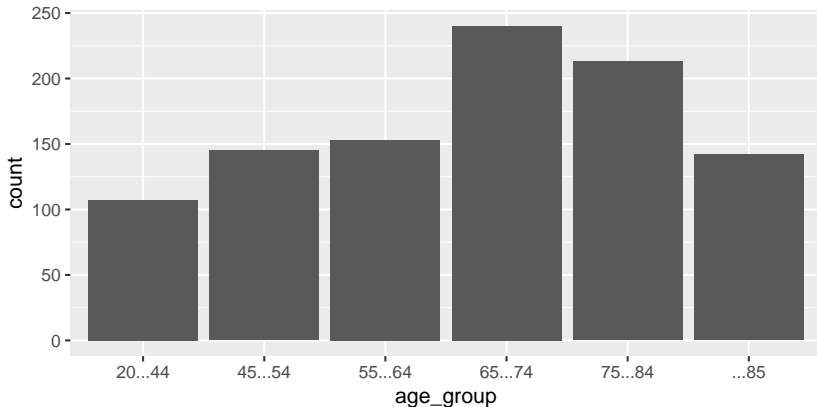
Simulation using CDC data

Data sources

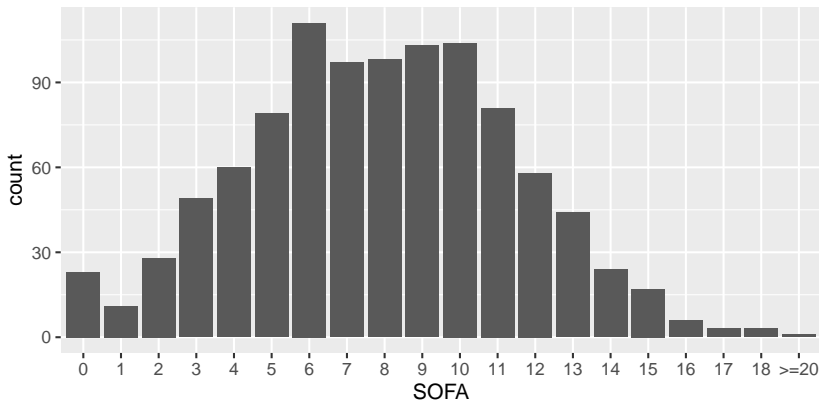
We took data from the CDC report Severe Outcomes Among Patients with Coronavirus Disease 2019 — United States, February 12–March 16, 2020



Simulated ICU population from CDC data distribution



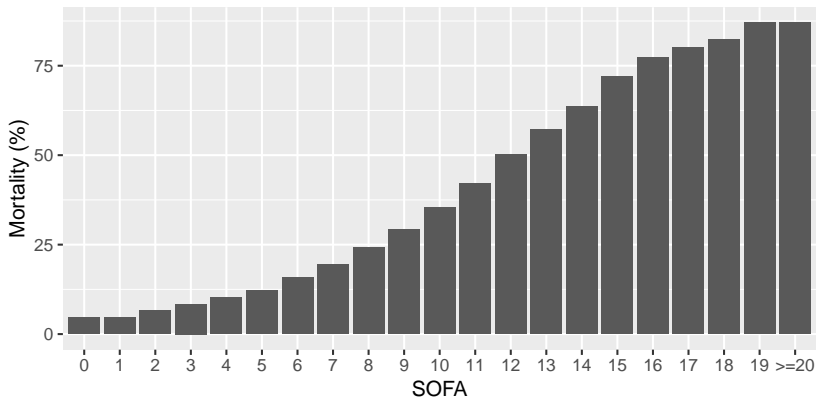
Simulated SOFA score distribution



Currently drawn from $f(SOFA|age) = N(8 + \frac{age-65}{30}, 3.5)$, need to replace with a distribution estimated from real data.

