Simulation, optimization, and process mining: practicals applications in healthcare

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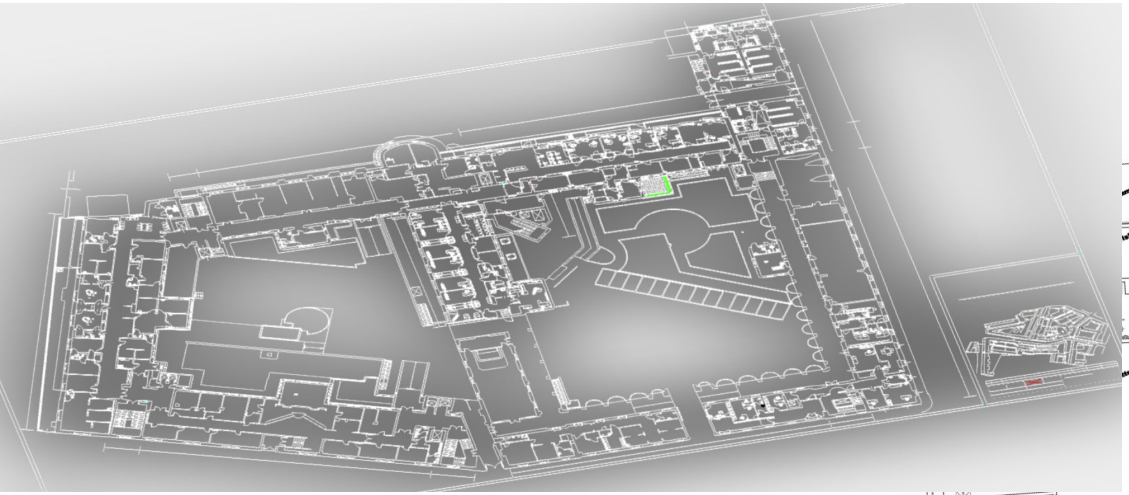
Building Information Modeling in Healthcare

- **Building Information Modeling (BIM)** methodology to manage complex buildings
- BIM serves as a **relational database repository** that integrates **several data typologies**, e.g., dimensional data, space functions, and spaces and building elements characteristics
- **Crowd modeling and simulation** to model and simulate crowd and pedestrian dynamics to optimize design solutions and to support safety management strategies in large spaces and building
- BIM can serve as a foundation for conducting simulations, which then enable the analysis of **different design scenarios**, potential hazards, and other factors that may impact the performance and safety of a building

The spaces of the model

- on the ground floor: **entrance**, **reception**, and **corridor** connecting with the **elevator** and **stairs**
- on the first floor: two **waiting areas** (W1 and W2), a **registration area**, two **blood draw rooms**



Simulation parameters

- **agent profiles**: three agent profiles (i.e., able-bodied patients, disabled or pregnant patients, and in-hospital patients), each with specific walking speed and size (e.g., to consider the wheelchair for disabled patients);

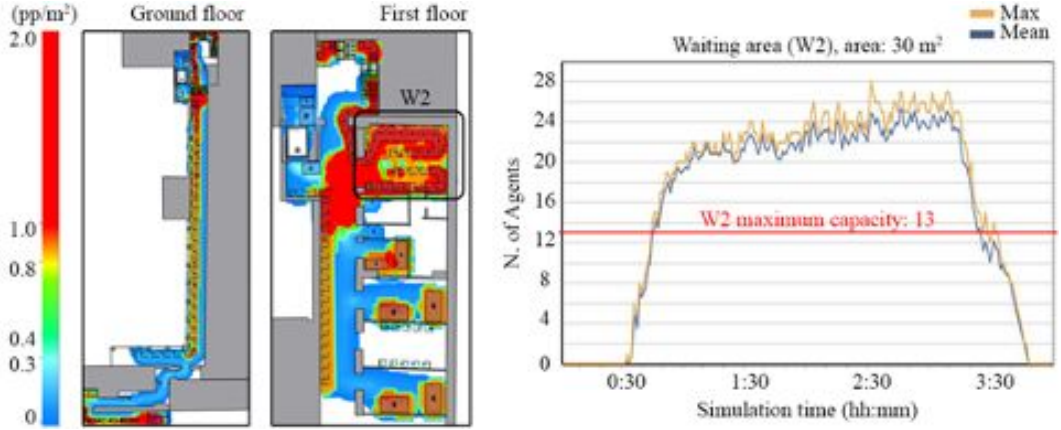
- **activity routes** (i.e., the sequences of activities): each agent profile has its own activity route;
(e.g., able-bodied patients are expected to use the stairs, while disabled or pregnant patients are more likely to use the elevator to reach the first floor. In-hospital patients come from other hospital departments, are not required to check in and register, and have priority for the blood test)

