Deliverable D 1.1

Definition of a reference taxonomy of AI in railways

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Contents

Executive Summary

This deliverable is the output of RAILS Work Package 1 Task 1.1. As such, it provides a taxonomy of Artificial Intelligence (AI) approaches that are capable of analysing, predicting and improving railway systems. In this document we make a distinction between different AI perspectives addressing areas such as knowledge representation, reasoning under uncertanties, planning, machine learning, computer vision, language processing, etc. *The deliverable aims at providing a taxonomical overview of relevant AI concepts* to support decisions about which AI techniques would be most appropriate in order to tackle the challenges associated to modern smart-railways. In addition, several advanced AI concepts such as "trustworthy AI" and AI ethics are introduced; the European directives and resolutions are considered in taking into account the ethical dimension of AI when investigating AI for railway systems. The taxonomy is the first step towards providing a general framework to support railway decision-makers to assess and understand the usability of AI-based approaches and to support industry stakeholders to promptly determine promising AI solutions to solve certain railway problems. The objective of this deliverable is to contribute in bridging the gap between AI and railway-domain experts in terms of basic concepts and terminology.

Please note that it was not in the scope of this deliverable to provide an extensive state-of-the-art that will be addressed in the continuation of the project activities, and in particular reported in deliverable D1.2. Relevant applications of AI from other high-tech sectors are also considered but they are just an input for a deeper investigation that will be conducted in Work Packages 2,3, and 4 as part of transferabiliy analysis.

Abbreviations and acronyms

Abbreviations / Acronyms	Description
ABM	Agent-Based Modelling
ACO	Ant Colony Optimization
AI	Artificial Intelligence
AI HLEG	High-Level Expert Group on Artificial Intelligence
ANN	Artificial Neural Networks
AR	Augmented Reality
ATO	Automatic Train Operation
CNN	Convolutional Neural Networks
CP	Constraint Programming
CV	Computer Vision
DARPA	Defense Advanced Research Project Agency
DBM	Deep Boltzman Machines
DBN	Deep Belief Networks
DCOP	Distributed Constraint Optimization Problem
DDP	Differential Dynamic Programming
DL	Deep Learning
DM	Data Mining
DT	Digital Twin
EAs	Evolutionary Algorithms
EC	European Commission
ERTMS	European Rail Traffic Management System
ESs	Evolution Strategies
ETCS	European Train Control System
EU	European Union
GAs	Genetic Algorithms
GBDT	Gradient Boosting Decision Tree
GDPR	General Data Protection Regulation
GP	Genetic Programming
GPS	Global Positioning System
GPU	Graphics Processing Unit
HMM	Hidden Markov Model
HSR	High Speed Rail
ILP	Inductive Logic Programming
IoT	Internet of Things
ITS	Intelligent Transportation System
JADE	Java Agent DEvelopment Framework
JRU	Juridical Recording Unit
KDD	Knowledge Discovery from Data
MA	Movement Authority
MaaS	Mobility as a Service
ML	Machine Learning
MOEAs	Multi-Objective Evolutionary Algorithms

MR	Mixed Reality
MSE	Mean Squared Error
NDP	Network Design Problem
NLP	Natural Language Processing
OCS	Occupancy Control System
OR	Operations Research
PM	Predictive Maintenance
PNN	Probabilistic Neural Networks
PR	Pattern Recognition
PROLOG	PROgramming in LOGic
PSD	Platform Screen Doors
PSIM	Physical Security Information Management
PSO	Particle Swarm Optimization
QA	Question Answering
R&D	Research and Development
RAILS	Roadmaps for AI integration in the raiL Sector
RM	Revenue Management
RNN	Recurrent Neural Networks
SA	Simulated Annealing
SCM	Supply Chain Management
SI	Swarm Intelligence
SIEM	Security Information and Event Management
SIL	Safety Integrity Level
SMEs	Small-Medium Enterprises
SVM	Support Vector Machine
SVR	Support Vector Regression
TDX	Toshiba Digital and Consulting Corporation
TL	Transfer Learning
TMS	Traffic Management System
VCA	Video Content Analytics
VE	Virtual Environments
WTMS	Wayside Train Monitoring Systems
XAI	Explainable Artificial Intelligence

1. Background

The present document constitutes the D1.1 “Definition of a reference taxonomy of AI in railways” of the S2R JU project “Roadmaps for AI integration in the Rail Sector” (RAILS). The project is in the framework of Shift2Rail’s Innovation Programme IPX. As such, RAILS does not focus on a specific domain, nor does directly contribute to specific Technical Demonstrators but contributes to Disruptive Innovation and Exploratory Research in the field of Artificial Intelligence within the Shift2Rail Innovation Programme.

Deliverable D 1.1 describes the work carried out in Task 1.1 of Work Package 1 whose objectives are:

- Define a taxonomy of AI to enable its application in railway transport;
- Determine the state-of-the-art of AI techniques in railway transport;
- Determine the state-of-the-art of AI application in Shift2Rail projects;
- Identify application areas of AI in railways.

Work Package 1 identifies essential conditions: it provides specific needs, investigates capabilities and gaps; it surveys techniques and methods for picking the right AI technology able to solve open problems or improve performance in railway scenarios. The main outcomes of Work Package 1 are:

i. A taxonomy of suitable AI techniques to be adopted for railways (this Deliverable);
ii. A map of the current state-of-the-art of AI aplication in railway research, including Shift2Rail projects and other relevant projects (Deliverable D 1.2);
iii. A set of current and potential application areas (Deliverable D 1.3).

2. Objective

Deliverable D1.1 is the first technical deliverable of Work Package 1, which aims at identifying the current potential of AI in the railway sector in order to provide an extensive evaluation of possible applications associatd to different railway subsystems. The objective of this deliverable is to define a reference taxonomy of AI approaches that are capable of analysing, predicting and improving railway systems In particular, we surveys the set of AI approaches that would be appropriate to address certain railway challenges. The ethical dimension of AI are also taken into account. Relevant applications of AI from other high-tech sectors are considered, but a deeper investigation will be conducted in Work Packages 2,3, and 4 as part of transferabiliy analysis. The deliverable provides an extensive description of concepts and definitions that are relevant in the AI and railway domain and are essential for a deeper understanding of the interconnections between all those concepts. The objective is to also provide an unambiguous and semi-formal knowledge representation with the help of conceptual diagrams such as class diagrams.

While the report is the first step towards providing a more general framework to support railway decision-makers to assess and understand AI usability, it is not in the scope of this specific deliverable to report the state-of-the-art of AI in railways since that will be addressed in the continuation of the project and in particular in deliverable D1.2.

3. Introduction

It is now widely accepted that artificial intelligence (AI) is influencing almost every bit of our life. A survey from Economic Intelligent Unit (conducted in late-2016) found that 44 per cent of executives said delaying AI implementation will make their business vulnerable to new, disruptive tech start-ups [1]. Railway is no exception. Thought AI is still at its very infancy stage for the railway sector, there are certain evidence showing that its potential should never be underestimated. For instance, reference [1] has listed several facets in railways where AI can play an important role: customer service, optimization of complex railway systems, improving safety and security of urban rail networks. Reference [1] concludes that “It is clear AI systems can be powerful and can solve the critical challenges that railways are facing today.”

Another article [2] is even more optimistic about the importance of AI for future railway industry [2]. It believes that AI will soon become a common tool used throughout the rail industry. Several topics are discussed where AI is supposed to be able to act as a game changer for the railway sector, such as capacity management, life cycle cost, maintenance, reducing error from both humans and computers, high-level automation and auto-adaptive systems.

Recent development of the application of AI to railway has already emerged. Toshiba has built an AI system that can enhance train timetabling for Greater Anglia (a train operator in the UK) [3]. Toshiba Digital and Consulting Corporation (TDX) and Mitsui, partly owned by Greater Anglia, provides digital twin software to the train operator to plan its rail timetable more efficiently and improve customer convenience. According to reference [3], TDX spent five months collecting data, including the existing timetable, train acceleration and braking performance and information about the position of signals, curves and the gradient of the line. They verified the data by going out on trains along the route to interview station and train staff so that they were aware of any human factors not present in the data.

In summary, a lot of AI experts and railway practitioners believe that the role of AI in the railway sector will become more and more influential, and a pivoting time where AI is used as a common tool will be seen in the future.

The overall objective of the RAILS research project is to investigate the potential of Artificial Intelligence (A.I.) approaches in the rail sector and contribute to the definition of roadmaps for future research in next generation signalling systems, operational intelligence, and network management.

This report is organized as follows. Section 4 introduces a taxonomy of Artificial Intelligence. Section 5 reports some relevant guidelines and regulations on AI. Section 6 provides a mapping of AI technologies that are already used, or are currently being studied, to the main railway subdomains, components or functions. Section 7 addresses some relevant AI applications in other sectors such as road, aviation and manufacturing. Finally, Section 8 concludes this deliverable.

4. A taxonomy of Artificial Intelligence

In recent years, the term “Artificial Intelligence” has increasingly become an integral part of daily life in the form of “smart” phones, “intelligent” vocal assistants, etc. However, due to its widespread use, the term AI is often improperly used as a synonym of closely related concepts such as “Machine Learning” and “Deep Learning”. Indeed, the latters are specific AI subfields characterised by the ability to learn from examples and to improve their accuracy with experience, like humans do, without being explicitly programmed.

At the beginning, it is important to define a comprehensive definition of what Artificial Intelligence (AI) actually represents. A basic definition associates AI to any machines acting in a way that seems intelligent [4] or exhibiting characteristics that are typical of human reasoning. In other words, according to this general definition, the research on AI aims at creating intelligent agents that think and act like humans. The main limitation of such definition is in the lack of a universally accepted definition of ‘intelligence’. Conceptually speaking, intelligence refers to the ability of an agent (e.g. a human being) to learn, understand, reason, plan, solve problems, etc. These aspects are very hard to quantify, describe and measure in a quantitative way. Therefore, in the context of the Artificial domain, the most common definition of intelligence is based on the ability of an agent to pass the ‘the imitation game’ (also known as Turing test), a test proposed by Alan Turing in his article entitled “Computing machinery and intelligence” (1950) [5]: a machine is deemed intelligent if it is indistinguishable from a human during a conversation with an impartial observer. An alternative definition is the one presented by the AI HLEG [6] according to which AI research refers to the concept of ‘rationality’ that is “the ability to choose the best action to take in order to achieve a certain goal, given certain criteria to be optimized and the available resources”.