Calibration of the SOFA score

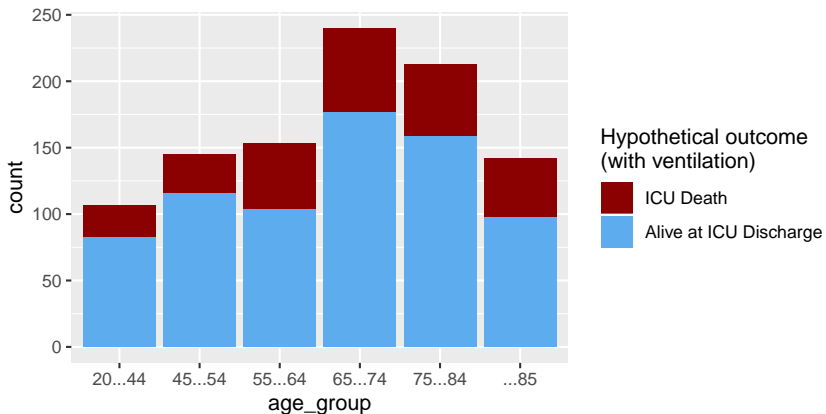
The Sequential Organ Failure Assessment (SOFA) score is a validated bedside predictor of ICU mortality. The calibration of SOFA scores is drawn from *Raith et al. JAMA, 2017*



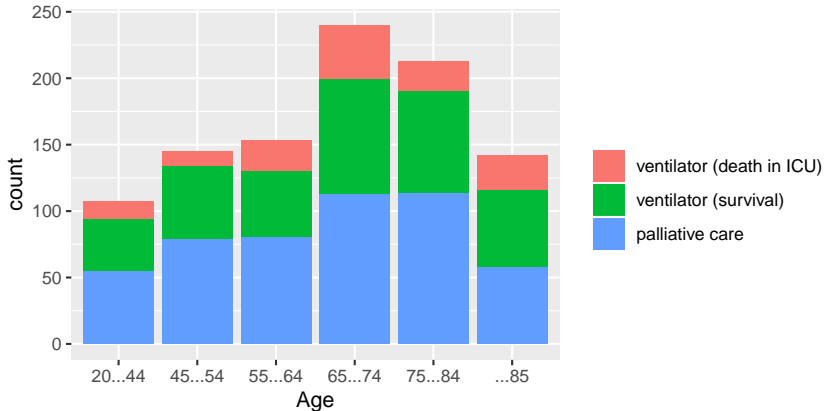
SOFA Score by Age

Age	Mean SOFA	Survival with Ventilator
20–44	6.9	77%
45–54	7.0	76%
55–64	8.2	71%
65–74	7.7	73%
75–84	8.5	70%
85	8.7	68%