- **agent generators** (i.e., the number of users created in the simulation and the time they enter the simulation): each scenario, i.e., the standard conditions and peak attendance scenario, requiress a specific generators according to the average number of patients that are typically registered

Scenario analysis

Identification of overcrowded areas and critical activities causing crowding phenomena

Density maps of the ground and first floor in the **peak attendance scenario**.
The waiting area W2 is the most overcrowded area exceeding the limit of 2 people per square meter as imposed by COVID-19 pandemic requirements.



The average and maximum number of people during the whole simulation in waiting area W2. According to the chart, the maximum capacity of the room (i.e., 13 patients) is exceeded by almost double for three out of four hours of the simulation.

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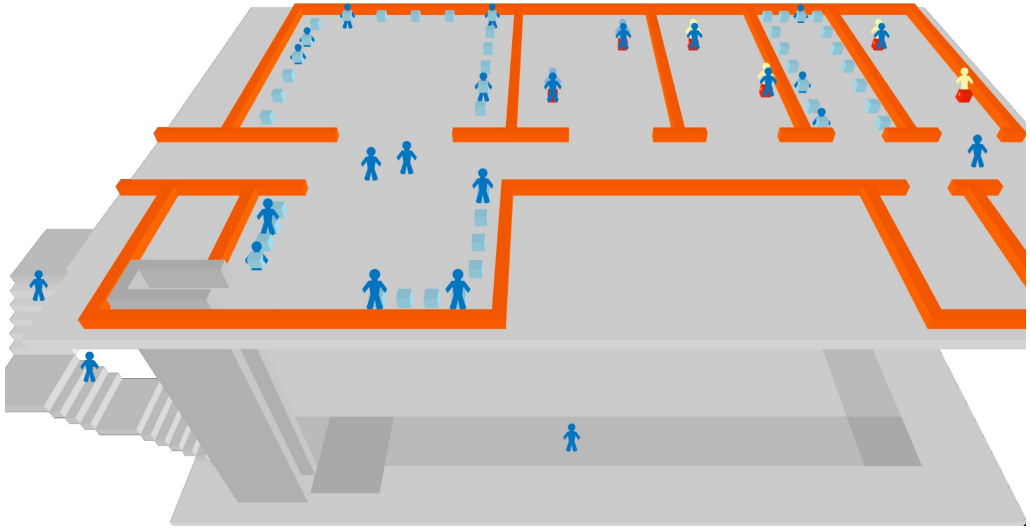
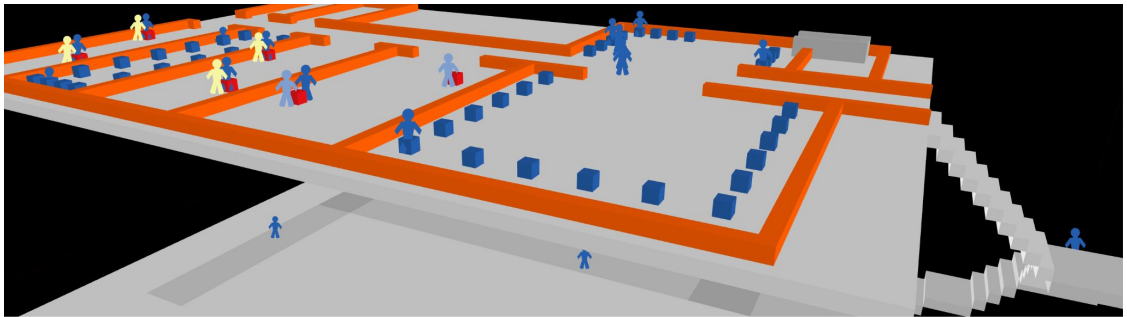
Agent-Based Modeling