Over the years, more structured and detailed definitions have been introduced. For example, in 1998 John McCartey wrote about AI [7]: “Artificial Intelligence is the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable”. Further recent definitions include:

1. “Artificial intelligence is a branch of science and as such, it can be defined as a set of computational technologies that are inspired by the ways people use their nervous systems and bodies to sense, learn, reason, and take action” (2017) [4];
2. “Artificial intelligence refers to systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals” (2018)[8];
3. “Any machine or algorithm that is capable of observing its environment, learning, and based on the knowledge and experience gained, take intelligent actions or propose decisions” (2018) [9];
4. “Artificial intelligence, the ability of a digital computer or computer-controlled robot to

perform tasks commonly associated with intelligent beings (2019)" [10].

The reported definitions are just some of those that can be found in the literature. Interestingly, they are very similar on some aspects (such as the ability to learn from experience or to take autonomous decisions) while tend to differ when it comes to defining in which 'shape' AI can be deployed (e.g. robot, software program, electronic computer, etc.). This latter point has been faced by the European Commission in its Communication on AI [8], where a reference to what AI-based systems can be is provided: "AI-based systems can be purely software-based, acting in the virtual world (e.g. voice assistants, image analysis software, search engines, speech and face recognition systems) or AI can be embedded in hardware devices (e.g. advanced robots, autonomous cars, drones or Internet of Things applications)".

All the described shades and aspects of the reported definitions are equally important and must be taken into account for the definition of a reference taxonomy of AI in railways. Nonetheless, design a definition for AI encompassing all these requirements is an insidious task that can easily result in something too specific and/or complex to be useful in a real scenario. Therefore, with the aim of framing the complexity and vastness of AI terminology, *in this project we provide a definition of AI as an integrated and structured concept represented by means of a class diagram including its most relevant aspects, children and their relations*. Referring with the term *Domains* to specific sectors (e.g., automotive, aviation, railways, healthcare, manufacturing, etc.) leveraging AI, the resulting taxonomy consists of four main classes:

- **AI Research Fields**, representing research areas that rely on AI techniques and would not exist without them, such as expert systems, data mining, pattern recognition, etc.;
- **AI Techniques**, representing methods, algorithms and approaches enabling systems to perform tasks commonly associated with intelligent behaviour (e.g., machine learning, evolutionary computing, etc.);
- **AI Applications**, representing cross-domain applications which leverage AI to improve performance and usability (e.g., computer vision, speech recognition, planning and scheduling etc.);
- **AI Adjuvant Disciplines**, represents domains at the same time benefitting from and beneficial to AI.

Figure 4.1 presents the Class Diagram relating the AI concept to techniques, research fields, applications and adjuvant disciplines according to the definitions given above. We do not aim here to develop the most exhaustive taxonomy; rather, we primarily focus on potential railway applications. Also, AI is constantly evolving and new concepts would need to be added as they emerge. The next sections will detail these aspects.

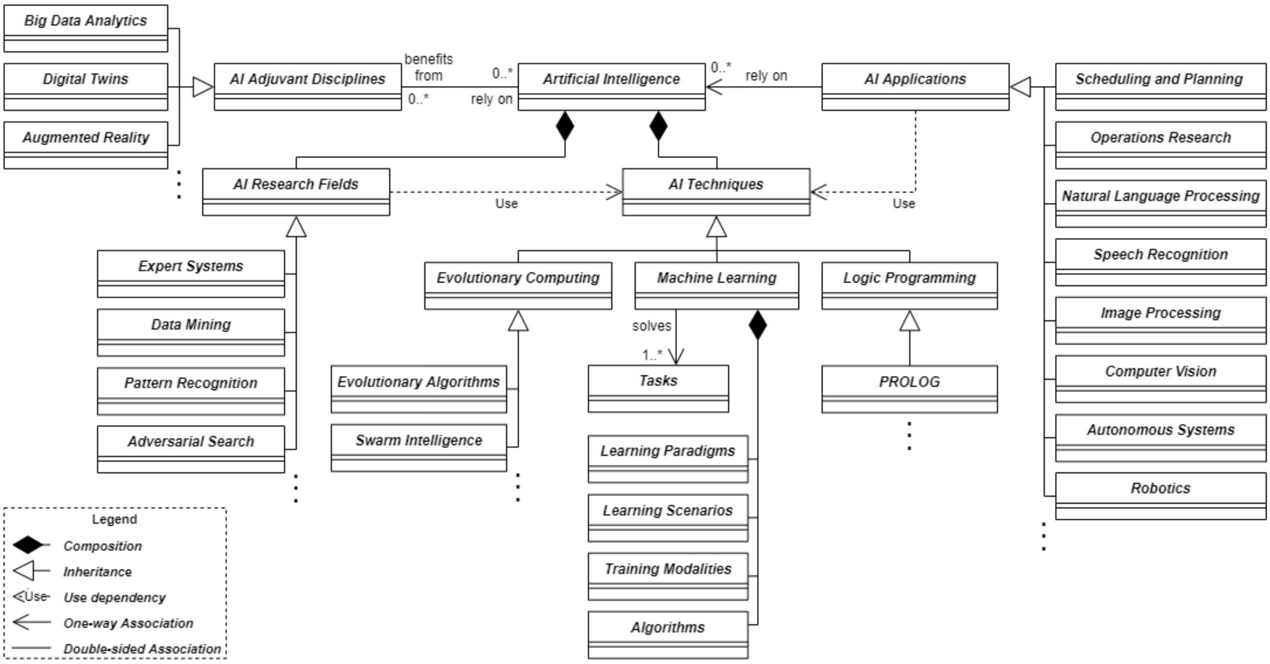

Fig. 4.1. Artificial Intelligence Taxonomy Class Diagram

4.1. AI Research Fields

The most widespread and well-known AI research fields are presented in the following. Note that given their continuous evolution (past and present), further definitions can be found in the literature.

4.1.1. Expert Systems

Whenever someone is unable to cope with a problem in a particular domain for any reason, it is possible to contact an expert from that domain who can find a solution [11]. In this sense, as defined by Kandel [12] in 1991, it can be said that 'Expert systems are computer programs that emulate the reasoning process of a human expert or perform expertly in a domain for which no human expert exists'. This is one of the various definitions of Expert Systems that can be found in the literature. Alternatively, Expert Systems can be summarized as follows: 'an expert system can be broadly defined as a computer system (hardware and software) that simulates human experts in a given area of specialization [13]'. From a more structured point of view, an expert system can be seen as the combination of a Knowledge Base and an Inference Engine. While the former contains the coded domain-specific knowledge of a problem, the latter consists of one or more algorithms to process it [11].

Different classes (or types) of Expert Systems can be found in the literature. However, to justify the *use* dependency between these Systems and what we have intended as AI Techniques, we will present just a few of them. Among the various types of Expert Systems, Rule-Based Expert Systems are considered as the simplest form of Artificial Intelligence. They represent knowledge through 'rule sets' indicating the actions to be taken in different situations [14], with these rules expressed as a set of if-then statements

[14–17]. Fuzzy Expert Systems use Fuzzy Logic in their reasoning process and/or in their knowledge representation scheme [11]; the knowledge is represented through fuzzy rules and fuzzy sets and, like in Rule-Based Expert Systems, fuzzy rules are expressed by if-then statements [15]. The great advantage of these systems is that most of the rules can be written in a language directly understandable by experts [18]. Lastly, a more sophisticated version of these systems is the Neuro-Fuzzy Expert Systems, based on the integration between Artificial Neural Networks (ANNs) and Fuzzy Expert Systems [19, 20]. This allows them to merge the learning ability of the former with the linguistic interpretation power of the latter [21]. If taken individually, the ANNs lack interpretability, while Fuzzy Systems are not able to learn; their combination can overcome their disadvantages while maintaining all the advantages [22].

4.1.2. Data Mining

Data Mining (DM), also known as *knowledge discovery from data* (KDD), is defined as the process of discovering useful information in data [23]. The term is intended to recall the work of mineworkers that have to mine the solid rock to extract the precious metals and stones. Similarly, DM gather all the means intended to analyse data (the solid rock) to extract the useful information within it (the precious stones) [24].

To this aim, the KDD process (in fig. 4.2) is composed of several steps in which Data Mining represents "an essential process where intelligent methods are applied to extract information from data" [23].

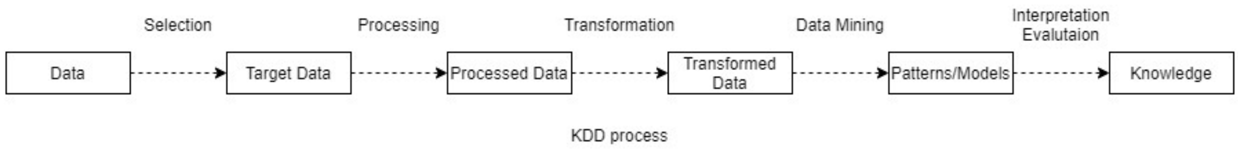

Fig. 4.2. Knowledge Discovering from Data Process

Therefore, DM offers techniques to analyse data in an automatic or semiautomatic manner, producing a knowledge that can be represented, for example, as a set of rules easy to understand by humans [25]. In particular, DM systems draw upon methods and techniques from Machine Learning (and Pattern Recognition) to extract knowledge from data [26], stored in (potentially) voluminous and heterogeneous datasets [25].

4.1.3. Pattern Recognition

As reported by Bishop in his 'Pattern Recognition and Machine Learning' [27], Pattern Recognition (PR) deals with the automatic discovery of patterns (i.e. regularities, correlations) in data through the use of computer algorithms. Thus, starting from raw data, by using pattern recognition approaches it is possible to make decisions (such as data classification) based on the extracted patterns [27, 28]. However, since PR problems are often too complex to be solved by hand-crafted algorithms, Machine Learning has always played a central role [29]. Furthermore, in most cases, input data variables are pre-processed to transform them into some new space of variable in which, hopefully, the pattern recognition problem will be easier to solve. An example of such a pre-processing state is ‘features extraction’ [27,29].

4.1.4. Adversarial Search

The use of AI in several domains is not something recent. However, the potential of AI in facing tasks usually considered impossible (or at least very hard) to be accomplished by a machine, has only recently been acknowledged by the mass audience. The merit is mostly by AI ability to beat chess[1] and go[2] world champions.