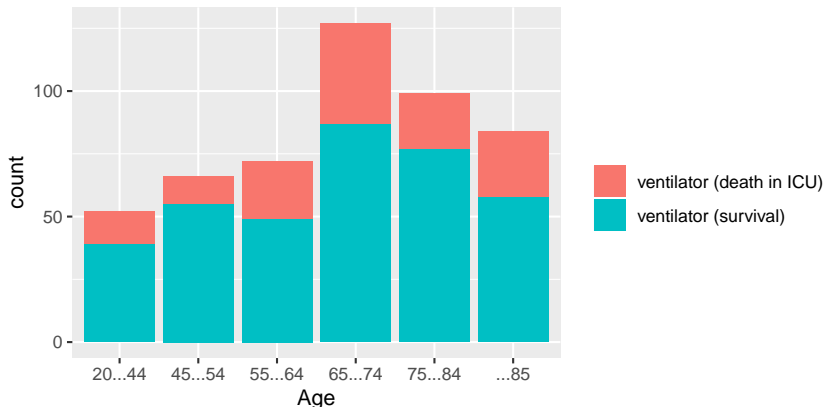
Simulated Hypotehtical Outcomes by Age



Lottery allocation

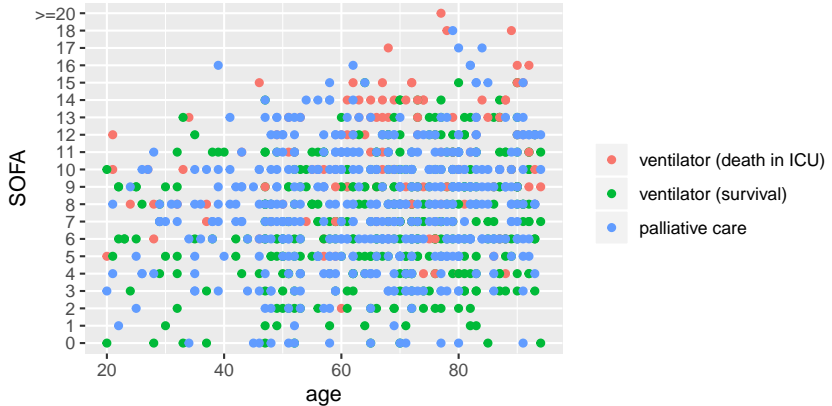


lottery allocation - ICU outcomes

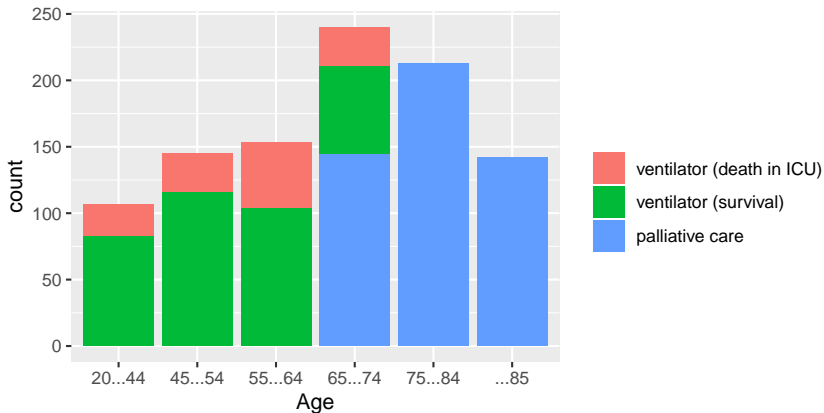


A random allocation of 500 ventilators would save 365 out of 1000 who were in need of mechanical ventilation. A lottery saves 12,268 (36%) out of a total of possible 33,927 life years.

Lottery- age vs. SOFA

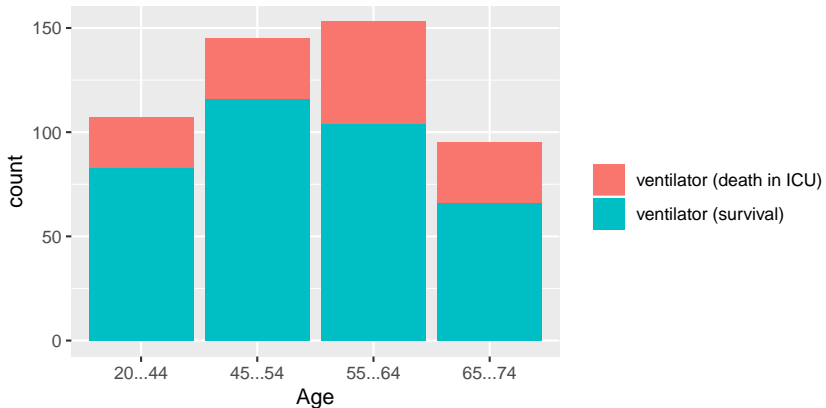


Youngest first allocation

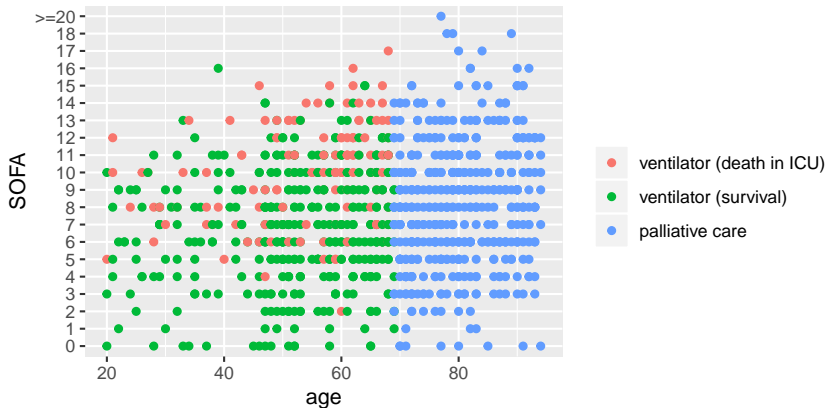


Youngest first allocation 500 ventilators would save 369 out of 1000 who were in need of mechanical ventilation. Youngest first saves 17.846 (53%) out of a total of possible 33.927 life years.

