**Overview of Artificial Intelligence for Healthcare Logistics**

Basically, our aim is to shed light on the capabilities of artificial intelligence for the area of healthcare logistics. This work focuses only on approaches applied to healthcare logistics, i.e. planning problems arising for logistical tasks, e.g. in hospitals or other care institutions. That is, AI for medical applications, e.g. to determine the probability for a certain disease, is excluded from this work.

Machine Learning

Machine learning describes a set of techniques that are used to solve a variety of real-world problems with the help of computer systems that can learn to solve a problem instead of being explicitly programmed.

*Supervised learning* - comprises methods and algorithms to learn the mapping from the input to the output.

*Unsupervised learning* - comprises methods and algorithms that are able to reveal previously unknown patterns in data.

*Reinforcement learning* - correct input/output combinations need not be presented, and sub-optimal actions need not be explicitly corrected. In the field of operations research, reinforcement learning is also called *approximate dynamic programming*, or *neuro-dynamic programming*.

Artificial Intelligence

AI research can be separated into different research streams. These streams differ on the one hand as to the objective of AI application—thinking vs. acting, and on the other hand, as to the kind of decision-making—targeting a human-like decision vs. an ideal, rational decision. Machine learning plays three major roles in this field of artificial intelligence. First, machine learning is relevant in the implementation of intelligent agents, precisely in the back-end layer of such agents. Second, the learning back-end in the intelligent agent dictates if and how the agent is able to learn, e.g. which precise algorithms it uses, what type of data processing is applied, how concept drift is handled, etc. There are two different types of intelligent agents - *simple-reflex agents* and *learning agents*. This differentiation considers whether the underlying models in the thinking layer are once trained and never touched again (“simple-reflex agent”) or continuously updated and adaptive (“learning agent”).

It is of interest how automated the necessary process steps are for an AI. The autonomy and the automation of important tasks are of particular interest, especially the necessary human involvement for the AI to execute.

Working Definition

*Data analysis* includes all necessary steps of pre-processing and automated generation of predictions based on new, incoming data—typically based on machine learning. The task of *recommendation* describes the interpretation of the results from the previous task. Finally, the last process task is making a *decision* and possibly *act* on it. We differentiate which of these tasks the AI handles and which is handled by humans, resulting in the three levels of *AI- Enrichment*, *AI-Enhancement* and *AI-Autonomy*.

Planning

Healthcare logistics can be divided into the three planning levels: strategic, tactical and operational. While strategic decisions are usually made for years or even decades, tactical decisions can be revoked on a yearly or monthly basis. Operational planning happens daily, often as offline decisions, or in real-time usually with online approaches.

A screenshot of a diagram

Description automatically generated

Care Levels

We differentiate between primary, secondary and tertiary care. Secondary care includes ambulatory care services, emergency medical services and hospital services. Tertiary care consists of home care services and residential care services.

A diagram of medical services

Description automatically generated

User Types

A framework would not be useful if all possible user types were included. Also, not all users have been targeted in the literature. Therefore, we distinguish the following three user types in our framework:

* Patients: Individuals who receive medical care from providers.
* Providers: Institutions or people that provide care to patients and charge payers

for that care. We divide this type again into two subgroups:

–  Hospital management, and

–  doctors and nurses.

* Payers: Institutions that pay providers for healthcare services, which include insurance carriers, private employers and the government.

Framework

A table with text on it

Description automatically generated with medium confidence

The overall four user types are abbreviated by P1–P3, with P1 meaning patients, P2.1 hospital management, P2.2 doctors and nurses, and P3 payers.

Literature Review

Publications that apply AI to medical problems, e.g. to determine the prob- ability for a certain disease, the probability that a certain treatment will be successful or survival predictions, e.g. in the intensive care unit (ICU). Machine learning approaches can predict rehabilitation potential. Researched topics also include AI-based decision support systems for personalised medicine and treatment as well as trends in telemedicine with AI. Neural networks can be used to predict future illnesses that can be of interest for insurance companies to determine expected costs. Several AI approaches have been proposed for radiotherapy. AI approaches are applied to the scanning of medical claims and the detection of fraud. AI methods are used to predict input for healthcare logistics problems.

AI for Optimization

An artificial neural network (ANN) to predict the patient volume arriving at an emergency department (ED). The authors state that the ANN can be used for this task, but it must be properly designed and include all relevant variables. Then, it can be used as an input for staffing the ED appropriately, aiming at shorter waiting times for patients as well as lower or more balanced workloads for the doctors and nurses. There are also time series-based forecasting models to predict long-term as well as short-term arrival rates at the emergency department.

Besides the overall patient volume, predicting the admission rates is another important problem arising for emergency departments that can be addressed by machine learning approaches. When three machine learning algorithms: logistic regression, decision trees and gradient-boosted machines (GBM) were used for predicting hospital admissions from Emergency Department, we found that GBM leads to the highest accuracy, while logistic regression should be chosen when interpretability is most important.

*Note; Length od Stay (LOS) is one of the main ED performance indicators.*

Bayesian network is a good option to develop a model for real-time predictions of length of stay, mortality and re-admission for hospitalised patients based on ED data.

Beds in ICUs are often scarce resources. Then, it is important to timely discharge patients to a regular ward when possible.

Due to high-cost pressures in many healthcare systems, it is crucial for hospitals to avoid unnecessary high spending. So to use machine learning approaches to identify high-cost patients. Outside of hospitals, several publications have used machine learning approaches to predict the demand for emergency medical services (EMS), i.e. ambulances. Good predictions can be used as input for ambulance location and relocation approaches to reduce response times.

Machine Learning algorithms can be used to predict waiting times at a walk-in radiology facility as well as waiting times for patients with scheduled appointments at radiology facilities.