Although this happened only in 2016, tasks encompassing an environment (with its own rules and limitations) and other (potentially competing) agents are among the first application AI has been intended for [30]. This research area goes under the name of ‘Adversarial Search’ and comprises algorithms, techniques and ideas from both Game Theory and Agent-Based Modelling. Since its dawn, where only ad-hoc and very specific algorithms were available, Adversarial Search has made giant leaps, with recent approaches able to surpass even human performance thanks to the advances in Deep Reinforcement Learning [31].

In this context, an individual agent can be seen as a boundedly rational entity that acts to achieve its own interests (e.g. by maximising a revenue function) by relying on simple decision-making rules. On the other hand, an environment model can be seen as a representation of the reality according to a certain abstraction level. By combining the two, it is possible to create a model (or a computer model) that simulates the interaction, and the actions, of multiple agents to enhance the behaviour of individual agents within an environment and hopefully re-create and predict complex phenomena. Thus, Agent-based modelling can be seen as a set of techniques that allows representing individual agents considering their interactions and dynamics. Conceptually, ABM deals with the characterization of the environment behaviour and properties starting from those (learning, adaption, reproduction, etc.) of individual agents and their interaction. It is worth noting that the term Adversarial does not necessarily imply that the other entities try to minimize the revenue of the ego agent.

4.2. AI Techniques

4.2.1. Evolutionary Computing

Evolutionary Computing is a particular computing kind that draws inspiration from the natural (biological) evolution and is strictly related to Computer Science. The idea behind Evolutionary Computing is to emulate the power of natural problem solvers (e.g. the human brain, the evolutionary process) [32].

Evolutionary Algorithms (EAs) are a subset of Evolutionary Computing, a generic population-based metaheuristic optimization algorithms. Thomas Back, in his book ‘Evolu-

[1] https://www.theguardian.com/technology/2017/dec/07/alphazero-google-deepmind-ai-beats-champion-program-teaching-itself-to-play-four-hour

[2] https://www.bbc.com/news/technology-40042581

tionary Algorithms in Theory and Practice: Evolution Strategies, Evolutionary Programming, Genetic Algorithms', says that: "They [Evolutionary Algorithms] model the collective learning process within a population of individuals, each of which represents not only a search point in the space of potential solutions to a given problem, but also may be a temporal container of current knowledge about 'laws' of the environment". EAs take inspiration and from the Darwinian Theory of Evolution (hence the name) [33, 34]: the two basic concepts that EAs inherit from Darwinian theory are the 'natural selection'. i.e. the adaptation of the individuals to the environment to survive, and the 'blind variation', i.e. the random genetic that parents transmit to their child without the interference of the environment [34]. In other words, EAs use mechanisms inspired by biological evolution, such as reproduction, mutation, recombination, and selection. Moreover, they take inspiration from natural processes such as the collective problem-solving behaviour of social insects (ACO – Ant Colony Optimization), the fish schools or birds flocks behaviour (PSO – Particle Swarm Optimization) and the adaptive molecular process of the human immune system (AIS – Artificial Immune Systems) [35]. However, in the last years, algorithms such as ACO, PSO, etc., i.e. those algorithms that are inspired more by interaction than evolution, have shifted under the term of 'Swarm Intelligence' (SI) [35]. From a computer science perspective, Evolutionary Algorithms (SI included) are 'stochastic optimization algorithms' [34], or 'metaheuristics' [35, 36].

Among the various EA the most popular, i.e. the most used nowadays, are certainly: Genetic Algorithms (GAs), Evolution Strategies (ESs), Multi-Objective Evolutionary Algorithms (MOEAs), Genetic Programming (GP) and the above-mentioned Swarm Intelligence Algorithms. These, excluding the latter, although they differ from each other in various aspects, are all based on the same core processes [35]. Each of them maintains a population of search points (i.e. candidate solutions, agents) that are typically generated randomly and iteratively evolve over a series of generations given the application of variation operators and selection: Variation operators generate changes to the members of the population (i.e. they move through the search space) and, after each generation, the new object value of each search point is calculated; then, Selection removes the search points with the lowest objective values. EAs differ from other metaheuristics precisely thanks to this process [35]. In essence, candidate solutions to the optimization problem play the role of individuals in a population, and the fitness function determines the quality of the solutions; thus, evolution takes place iteratively removing solutions with lower quality.

On the other hand, as already mentioned, Swarm Intelligence algorithms are concerned with the design of intelligent multi-agent systems by taking inspiration from social interaction between mostly non-sophisticated individuals (insects, birds etc.) who are however able to perform complex tasks thanks to their collaboration [36]. Such traditional EAs, SI algorithms are also used to solve optimization problems. Such problems are often characterized by a high complexity that translates in an exponential computation time if the optimal solution is coveted (complete methods). Although SI-algorithms, as an approximate method, do not guarantee an optimal solution, they can achieve good solutions in a good time and are also easier to implement [36]. Two of the most notable SI algorithms are Ant Colony Optimization and Particle Swarm Optimization. The former is inspired by the way ants bring food to the colony. Starting randomly, the ants go out in search of food, leaving a more intense pheromone trail as the path to the destination is shorter. Once the food is found, they return to the colony leaving behind a pheromone trail which intensity depends on the quality and quantity of the resources. Thus, such a technique, given an optimization problem, starts deriving a set of possible solutions and creating a 'pheromone model' which is used to probabilistically generate solutions. ACO could be applied to solve network optimization problems [36]. The latter, on the other hand, is inspired by mosquitoes, birds etc. swarms. The fundamentals lie in particles of a swarm, that represent potential solutions, which move towards the solutions space according to its 'velocity' (rate of change) and the difference between its current position, respectively the best position found by its neighbours, and the best position it has found so far [36]. The velocity is modified according to the personal best position and the best position found by neighbour particles. This technique could be used to solve dynamic optimization problems, i.e. optimization problems which optimal solution dynamically changes [37].

4.2.2. Logic Programming

Logic Programming has its roots in the early 1970s and is based on the Kowalski idea [38] of using the 'Predicate Logic as Programming Language' (that is also the paper title) to enable a man-to-machine communication which is as user-oriented as possible. According to this idea, and given the advent of PROLOG (PROgramming in LOGic) as language programming based on it [39], it is possible to assert that Logic programming is a programming paradigm which is largely based on formal logic and any program written in a logic programming language is a set of sentences in a logical form expressing facts and rules about some problem domain. Each role is expressed as '*Result* ← *Clauses*'; it is important to note that a pure logic program is not sensitive to the order of the *clauses*, vice versa PROLOG is (thus, it can be seen as an approximation to fully declarative logic programming) [39].

However, our purpose is not to fully describe the behaviour of a program based on this paradigm, but to describe its use related to AI. In particular, Inductive Logic Programming (ILP) is the intersection between Logic Programming and inductive learning [40]. ILP allows a better approach to the ML basic purpose, i.e. extract knowledge and make hypotheses starting from examples. However, classical ML techniques have two main limits which are solved by applying logic programming. The first regards the use of propositional logic to express the learned knowledge, however, it is not always possible; thus, first-order logic could be used to address this issue. On the other hand, the second problem regards the use of previous knowledge during the training; through logic, knowledge can be well represented and, thus, used in the induction task [40].

4.2.3. Machine Learning

Machine Learning is a particular sub-field of AI characterised by the ability to learn from examples and improve with experience, as humans do, without being explicitly programmed. When provided with sufficient data, an ML algorithm can learn to make a prediction or solve more general problems. Systems supported by ML can improve the performance in specific tasks, based on previous experience or provided data that is used to train the machine to perform the desired tasks. The interest in ML comes from the fact that ML applications allow performing tasks such as classification, object detection, landmark localization, and so on, better than expert humans operators. In Tom Mitchell's Machine Learning [41], a more formal definition of ML is given: “Machine Learning is the study of computer algorithms that improve automatically through experience”.

Given its complexity and vastness, for Machine Learning we can do the same considerations we have done about Artificial Intelligence. In figure 4.3 a Machine Learning Class Diagram is proposed basing on the following rationale: “Machine Learning can solve a given *task* by means of a specific *Algorithm* trained by using a specific *Learning Paradigm* in a particular *Learning Scenario* and considering a fixed *Training Modality*”. Therefore, we can identify ML as an integrated concept composed of:

- **Learning Paradigms**, referring to the strategy used to guide the algorithm during the learning process;
- **Learning Scenarios**, describing distinctive characteristics of the task under analysis;
- **Training Modalities**, representing how the training phase is implemented;
- **Algorithms**, representing the sequence of operations used to train a specific model (e.g. SVM, ANN, etc.);
- **Tasks**, namely the goal that the user wants to obtain by using a ML algorithm.

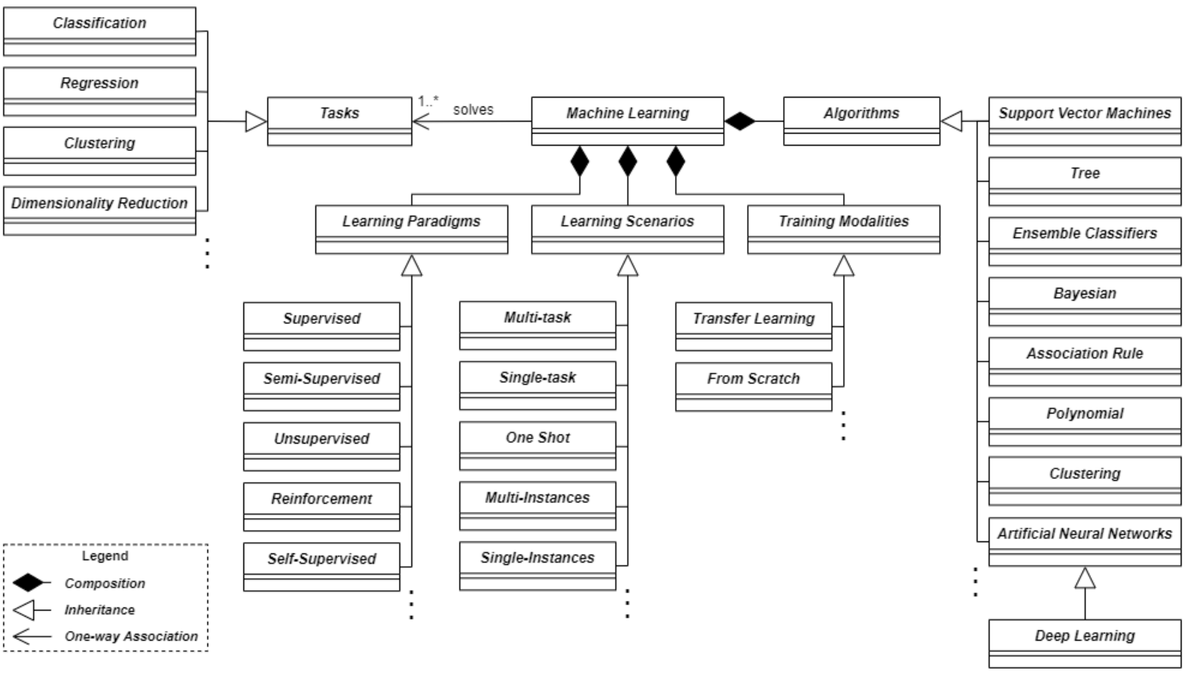

Fig. 4.3. An ML Class Diagram (extract from Figure 4.1)

An exhaustive analysis of the world of Machine Learning goes beyond the purpose of this deliverable. Therefore, we will present only the most important concepts related to it, together with a brief description.