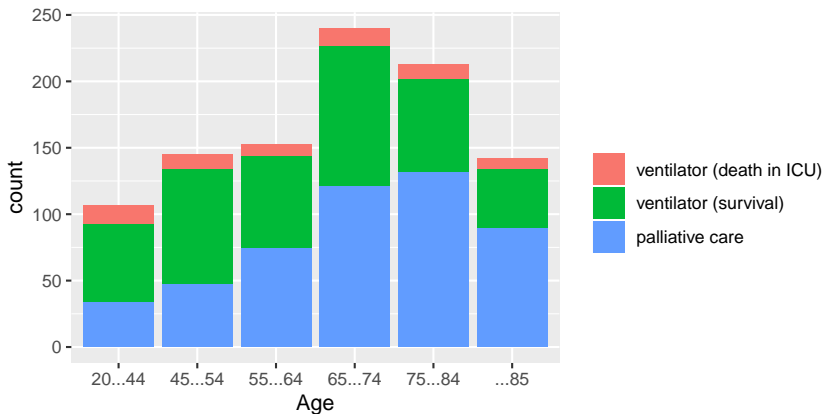
Youngest first - ICU allocation



Youngest first allocation- age vs. SOFA



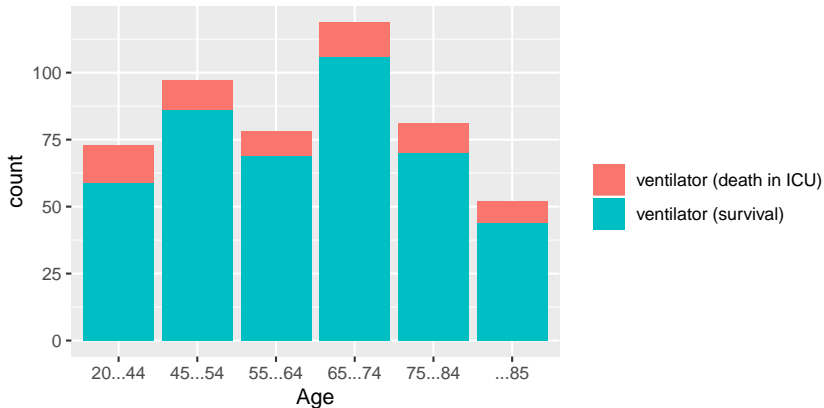
Maximizing ICU survival



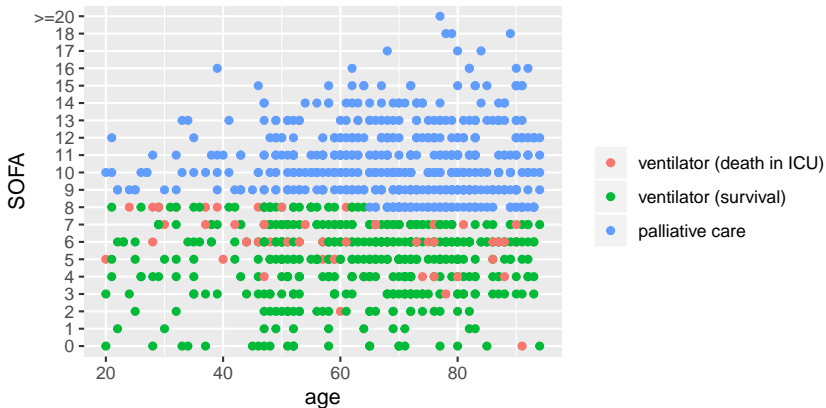
A $P(ICU_{survival})$ triage system of 500 ventilators would save 434 out of 1000 who were in need of mechanical ventilation.