Agent-based modeling (ABM) focuses on interactions among individual autonomous entities to understand macro phenomena emerging from micro-scale behaviour





CODE EXAMPLE:

```
(...)
to check-workers-waiting-pat
 if any? workers with
  [ type-of-w = "empl" and state = "free"
    and not empty? waiting-list-reg ]
    [ ask one-of workers with
      [ type-of-w = "empl" and state = "free"]
      [
       let pat item 0 waiting-list-reg
       set wa-list-reg remove-item 0 wa-list-reg
       set state "waiting"
       set working-with pat
       call-a-patient self pat
       ]
      ]
…
```

NetLogo 3D version

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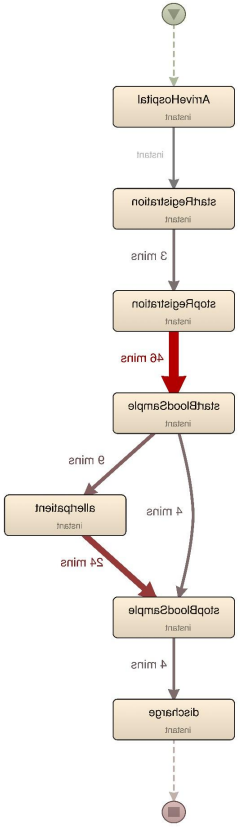
Simulation and process mining

The simulation generate an Event-Log >> process discovery

EG., from simulation we can collect event-log:

```
case138,stopBloodSample,2023-03-21 07:50:04+00:00,nurse4,7
case137,discharge,2023-03-21 07:51:04+00:00,nurse3,4
case144,ArriveHospital,2023-03-21 07:51:34+00:00,"-",0
case145,ArriveHospital,2023-03-21 07:52:33+00:00,"-",2
case139,startBloodSample,2023-03-21 07:53:04+00:00,nurse3,6
case144,startRegistration,2023-03-21 07:54:28+00:00,empl2,0
case138,discharge,2023-03-21 07:54:53+00:00,nurse5,3
case145,startRegistration,2023-03-21 07:56:12+00:00,empl4,2
case139,startBloodSample,2023-03-21 07:58:54+00:00,nurse5,8
case140,discharge,2023-03-21 07:59:36+00:00,nurse1,7
```



Simulation and process mining

Hospital Information System > real Event-Log

Emergency Department (Sept. 22)

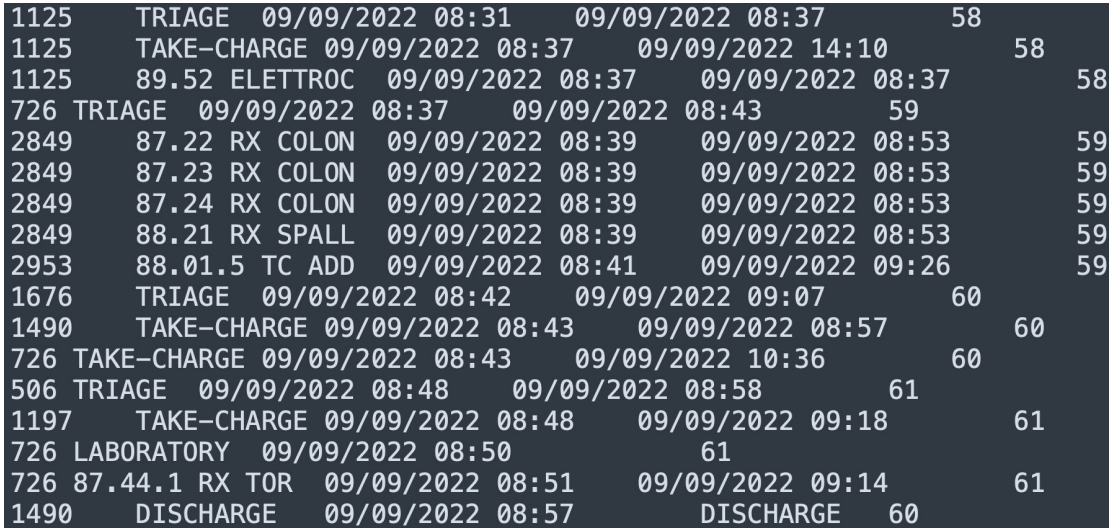
- 3,042 traces (i.e. patients)

- 116 different activities

- 3 < events < 32 p.t.