4.2.3.1. Learning Paradigms

Machine Learning Algorithms can ‘extract knowledge from the data’. How they do that depends on the specific Learning Paradigm:

- Supervised Learning: a labelled training set is provided by an external supervisor. Each example of the dataset is a description of a situation and comes with a label (specification, class) that represents the correct action the system should take in that situation. The objective of this kind of learning is for the system to extrapolate, or generalize, its responses as to act correctly in situations that are not described in the training set [42].
- Unsupervised Learning: unlike the above paradigm, it aims at finding structure hidden in collections of unlabelled data [42].
- Reinforcement Learning: it may seem a type of unsupervised learning because it does not rely on examples of correct behaviour, however, reinforcement learning aims at making a system able to take actions that would maximize the reward or minimize the risk by using observations gathered from the interaction with the environment. In order to produce intelligent programs (also called agents), reinforcement learning goes through the following steps: (1) Input state is observed by the agent; (2) Decision-making function is used to make the agent act; (3) After the action is performed, the agent receives reward or reinforcement from the environment; (4) The state-action pair of information about the reward is stored [42, 43]. In other words, “reinforcement learning is concerned with the problem of finding suitable action to take in a given situation in order to maximize a reward” [27]. Optimal output must be found through a trial and error process; in this sense, particular action not only affects the reward but also has an impact on the successive step of the process. Reinforcement learning is a powerful kind of learning; for example, using appropriate techniques of reinforcement learning, a neural network can learn to play games like backgammon [27].
- Semi-supervised Learning: it involves the usage of clustering algorithms to solve classification or regression problems. This kind of algorithm is used when the dataset is huge and it is not fully labelled. The concept is that it is possible to solve a classification problem using a huge amount of data and reducing the labelling cost [24].
- Self-supervised Learning: another way to exploit supervised learning in an unsupervised way is represented by self-supervised Learning. Inspired by text processing, the core idea is to ‘create’ a set of labels by considering different variants (e.g. distortions, colourisations, parts, etc.) of the same instance (self) to train a model in a supervised manner on big dataset lacking the labels. This allows us to use the sample itself both as an input and a label, by exposing the relations between the parts of the instance.

4.2.3.2. Tasks

A task can be defined as a problem that can be solved through Machine Learning approaches:

- Classification: the problem of predicting the class of a given instance. Classification algorithms will learn from data a model that is capable of automatically classifying new instances. Traditionally, they need a labelled training dataset which leads to the common thinking that these algorithms are strict related to the Supervised Learning Paradigm. However, classification problems can be faced also starting from a dataset that is not totally labelled (Semi-supervised Learning) or without labels (Self-supervised).

- Regression: this problem deals with the prediction of a numeric attribute (or numeric label). A Regression algorithm produces a model that fits the data points and predicts the target numeric value of new instances.
- Clustering: the problem to split the instances into natural groups. Clustering algorithms try to group the unlabelled (in most cases) instances of the dataset into different groups according to a certain distance/similarity measure to keep together 'similar' instances and separate 'different' ones.
- Dimensionality Reduction: Some techniques can be used to reduce the size of the dataset to obtain better performances (like accuracy). A dataset can be reduced both in terms of columns (e.g. feature/attribute selection, PCA) and in terms of entries/samples (e.g. sampling). This also decreases the memory occupancy (fewer data must be stored).

Regarding Classification and Regression further considerations must be made. As for classification, it is necessary to define the type of output that could be 'deterministic' (an instance belongs to a determinate class) or 'probabilistic' (the algorithm will provide series of probabilities related to the belonging of an instance to a given class). Furthermore, classification algorithms can be divided into 'binary classifier' or 'Multi-class classifier' and some of them can work only with datasets that contain linearly separable data (data must be separable with a straight line).

4.2.3.3. Algorithms

Machine Learning involves many kinds of algorithms that differ in some characteristics (section 4.2.3.6). Given that, their exhaustive presentation goes far beyond the purposes of this deliverable. However, for the sake of knowledge, it is important to mention some of them. Note that we are considering Algorithms, not models; as defined above, an Algorithm represents a sequence of operations required to train a specific model of Machine Learning. Among the widely spread ML Algorithms we have: *Support Vector Machines* (e.g. SVM, Non-Linear SVM, Support Vector Regression, ε-SVR, etc.); *Tree-based Algorithms* (e.g. C4.5, C5.0, Model Trees, etc.); *Ensemble Classifiers* (e.g. Random Forest, Rotation Forest, AdaBoost, Additive Logistic Regression, Logistic Model Trees); *Bayesian Algorithms* (e.g. Naive Bayes, Bayesian Networks, etc.); *Association Rule Algorithms* (e.g. Apriori, FP-growth, etc.); *Polynomial Algorithms* (e.g. Linear Regression, Linear Discriminant Analysis, etc.); *Clustering Algorithms* (e.g. K-means, X-means, hierarchical/incremental clustering approaches etc.)*Artificial Neural Networks* (e.g. Multilayer Perceptron, Deep Neural Networks). Detailed analysis and explanations concerning these algorithms can be found in [27] and [24].

Deep Learning

In recent years, Deep Learning Algorithms (also known as Deep Neural Networks) have had a great impact on AI Applications as Speech Recognition, Computer Vision, and also Natural Language Processing.

Deep Neural Networks are a particular subset of ANNs characterized by a very 'deep structure', i.e. they are composed of several hidden layers. The key aspect of those kinds of networks is the automatic feature extraction. While classical ML techniques make predictions from a set of features that have been prespecified by the user, Deep Learning Techniques are able to autonomously learn the best input representation. This characteristic is typical of Representation Learning Techniques that transform features in input into some intermediate representation to make the prediction; in the case of Deep Neural Networks, features undergo different transformation steps to create complex ones. This process is known as 'Feature Learning'.

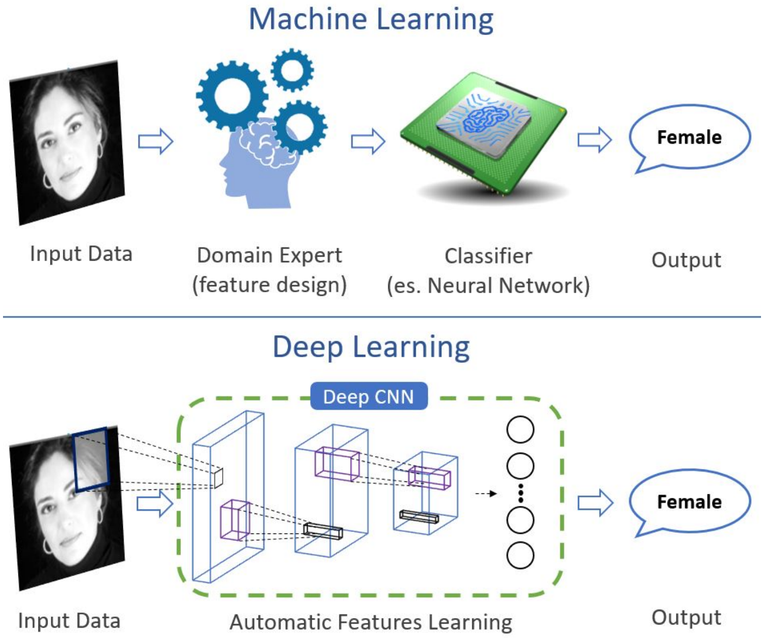

Fig. 4.4. Classical Machine Learning vs Deep Learning

The key factors that contributed to the spread of deep networks are, above all, the huge amount of data not available before and the easy availability of high-speed computation in the form of the Graphics Processing Unit (GPU). Deep networks, being characterized by several hidden levels, are characterized by a large number of parameters. Their optimization and the iteratively processing of the massive training dataset require a huge computational power that has been one of the biggest technical limitations in deep networks. Training requires a lot of time, fortunately, in the last period, the evolution of General-Purpose GPU (GP-GPU) has brought great benefits by greatly reducing the training times of these networks.

There are different kinds of Deep Neural Networks. From Deep Convolutional Neural Networks (the 'deep' counterpart of the Multilayer Perceptron), that are widely used in problems that involve image analysis; to Recurrent Neural Networks that are neural networks in which connections between neurons can form cycles, particularly useful in processing sequences of data, thus to solve learning problems as writing recognition, speech recognition and so on; to Deep Boltzmann Machines and Deep Belief Networks, which are two types of Stochastic Deep Network in which the units correspond to random variables; to Autoencoders, networks used most of all for unsupervised training that is able to learn an efficient coding of its input, the concept is to reconstruct the input through intermediate representations that compress or reduce their size [24].

4.2.3.4. Learning Scenarios

Learning scenarios indicate the characteristics of the task under analysis in terms of the number of tasks, the number and type of instances, etc.; In other words, the boundary conditions of the learning process.

Single-task Learning Scenario represents the base case of learning, indeed the aim is to build a model through an ML Algorithm which can solve a particular task. The opposite side of the coin is represented by the Multi-task Learning Scenario which rationale is to train tasks in parallel while using the same and shared data representation. However, separating learning could have some disadvantages as there could be a disparity of knowledge between the various tasks, i.e. a given task could learn something useful for another task but that this has not learned; but, this is how Single Task Learning works. On the other hand, Multi-task Learning aims to build the same model, so there is no disparity of knowledge, that is able to perform different tasks [44]. A suitable example can be done considering Neural Networks (whether Deep or not): if N identifications need to be performed (shapes, shadows, text, orientation, etc.), Single Task Learning expects to create N different networks (one for each task); otherwise, Multi-task Learning expects to create a single network with the same single (or multiple) hidden layer and N outputs, in this way same features, thus knowledge, can be used for all the N tasks [44].