Maximizing ICU survival saves 16,295 out of a total of possible

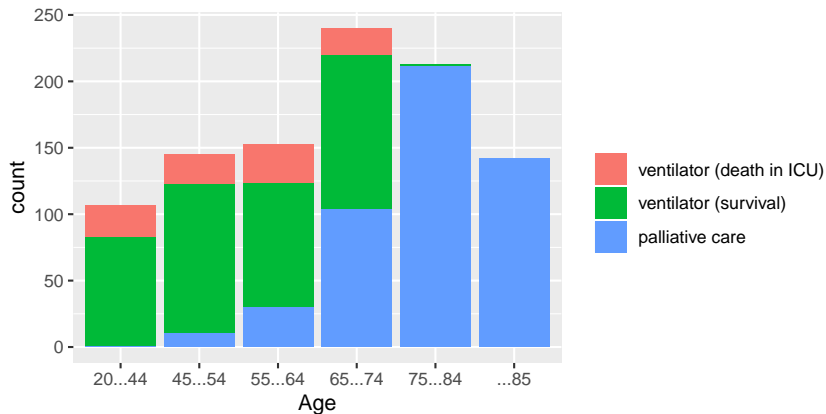
Maximizing ICU survival- ICU Outcomes



Max ICU survival- age vs. SOFA

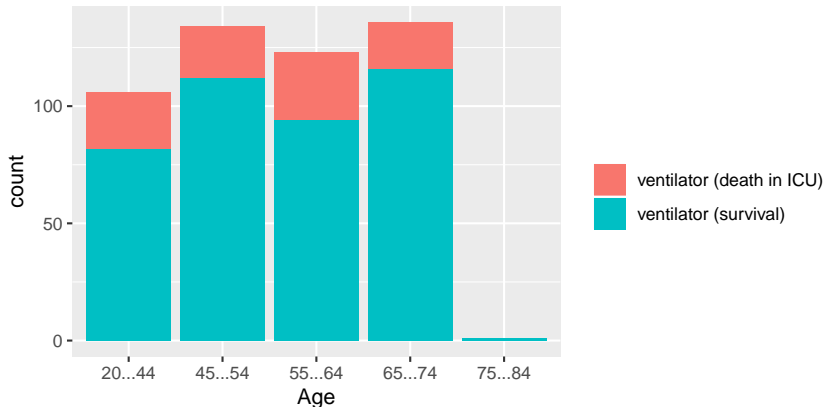


Maximizing Life-years gained

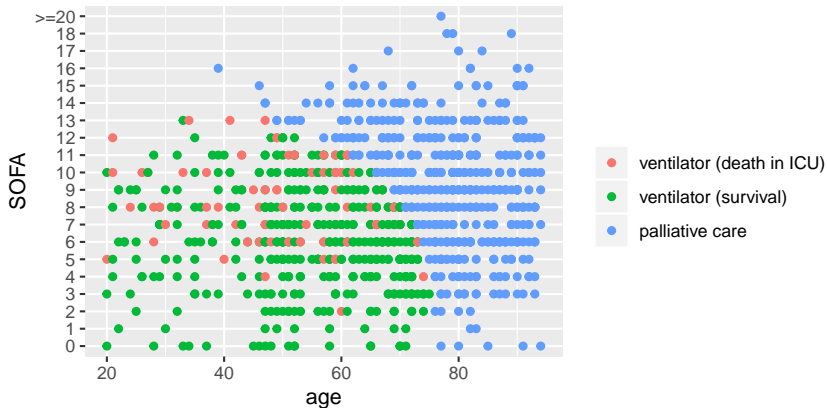


Prioritizing life-years for 500 ventilators would save 405 out of 1000 patients admitted to the ICU. Maximizing life-years gained saves 18,601 out of a total of possible 33,927 (55%) life-years.

Max Life Years- ICU Outcomes by Age



Max life years- age vs. SOFA



Maximizing life-years vs. ICU survival

Prioritizing young sick patients over old healthy patients leads to more ICU deaths in exchange for more life-years gained.

The Tradeoff

Prioritizing life-years gained over ICU survival saves an additional 2,306 life-years for this 1000 patient sample, at a cost of 29 more deaths in the ICU.