- High number of variants

Filters > Discovery main paths



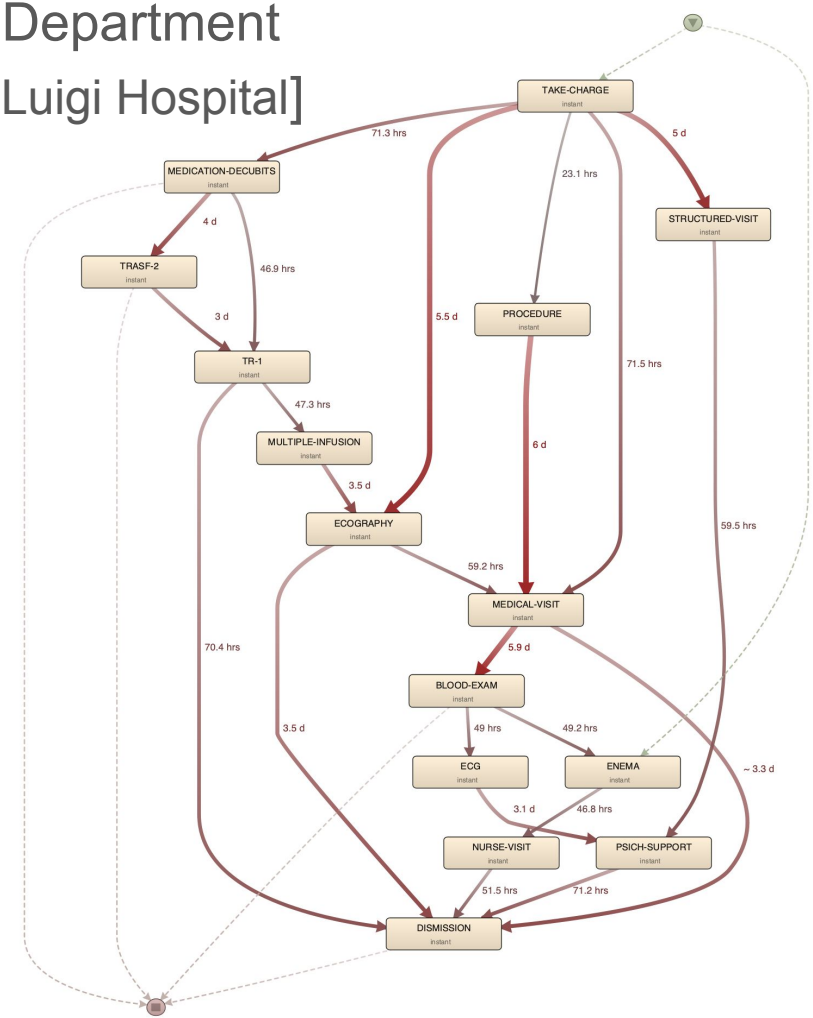
Process discovery

Emergency Department [Orbassano S.Luigi Hospital]

The most **frequent activities**, in this particular case, are related to X-Ray of different part of the body (thorax, foot, hand, ankle, wrist...).

Additionally, some patients go directly from Triage to **Electrocardiogram** and others pass through the **Short-Stay Observational Unit**.

Among the main activities, we find **Laboratory**, which indicates special exams, like blood or other body fluid tests.



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Process Mining and Optimization

A real-world scenario on **workshift scheduling** (complexity of managing medical care in the healthcare organization, for the importance of workload balancing, e.g. scheduling surgical procedures)

A *decision-support system* that automatically generating **rostering plans** by combining optimization and process mining methodologies

Leveraging a *real-life dataset* we built a **healthcare event log**, and analyzed it in order to discover the main causes for delays and lagging cases.

The discovered information – such as the IR procedures requiring more time – is then used to generate an **optimized scheduling** able to take into account all these aspects.