These are not the only possible Scenarios. Also the number and type of the dataset samples can define different Scenarios. For the sake of knowledge, we can consider Single-Instance Learning Scenario (i.e. each instance represents an independent event), Multi-Instances Learning Scenario (i.e. instances are grouped in bags, each bag represents a different event and instances belonging to the same bag represents the same event described form different points of view), One-Shot Learning Scenario (i.e. the learning is performed on one or few samples), and so on.

4.2.3.5. Training Modalities

Learning Modalities indicate how the training phase is implemented. Among the others modalities, a Machine Learning Model can be built *From Scratch*, i.e. the ML Algorithm on a given dataset and the model (and, thus, its parameters) is built starting from those data, or through Transfer Learning Techniques.

The main problem of the common Machine Learning Techniques lies in their basic assumption, i.e. the training and test set are derived from the same feature space and, especially when it comes to numeric features (or attributes), it is assumed that the same feature in both the sets follows the same distribution. The problem arises when, and if, the distributions change; in this case, the model needs to be retrained but this is often expensive and, in some cases, impossible. This is the basic concept on which the Pan's et Al. paper "A survey on Transfer Learning" [45] is based, according to which the use of Transfer Learning (TL) techniques could remedy this issue. Conceptually, these techniques involve transferring knowledge learned in previous tasks to novel tasks, or else through TL techniques it is possible to transfer knowledge from a source domain or task to a target domain or task; practically, this is what people do to solve new problems in a faster and better manner [45]. Note that the domain indicates the origin field of the problem, otherwise the task indicates the problem itself that must be solved.

Generally speaking, Transfer Learning goes beyond the concept of both Supervised and Unsupervised Learning referring to these paradigms to cope with different situations. Indeed, reference [45] defines three different TL approaches considering different kinds of source and target domains and tasks:

1. In Inductive Transfer Learning source and target tasks are different, otherwise it doesn't matter if the source and target domains are similar or not. However, to induce a predictive model trained on the source domain, labelled data in the target domain are required;
2. In Transductive Transfer Learning the source and target tasks are the same but domains are not. In particular, this approach is used when labelled data are not available in target domains while they are in the source domain.
3. Unsupervised Transfer Learning focuses on solving unsupervised problems (e.g. clustering, dimensionality reduction, etc.) in the target domain. It is similar to the first approach but tasks, even different, are related. Differently, there are no labelled data available in both source and target domains.

As regards the TL, also in this case, among the various ML Techniques, Deep Learning is the one that benefits most from it. As we will explain in 4.2.3.3, there are different types of Deep Neural Networks. Considering the most spread CNNs, we can assert that they can be trained from scratch, i.e. a CNN can extract significant features and the classification model directly from the dataset in input, or through Transfer Learning approaches. This alternative derives from the fact that the training from scratch is subject to two problems which in some cases cannot be ignored:

i. Quality and size of the dataset: to well train a CNN, or a Deep Neural Network in general, i.e. properly tune millions of parameters, *in many cases* a huge dataset is required. The problem lies in the fact that it is not always possible to find proper examples, thus these kinds of datasets are difficult to build. Moreover, its construction will be expensive and time consuming since those examples must be labelled too. A solution could be represented by data augmentation techniques, however, also in this case, directly learning so many parameters from only thousands of training samples will result in overfitting [46].

ii. Computational Power: to train a Deep Network in a reasonable time it is required a proper computational power that is not always achievable.

Through Transfer Learning it is possible to obtain on small datasets more or less the same performances of CNN trained on large-scale datasets [46]. The purpose is to train a network on a 'base' dataset and task, and then 'transfer' learned features to a second network to be trained on a 'target' dataset and task. Once trained a base network, its first layers are used as first layers of another (target) network. At this point, one can choose how to proceed [47]:

i. The first approach consists in training the target networks on its dataset and 'fine-tune', during the training, also the features copied from the base network;

ii. The second approach consists in 'freeze' the copied features leaving them unchanged during the training phase. In this case, pre-trained CNN can be seen as a feature extractor. It is important to note that this process will work if the learned features are both general and suitable on both base and target datasets.

To understand which is the best approach to use, considerations must be made concerning the size of the target dataset and the number of parameters in the copied layers. If the target dataset is small and the copied layers are characterized by a significant number of parameters, fine-tuning could lead to overfitting, thus the latter approach could be better than the former; otherwise, in case the dataset is sufficiently large or the number of parameters is small, then fine-tuning can be considered [47].

Lastly, it is important to note that CNNs usually work better the bigger the input dataset is. Since adding new samples, as seen, may not always be possible, to increase the size of the dataset, data augmentation techniques can be used to provide new images starting from those already present in the dataset by applying simple transformations (e.g. translation, rotation) [24, 46].

4.2.3.6. Characteristics of ML Techniques

In addition to what has just been described, ML Techniques differ on the kind of dataset they can work with, performances, stability and reproducibility, explainability, and so on. All these concepts will be defined below.

Dataset characteristics

ML algorithms differ for the type of the dataset they can work with. First of all, a dataset can contain tabular data or can be composed of images and sequences; we will refer to this as Dataset Structure:

i. Tabular Dataset: the dataset is composed of independent instances described by a set of attributes. This is the most popular structure used by many algorithms.

ii. Image Dataset: generally, Deep Learning algorithms (as CNN) work with this kind of dataset.

iii. Sequential Dataset: the order of the data matter, e.g. time series and text.

For Tabular Datasets, further consideration must be made. Each instance is described by a series of 'Attributes' each of which can be nominal or numeric. In some cases the whole dataset must have only numeric or nominal attributes, in other cases, it could have attributes of both types.

Furthernmore, datasets can be labelled or unlabelled. That means that a class, in case of a labelled dataset, is associated with each instance. That class (label) can be nominal, for classification problems, or numeric, for regression problems. Otherwise, a dataset can also be hybrid, as already mentioned for the Semi-Supervised Learning Paradigm (only a few instances are labelled).

For classification problems, it is important to know if the classification technique can work with not balanced dataset; e.g., for binary classification problems, a dataset could have many instances that belong to a particular class and few instances that belong to the other class (balanced datasets ideally have a 50/50 ratio).

Lastly, there are cases in which the instance in the tabular dataset could be grouped into 'bags'. In this case, each instance in the bag describes the same item from a different point of view. For a classification problem, e.g., in case the tabular dataset is composed of single independent instances, a class is associated with each of them; on the other hand, for the case that we are considering now, a class is associated with each bag.

According to what just said on Tabular Datasets, the following scheme can be made as given in Fig 4.5.

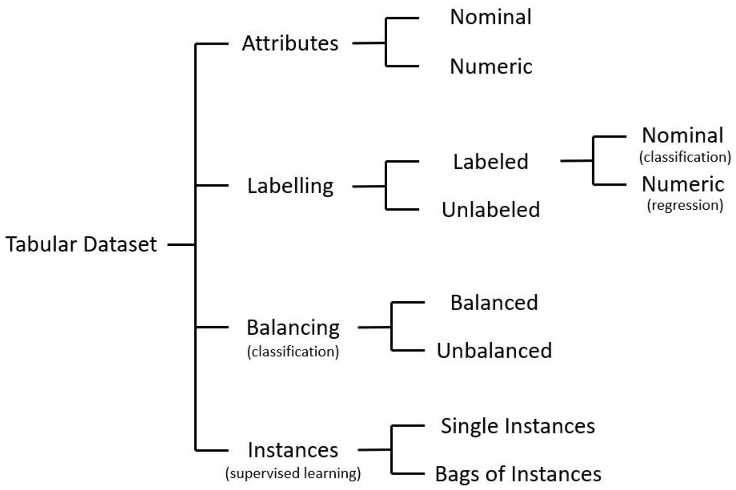

Fig. 4.5. Scheme for Tabular datasets

It is important to note that knowledge can be easily extracted from Image dataset through CNNs, or other Computer Vision and Image Processing approaches, and from tabular dataset through classical ML Algorithms considering the data points *independent and identically distributed (i.i.d.)*. However, for particular applications the i.i.d. assumption will be a poor one [27]. An example lies in the handling of Sequential data, where the temporal sequence of the entries matters and represents a part of the whole knowledge (e.g. financial forecasting); treating them as i.i.d. will lead to the loss of sequential pattern. The main issue in such cases lies in the fact that if we want to model these events, it is not possible to consider that a certain observation depends on all the previous ones since the model's complexity will grow without limits. *Markov Models* can help to face this issue since they allow us to consider a given prediction dependent on the most recent observations only [27].

For the sake of knowledge, when it comes to *Discrete* sequential data, the *first-order Markov Model (chain)* represents a simple and probabilistic model. It assumes that a symbol can be predicted using its conditional probability given the preceding one and, usually, the conditional probabilities used in such models are always the same for each chain state. Higher-order Markov chains can be easily derived from the first-order simply considering the conditional distribution of the N antecedent symbols. These are generally named *N-gram models* (i.e. (N-1)-th order Markov Models) and are extremely useful for NLP tasks (e.g. machine translation, speech recognition, etc.) [24].

Other models that are extremely used to solve such tasks are the *Hidden Markov Models* (HMM). By definition, "an HMM is a doubly stochastic process with an underlying stochastic process that is not observable (it is hidden), but can only be observed through another set of stochastic processes that produce the sequence of observed symbols" [48]. Unlikely regular Markov Models, an HMM represent a process through a sequence of named state and the output is represented by a sequence of state names; moreover, a probability distribution of possible output is associated with each state and the same output can belong to more than one state [30].

Theoretical Performances

One of the main difficulties in comparing various algorithms that learn from examples is the lack of a formally specified model by which the algorithms may be evaluated [49]. A way to understand the potential of algorithms, and maybe rank them, is to individuate and analyze some generic characteristics that allow us to theoretically quantify the algorithm's performances.

What we are interested in are the Computational Complexity and Evaluation Metrics. However, as mentioned, all of these can be approximated only at a theoretical level since the real values depend on a lot of factors (such as dataset quality, environment, etc.):

i. Computational complexity: it concerns the time that an algorithm employs to train the model and perform a prediction. More specifically, we can divide it into Training Computational Complexity and Prediction Computational complexity. Computational Complexity will be outlined using the 'Big O Notation': it gives an approximation of the complexity (constant, linear, quadratic, etc.) in terms of the samples' number, attributes number, and so on. However, for Deep Learning Techniques, as we will see, the complexity calculation will be not simple or immediate.
ii. Theoretical Evaluation: 'Theoretical' because real performances depend on a lot of factors; thus, to achieve them some on-field experiments are needed (real data, real conditions, etc.). It should be noted that each class of algorithms has its metric: for classification problems, we will consider Accuracy, otherwise for regression problems we will consider the Mean Squared Error (MSE).