Three steps methodological framework

1) a multi-criteria mixed **integer linear programming model**, which models the problem of determining the monthly rostering balancing the monthly working hours of the healthcare personnel in accordance with a list of operative and contractual constraints

2) a **sequence pattern mining algorithm** to mine frequent contiguous sequential patterns from data, that is to identify constraints that are possibly not explicitly reported as domain knowledge

3) the **adaptation** of the rostering plan provided by the multi-criteria model in such a way to increase the number of the patterns mined in the second step while maintaining the feasibility and the optimality of the initial rostering solution

Di Cunzolo, Matteo, et al. "Combining Process Mining and Optimization: A Scheduling Application in Healthcare." *Business Process Management Workshops 2022, Münster, Germany, September 11–16, 2022,* Springer International Publishing, 2023.

Managing the emergency department patient flow

An online optimization approach with look-ahead embedded in simulation model: exploiting the prediction based on ad hoc process mining model, the proposed online algorithm is capable to pursue different policies to manage the access of the patients to the critical resources.

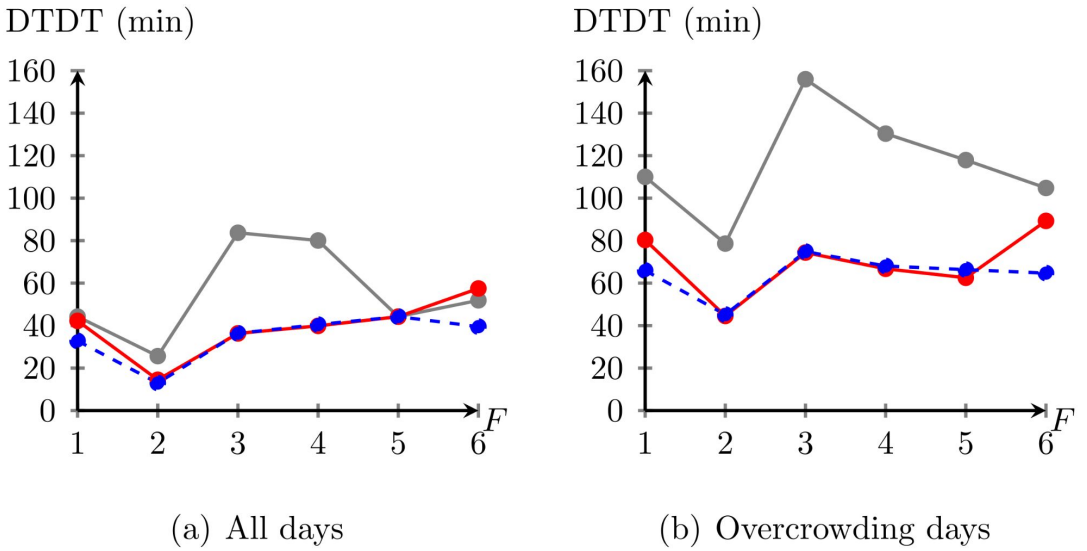

Fig. 12. Average DTDTs of patients in the frames $F = 1, \ldots, 6$ of the day (baseline in grey, Σ_X in red, Σ_H in blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

D. Duma, R. Aringhieri, Real-time resource allocation in the emergency department: a case study, Omega 117 (2023)

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CH4I project

CH4I project concerns **data and AI techniques** to improve the **organization** of industries for human healthcare, animal welfare, and agrifood safety

The project focuses on **processes**, often implicit and hidden in the tacit knowledge of workers, to be reconstructed and optimized:

- to maximize the gain from innovation on AI
- to benefit from the increasing amount of data generated from the systems

Circular Health for Industry

The project Circular Health for Industry has been financed by "Fondazione Compagnia di San Paolo" on the call "Intelligenza Artificiale, uomo e società"

Fondazione Compagnia di San Paolo

https://ch4i.di.unito.it

RIsPOSTE project

The RIsPOSTE project addresses the problem of a hospital's and community's ability to reorganize health care in **emergencies** such as epidemics from different perspectives, proposing **telemedicine** solutions and a **digital twin** to model organization, technology, building and space.

RIsPOSTE - seRvizi dIgitali Per cOntraSTare l'Epidemia

Funded by "INFRA-P2 - Potenziamento di laboratori di prova ed infrastrutture di ricerca già esistenti nella disponibilità di organismi di ricerca pubblici e progetti di ricerca e sviluppo finalizzati al contrasto della pandemia Covid-19" of **Regione Piemonte**

https://risposte.di.unito.it

Thank you