Stability & Reproducibility

The question we must answer is: does the output of the algorithm change as the conditions change? About that, there are two kinds of variability that we must consider:

i. Stability: an algorithm is unstable if training the model with a slightly different training set causes the model to change. This means that even with the inclusion of new training instances, the resulting model could vary considerably and, with it, the prediction. This is what happens, for example, to decision trees. We will see that there are some algorithms (Ensemble Learning) that can only work with unstable algorithms. On the other hand, an algorithm whose model does not change is called stable.
ii. Reproducibility: “Reproducibility in empirical AI research is the ability of an independent research team to produce the same results using the same AI method based on the documentation made by the original research team” [50]. Reproducibility is a problem that affects all the scientific world [51], and not only Artificial Intelligence. A large number of results published in papers today are not reproducible, thus are difficult to validate [50]. Problems, in this sense, derive from the non-sharing of data and source code, from the lack of good documentation [50, 52] and the non-replication of the experiment in the original lab [53]. Unfortunately, for Artificial Intelligence, more precisely for Machine Learning, non-determinism often resides in training procedure; error is highly sensitive to the code, the data, and the hyperparameters of the learning model [52].

Explainability and Interpretability

The Explainability topic will be discussed in section 5.7. Here, we just mention the possibility to create a ‘Comprehensibility ranking’ as follows:

i. Transparent level: the model is transparent and the knowledge is expressed by rules or models that are easily understandable by humans.
ii. Tricky level: the comprehensibility is a little bit tricky and some techniques are required to get human understandable models.
iii. Black-box level: the model that comes out from the technique is totally black-boxed.

ML Characteristics Overview

Based on the above analysis, we summarise all the outlined characteristics. Firstly, let consider the generic features, i.e. those that can be taken into consideration for all the possible algorithms:

i. Learning and Purpose:
   a. Task - Classification, Regression, Clustering, Dimensionality Reduction;
   b. Learning Paradigm - Supervised, Unsupervised, Reinforcement, Semi-supervised, Self-Supervised, etc.;
ii. Dataset Characteristics:
   a. Dataset Structure - Tabular, Image, Sequence;
   b. Attributes Type - Only Nominal, Only Numeric, Nominal and Numeric;
   c. Dataset labelling - labelled, Unlabelled, Hybrid;
   d. Label Type - Nominal, Numeric;
   e. Instance Type - Bags, Single;

iii. Theoretical Performances:
   a. Computational Complexity - Big O notation;
   b. Theoretical Evaluation - approximation of Accuracy (classification) or MSE (regression).
iv. Reproducibility & Stability:
   a. Stability - Stable, Unstable;
   b. Reproducibility;
v. Comprehensibility Ranking:
   a. Comprehensibility Level - Transparent, Tricky, Black-box;

Furthermore, there are other features depending on the purpose:

vi. Classification Problems:
   a. Dataset Balancing - Required, Not Required;
   b. Linearly Separable Data - Required, Not Required;
   c. Linearity - Linear, Non-linear;
   d. Output Type - Deterministic, Probabilistic;
   e. Classification Type - Binary, Multi-class.
vii. Regression Problems:
   a. Linearity - Linear, Non-linear.

4.3. AI Applications

4.3.1. Scheduling and planning

Scheduling and planning is a decision-making process that is used on a regular basis in many manufacturing, services and transport industries [54]. It deals with allocation of resources to tasks over given time periods and its goal is to optimize one or more objectives. The resources and tasks in an organization can take many different forms. The resources may be machines in a workshop, runways at an airports, crews at a construction site. The tasks may be operations in a production process, take-offs and landings at an airport, executions of computer programs. The objectives can also take many forms, such as minimizing completion time of the last task, or the number of tasks completed after their respective due dates.

Scheduling and planning can be addressed using various AI Applications, for example, Evolutionary Algorithms [55], Logic programming [56], etc. already described in section 4.2.

4.3.2. Operations Research

Operations Research (OR) is considered as a scientific approach to decision making which involves the use of mathematical model(s) to represents real issues, usually under specific conditions (e.g. scarce resources) [57].

Typically, an Optimization Model, more specifically mathematical optimization or mathematical programming, consists in finding the best available solution (in terms of value) from a set of alternatives [58] in relation to an objective function closely related to the problem itself. Therefore, the objective function can vary from problem to problem, in addition, each of these problems may have to do with more than one function. Such problems deal with different disciplines, therefore mathematics has been interested in the development/research of solution methods for centuries [59].

Optimization problems span from the minimization/maximization of a cost or loss function, to network optimization problems such as the research of the minimum path or the path with the minimum cost, to dynamic optimization problems in which the optimal solution dynamically changes, and so on. However, as mentioned before, OR also deals with algorithm that are able to face these problems. For the sake of knowledge, Contraint Programming (CP) is defined as a "powerful paradigm for solving combinatorial search problems that draws upon a wide range of techniques from artificial intelligence, computer science, and operations research" [60]. Constraint programming involves both mathematical and computer programming. In the former case, a real-world problem must be modelled through a set of decision variables and related constraints, then a constraint solver can find the solution in terms of decision variables' values, respecting the imposed constraints. In the latter case, i.e. computer programming, the user must define a strategy to search for a solution [60]. However, this kind of 'programming' differs from the imperative one since it does not specify a sequence of steps to execute, but rather the properties that the solution must achieve. Anyhow, CP is not the only approach that is based on AI. Indeed there are others approaches based on AI Techniques such as Evolutionary Algorithms and Swarm Intelligence [61], Reinforcement Learning [62], etc., already described in previous sections, that can be used to face OR problems.

4.3.3. Computer Vision

Computer Vision (CV) is often considered an AI discipline addressing AI applied to the visual world [63]. Such a definition suggests that CV would not exist without AI. However, that might not be totally correct. Indeed, several CV applications (e.g., making computers able to perform tasks based on the analysis of visual inputs such as images) have been designed long before the development of modern AI techniques and do not rely on intelligent decision making (e.g., edge detectors). According to the taxonomy defined in this report, CV can be considered as an AI Application.

Computer Vision enables computer systems to automatically see, identify, and understand the visual world by mimicking human vision [64]. This makes a great contribution to AI since it allows intelligent agents to acquire knowledge other than that derived from other non-visual sensors [65]. Conceptually, CV tries to describe the world as seen through images and reconstruct its properties [66]. On the other hand, because of both the complexity of real-world modeling and a large amount of required knowledge, CV systems can greatly benefit from the application of ML techniques; Machine Learning algorithms can be applied both for improving the perception of the surrounding environment and for bridging the gap between the representation of the environment and the representation needed by the system [67]. In recent years, Convolutional Neural Networks (CNN) have become a de-facto standard in computer vision [64]. Moreover, Computer Vision benefits from Image Processing techniques to extract information from images [67, 68].

Both CV and ML techniques are already in use (or under testing) in several domains. For instance, in automotive, these applications allow cars to drive autonomously on roads they have never seen before by also using a variety of sensors to perceive their surroundings, such as Lidar, sonar, radar, GPS. Systems based on artificial intelligence used in autonomous transportation can substantially reduce the number of accidents and, as a result, reduce the number of fatalities [4].

4.3.4. Image Processing

Image Processing includes all those techniques and methods that, starting from an image, aims to emphasize some its aspects producing a modified or processed one; in other words, such a process filters images to extract certain information from them [69]. Moreover, Image Processing represents the whole image analysis life cycle since it includes phases as image acquisition, image enhancement, image pre-processing and image segmentation [70, 71].

With the advent of Deep Learning, as happens for Computer Vision, also Image Processing has been often strictly related to AI. However, Image Processing techniques does not necessarily have to rely on DL. For the sake of knowledge, we can consider the Anisotropic Diffusion technique that aims to reduce image noise without damage others significant information (e.g. edges, indeed it can be used to perform Edge Detection too). Such technique, introduced by Perona and Malik [72], lies on partial differential equations (PDE) [73], and not on AI. However, when it comes to filtering images, mostly in a convolutional way (use the same filter that is smaller than the image sliding it on the whole image), CNNs play a very useful role and are widely adopted.

4.3.5. Natural language processing

Natural Language Processing (NLP), as the name suggests, deals with the analysis of the human language and its informatic treatment. Thus, NLP can be seen as a subfield of linguistic, but also of computer science and information engineering, and, moreover, it can benefit from the AI (sometimes NLP is seen as an AI subfield). NLP involves several possible analyses that can be done on natural language, both on the text and the spoken side, such as speech recognition, natural language understanding, natural language generation, and so on. Note that NLP does not study the language itself but develops a computer system to communicate by natural language.

One of the important applications of NLP is *information extraction* which extracts explicit or implicit information from text. The outputs of systems can vary, but often the extracted data and the relationships within it are saved in relational databases [74]. Commonly extracted information includes named entities and relations, events and their participants, temporal information, and tuples of facts. Second is *Text Generation*. Many NLP tasks require the generation of human-like language. Summarization and machine translation convert one text to another in a sequence-to-sequence fashion. This could be useful for automatically generating information messages to passengers, particularly in exceptional conditions due to disruptions and unexpected traffic changes. Finally, *question answering* (QA) gathers relevant words, phrases, or sentences from a document. QA returns this information in a coherent fashion in response to a request.

4.3.6. Speech Recognition

Speech Recognition is the audio-based version of NLP. The task, desiderata, problems and aims are very similar, with the main differences laying in the type of the data to analyse. These similarities allowed Speech Recognition to leverage experience in NLP to design solutions able to cope with the different issues associated with linguistic analysis. Hoever, the different type of input data (sequence of characters for NLP and audio streams for Speech Recognition) results in the possibility of using techniques from other domains (e.g. CNN from image processing) that are not really suited for text processing [75]. The flip-side of the coin is represented by some difficulties that Speech Recognition must take into account, such as background noise or voices from different speakers [76].

4.3.7. Autonomous Systems

According to the definitions at the beginning of this taxonomy, Intelligence, in the artificial world, means the ability to analyse the surrounding environment and then perform actions to reach particular goals. Considering this, and based on Pratihar's et al. [77], a system can be called 'autonomous' when it can independently perform an assigned task (without human intervention). However, as also reported in their book, not all the intelligent systems are also autonomous: an Intelligent Autonomous System is defined as an autonomous system that is able to make decisions on-line, in an independent manner, depending on the demands and particular conditions. Nowadays, Intelligent Autonomous Systems are involved in many domains to solve different type of tasks: from self-driving vehicles and drones (both in civil and military domain), to robots in deep sea and space (or high-risk operating environment in general), to manufacturing robots, and so on. The enabling technology that has allowed the widespread diffusion of these systems is certainly AI (mostly in its Machine Learning and Deep Learning form), but also Big Data since it allows the availability of large datasets from different domains, are important drivers of these developments [78]. Although Intelligent Autonomous systems can be so powerful and versatile (i.e. cross-domain), they are affected by certain problems mostly related to ethics, trustworthy and explainability [79] since they derive from AI. As autonomous, the actions of these systems no longer resort to specific programming by human operators, instead they can rather learn and adopt new strategies as they 'live' immersed in their operating environment. This means that they will reach a point where their actions may no longer be intelligible [78]. Therefore, since they have to cohabit with modern society, it is important that their behaviour respects ethical, legal and social norms [80].

4.3.8. Robotics

Robotics is the branch of technology that deals with the design, construction, operation, and application of robots. The evolution of robots goes from those of the first generation (Programmable robots) which always repeat the same program in strictly defined conditions, to those of the second generation (Adaptive robots) that are able to orient themselves independently and to adapt to the surrounding environment, up to the third generation robots (Intelligent robots) which, equipped with various sensors and a micro-computer that processes information, can adapt their actions according to the situations; note that these kinds of robots can coexist and each of them is used where possible and necessary [81]. Therefore, not all robots are intelligent and, being mechanical, they do not need to have a humanoid shape (just think of industrial mechanical arms). An Intelligent Robot "is a mechanical creature which can function autonomously"; "Intelligent" implies that the robot does not do things in a mindless, repetitive way [82]. From here, it is possible to derive a definition of *AI Robotics* as the application of AI techniques to robots, thus they will be able to learn, plan and solve problems [82].

4.4. AI Adjuvant Disciplines

Beside what has been already analyzed, there are other disciplines (or concepts, or topics) that can be considered when it comes to AI. As fore the above concepts, the aim is not to be exhaustive, otherwise we are interested in what had already been used in the rail sector, and what we consider important for it, at the best of our knowledge.

AI Adjuvant Disciplines differ from AI Application, according to our definitions, since in this case a double-sided association is possible. It means that AI can benefits from such Disciplines meanwhile them can rely on AI. Clear examples are Digital Twins, Augmented Reality and Big Data Analytics.

4.4.1. Digital Twins

Digital Twins gives a huge contribution to the data acquisition when it comes to AI. Indeed, if the system we want to build is AI-based (precisely, ML- or DL-based) data collection is one of the most important issues that we should deal with, especially in safety-critical domains. The main difference between Machine Learning and Deep Learning techniques lies in the feature extraction, if the ML algorithms require a structured dataset (for which the features have already been identified, perhaps by domain experts), the DL techniques are able to automatically and independently learn both the most significant features and the model. The problem is that, in many cases, these techniques require a wide dataset to achieve great performances (in terms of accuracy, or other related metrics), and even if it were not so, the issues relating to data collection persists in those cases in which the act of collection itself could harm people or infrastructures. Just think of any system whose failure could cause a serious accident, collecting data on the field would be impossible, or at least unethical. On the other hand, also the maintenance could involve many risks for the staff, indeed, nowadays, we are moving towards the so called "smart maintenance", i.e. proactive on-line maintenance that involves the use of IoT sensors (or other 'smart' data collection mechanism), in order to reduce these risks and obtain a predictive maintenance instead of a reactive one. However, to predict a fault, data about its characteristics are required but, in many cases, the occurrence of the failure could lead to very unpleasant consequences. To face these problems, and not only, the use of Digital Twins could be an excellent solution.

In [83] the authors provide a literature review and a classification about Digital Twins (DT) in manufacturing. Among the other concepts, it presents few different definitions of DT that could be summarized as follow: a Digital Twin is a virtual representation of a physical system that is linked to and synchronized with it through mathematical models, sensors, etc. Thus, a Digital Twin is nothing more than a Digital Model that has a physical counterpart. Therefore, all the simulation techniques can be used to test the system's reaction to certain inputs in order to collect information about faults without hurt anyone or anything. In literature, different papers can be found about the implementation of Fault Injection techniques [84] in order to record data relating to the malfunctions and perform Predictive Maintenance [85, 86] or Fault Diagnosis [87, 88].

4.4.2. Augmented Reality

As defined by Azuma in his work 'A Survey of Augmented Reality' (1997) [89], Augmented Reality (AR) is a variation of Virtual Environments (VE) which technologies completely immerse a user in a synthetic environment that modify the real world removing objects or adding virtual ones, superimposed upon or composited with the real world, which displays information that the user cannot directly detect with his own sense. A more recent state-of-the-art has been provided by Carmigniani et Al. [90] in 2011, including a classification of possible AR systems in fixed indoor (or outdoor) systems, mobile indoor (or outdoor systems) and mobile indoor and outdoor systems. A mobile system allows the user to move around without constrains, otherwise, a fixed system does not. The choice lies in the particular application that has to be implemented. Indeed, AR systems can be used to improve or solve different issues in many domains such as design and manufacturing [91, 92], industrial [93, 94], automotive [95, 96], even education [97], and so on. Moreover, AR systems also produce great benefits for maintenance activities. For the sake of completeness, it must be indicated that in this case, as also in many others already mentioned, the main concept, which is always linked to AR, is that of Mixed Reality (MR), i.e. a 'kind of' reality that is interposed between the virtual and the real environment [94], where real and virtual objects 'coexist'. Operators equipped with MR devices, they can be supported in quality control inspections [98], remote maintenance [99, 100], or even trained to improve their assembly and maintenance skills under software or human expert supervision [101].

4.4.3. Big Data and Big Data Analytics

When it comes to Big Data Analytics, a brief overview on Big Data seems to be mandatory. As we have seen in the Chapter 6 introduction, a unique definition for Artificial Intelligence cannot be identified, however, in the case of Big Data we have almost the same definition that evolves in time [102]. Conceptually, Big Data deals with the progressive increase in available data, and it is precisely on some characteristics of these data that the most agreed definition of Big Data is based. Indeed, this definition, named 'The 5 V's (or 5+1 V's) of Big Data', mostly deals with data characteristics. According to this, to talk about Big Data following characteristics must be considered:

- Volume, i.e. a large amount of collectible data;
- Velocity, i.e. collect data as fast as possible, the acquisition must face data growth;
- Variety, i.e. collect data from multiple sources;
- Veracity, i.e. collected data must be clear, truthful, reliable etc.;

- Variability, i.e. the structure and meaning of data could change, evolve.

Lastly, the sixth V is quite important: Value. Collected data must add value to the business or research. Indeed, nowadays, data are considerated a source of economic (for business [103]) or knowledge (for research, e.g in healthcare [104]) gain. However, rough data are worthless in any case. Even if the acquisition, extraction, and integration phases are extremely important to obtain the 5 V's above, to 'give' value to the data, they must be properly analyzed. Here is where the Big Data Analytics Techniques play an important role.

According to Russom [105], "Big Data Analytics is where advanced analytic techniques operate on big data sets". Normally, Data Analytics techniques are used to extract relationships, rules, or patterns between the data [106, 107] in order to perform a decision-making process. However, prediction techniques could also be used to perform, for example, business trend prediction; moreover, clustering algorithms can also be used. Anyhow, problems with the use of ML techniques for Big Data Analytics arise given the 'variety' characteristic of the data. Generally, in ML input data are 'standardized' in order to have an equivalent structure, thing that is very complex to do for Big Data. This does not mean that ML techniques cannot be applied, but they must be revisited and/or adapted [106].

5. Guidelines and regulations on AI

5.1. The European Viewpoint

One of the first steps done by the European Commission (EC) was to define what AI is and in what shapes it can be implemented. In particular, in April 2018, the EC released the final version of “Artificial Intelligence for Europe” [108] and, shortly later, “Artificial Intelligence: A European Perspective” [109] with the aim of laying the foundation for a European initiative on AI. On the first page the document defines what AI systems are in a simple but precise and complete manner that can be summarised as:

“AI-based systems can be purely software-based, acting in the virtual world (e.g. voice assistants, image analysis software, search engines, speech and face recognition systems) or AI can be embedded in hardware devices (e.g. advanced robots, autonomous cars, drones or Internet of Things applications).”

The document defines a set of basic guidelines to boost and support the AI initiative, analysing the European Union’s position within an international landscape. The key faced aspects can be summarised as follows:

- The development of the infrastructure needed to support the AI initiative, in terms of funds, public/private parties cooperation and data availability. The latter point is framed within the context of the General Data Protection Regulation (GDPR) [110], with the aim of providing companies and research entities with the data needed, while enforcing privacy and fair data usage (section 5.2);
- The definition of rules, regulations and guidelines *to ensure an appropriate ethical and legal framework*. This is a crucial point which will guide the EC to pursue a sustainable approach to this technology;
- The development and promotion of standards for safe and liable AI, especially in the context of autonomous decision-making.

The document ends by defining a timeline (figure 5.1 for the development and release of the documents addressing these and other aspects central for the European AI infrastructure.

To further help in defining AI and its applications, in the same period the EC was also asked for a brief report on the state-of-the-art in AI. The resulting report [4] highlights how AI has moved from being a pure academic area of study to a set of mainstream technologies having a substantial impact on everyday life. On this line, the work reports on only the growing trend of AI-based applications, but also some very important examples of AI applications that are already in use, such as chat-bots.

As part of and to support the implementation of the “European Strategy on Artificial Intelligence”, in June 2018 the European Commission set up the *High-Level Expert Group*

The Commission will:

- set a framework for stakeholders and experts – the European AI Alliance – to develop **draft AI ethics guidelines**, with due regard to fundamental rights, **by the end of the year**, in cooperation with the European Group on Ethics in Science and New Technologies;
- **issue a guidance document on the interpretation of the Product Liability Directive** in light of technological developments **by mid-2019**. This will seek to ensure legal clarity for consumers and producers in case of defective products;
- publish, **by mid-2019**, a **report on** the broader **implications** for, potential **gaps in and orientations for,** the **liability** and **safety frameworks** for AI, Internet of Things and robotics;
- support research in the development of **explainable AI** and implement a pilot project proposed by the European Parliament on **Algorithmic Awareness Building**[63], to gather a solid evidence-base and support the design of policy responses to the challenges brought by automated decision-making, including biases and discrimination (2018-2019); and
- support national and EU-level **consumer organisations and data protection supervising authorities** in building an understanding of AI-powered applications with the input of the European Consumer Consultative Group and of the European Data Protection Board.

Fig. 5.1. Timeline defined by the EC for AI infrastructure development.

on Artificial Intelligence[1] (AI HLEG). The group consists in 52 experts, identified by an open selection process, comprising representatives from academia, civil society, as well as industry. The AI-HLEG is also the steering group for the European AI Alliance, a multi-stakeholder forum for engaging in a broad and open discussion of all aspects of AI development and its impact on the economy and society.

5.2. General Data Protection Regulation

The General Data Protection Regulation (GDPR) is a document introduced by the European Parliament in 2016, consisting a set of rules to regulate the activity of any company operating with data belonging to citizens from any European country [111]. The document lays the foundation for the right of any European citizen to be the only owner of any data associated with his/her life and activities. To this aim, GDPR is structured in a series of points and examples that cover a vast set of situations. It is important to note that this regulation forces any company (European or not) to be compliant with it if it manages European citizens' data.

This document is of a crucial importance for any AI-based project, since the data used to train the models must be collected, processed, stored and managed in a fully GDPR compliant manner. Aspects to be taken into account will change based on the type of data relevant projects relay on. Among all, we present some articles to be noted for applications of (brief extracts form the May 2018 revision):

- Art.1: Regulation lays down rules relating to the protection of natural persons with regard to the processing of personal data and rules relating to the free movement of

[1]https://ec.europa.eu/digital-single-market/en/high-level-expert-group-artificial-intelligence

personal data. This Regulation protects fundamental rights and freedoms of natural persons and in particular their right to the protection of personal data;

- Art. 2: This Regulation applies to the processing of personal data wholly or partly by automated means and to the processing other than by automated means of personal data which form part of a filing system or are intended to form part of a filing system;
- Art. 22 (figure 5.2: The data subject shall have the right not to be subject to a decision based solely on automated processing, including profiling, which produces legal effects concerning him or her or similarly significantly affects him or her;
- Art. 44: Any transfer of personal data which are undergoing processing or are intended for processing after transfer to a third country or to an international organisation shall take place only if, subject to the other provisions of this Regulation, the conditions laid down in this Chapter are complied with by the controller and processor, including for onward transfers of personal data from the third country or an international organisation to another third country or to another international organisation. 2All provisions in this Chapter shall be applied in order to ensure that the level of protection of natural persons guaranteed by this Regulation is not undermined.

Article 22 is really important since it places important limitations on the use of systems capable of taking autonomous decisions that can impact users. Article 44 is equally important since it imposes strict laws for the protection of privacy, and therefore for the management of EU citizens' data, by foreign companies.

Article 22. Automated individual decision making, including profiling

1. The data subject shall have the right not to be subject to a decision based solely on automated processing, including profiling, which produces legal effects concerning him or her or similarly significantly affects him or her.
2. Paragraph 1 shall not apply if the decision:
   (a) is necessary for entering into, or performance of, a contract between the data subject and a data controller;
   (b) is authorised by Union or Member State law to which the controller is subject and which also lays down suitable measures to safeguard the data subject's rights and freedoms and legitimate interests; or
   (c) is based on the data subject's explicit consent.
3. In the cases referred to in points (a) and (c) of paragraph 2, the data controller shall implement suitable measures to safeguard the data subject's rights and freedoms and legitimate interests, at least the right to obtain human intervention on the part of the controller, to express his or her point of view and to contest the decision.
4. Decisions referred to in paragraph 2 shall not be based on special categories of personal data referred to in Article 9(1), unless point (a) or (g) of Article 9(2) apply and suitable measures to safeguard the data subject's rights and freedoms and legitimate interests are in place.

Fig. 5.2. GDPR article 22.

5.3. Ethics guidelines for trustworthy AI

Among all the topics faced by the AI HLEG, ethics and trustworthy AI represents those for which EU citizens are rising more concerns. Therefore, in December 2018 AI HLEG presented the first draft of “Ethics Guidelines for Trustworthy Artificial Intelligence” [112], with the aim of collecting opinions and comments about the topic. Following more than 500 comments and further deliberations by the group in light of discussions on the European AI Alliance, a stakeholder consultation and meetings with representatives from Member States, the Guidelines were revised and published in April 2019.

According to the Guidelines, trustworthy AI can be defined as having three main characteristics: **lawful**, meaning that it must respect all applicable laws and regulations; **ethical**, meaning that it should follow ethical principles and value; **robust**, referring both to the technical perspective and to the need of taking into account its social environment. It is necessary that these components work in harmony to achieve trustworthy (figure 5.3).

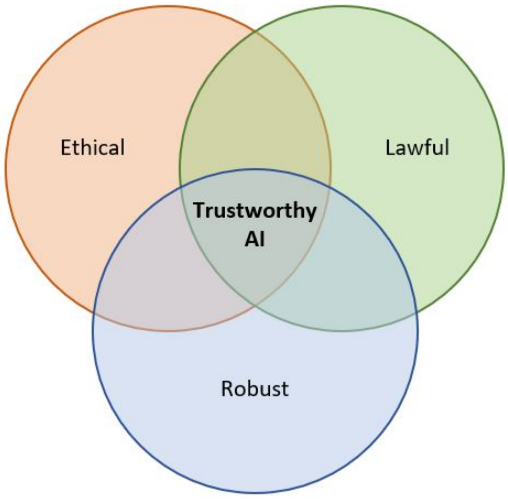

Fig. 5.3. Trustworthy AI Characteristics

Moreover, four ethical principles are set out on which the trustworthy must be based:

Respect for the freedom and autonomy of human beings : AI systems should not subordinate or manipulate humans, instead they should augment or empower human cognitive. That is, respect for the autonomy and freedom rights must be guaranteed for those users who interact with AI systems;

Prevention of any kind of harm : in order to protect human dignity and integrity, AI systems, ah the environoment in which they operate, shuld be secure and safe. In addition, precautions must be taken to avoid malicious use of these systems.

Principle of fairness : fairness deals with “the ensuring of equal and just distribution of both benefits and costs, and ensuring that individuals and groups are free from unfair bias, discrimination and stigmatisation”. Moreover, as already mentioned in the first point, AI systems should not affect users’ freedom of choice. From another point of view, fairenss implies the possibility for humans to contrast the decisions made by these systems. Consequently, these decisions must be easily understood, therefore the last principle:

Principle of explicability : decision-making processes need to be transparent, i.e. the capabilities and purpose of AI systems must be clear and decisions explainable in order to be contested when necessary.

On the basis of these principles, the Guidelines list seven key requirements that AI systems should meet in order to be deemed trustworthy:

Human agency and oversight : AI systems should empower human beings, allowing them to make informed decisions and fostering their fundamental rights. At the same time, proper oversight mechanisms need to be ensured, which can be achieved through human-in-the-loop, human-on-the-loop, and human-in-command approaches;

Technical Robustness and safety : AI systems need to be resilient and secure. They need to be safe, ensuring a fall back plan in case something goes wrong, as well as being accurate, reliable and reproducible. That is the only way to ensure that also unintentional harm can be minimized and prevented;

Privacy and data governance : besides ensuring full respect for privacy and data protection, adequate data governance mechanisms must also be ensured, taking into account the quality and integrity of the data, and ensuring legitimised access to data;

Transparency : the data, system and AI business models should be transparent. Traceability mechanisms can help achieving this. Moreover, AI systems and their decisions should be explained in a manner adapted to the stakeholder concerned. Humans need to be aware that they are interacting with an AI system, and must be informed of the system's capabilities and limitations;

Diversity, non-discrimination and fairness : Unfair bias must be avoided, as it could have multiple negative implications, from the marginalization of vulnerable groups, to the exacerbation of prejudice and discrimination. Fostering diversity, AI systems should be accessible to all, regardless of any disability, and involve relevant stakeholders throughout their entire life circle;

Societal and environmental well-being : AI systems should benefit all human beings, including future generations. It must hence be ensured that they are sustainable and environmentally friendly. Moreover, they should take into account the environment, including other living beings, and their social and societal impact should be carefully considered;

Accountability : Mechanisms should be put in place to ensure responsibility and accountability for AI systems and their outcomes. Auditability, which enables the assessment of algorithms, data and design processes plays a key role therein, especially in critical applications. Moreover, adequate an accessible redress should be ensured.

The guidelines further highlight the Commission's human-centric approach, stressing the role of AI *as a tool operating in the service of humanity and the public good, aiming to increase individual and collective human well-being.* These aspects become even more critical in domains involving a massive human presence, such as transport systems. In particular, despite designed to cope with as many domains as possible, the following are the four main points playing a central role in transports: the right for people to have the final decision (Human agency and oversight); the need to be fail safe (Technical Robustness and safety); the will of benefit as many individuals as possible (Societal and environmental well-being); the ability of reconstructing the command and responsibility chain (Accountability).

5.4. A European strategy for data

As described in the EC documents [109], the core for any AI-driven project is data. Therefore, the EC released a set of guidelines [113] to define the EU strategy for data from different points of view. The documents makes a large use of examples to describe situations for which the availability of data, properly processed by automatic means, can lead to improvement for EU citizens' such as

- personalised medicine;
- the creation safer and cleaner transport systems;
- the generation of new products and services
- the reduction of costs of public services;
- the improvement of energy sustainability and efficiency.

The core of the document is thus the development of strategies, means and infrastructure for the gathering, management and leverage of data for the *public good* (figure 5.4).

> ***Data for the public good***: *Data is created by society and can serve to combat emergencies, such as floods and wildfires, to ensure that people can live longer and healthier lives, to improve public services, and to tackle environmental degradation and climate change, and, where necessary and proportionate, to ensure more efficient fight against crime. Data generated by the public sector as well as the value created should be available for the common good by ensuring, including through preferential access, that these data are used by researchers, other public institutions, SMEs or start-ups. Data from the private sector can also make a significant contribution as public goods. The use of aggregated and anonymised social media data can for example be an effective way of complementing the reports of general practitioners in case of an epidemic.*

Fig. 5.4. Data for public good.

5.5. A European approach to excellence and trust

With the fast spread of AI, in this document [114] the EC describes its committing to enable scientific breakthrough, to preserve the EU's technological leadership and to ensure that new technologies are at the service of all Europeans, improving their lives while respecting their rights. In particular,

- for citizens to reap new benefits for example improved health care, fewer breakdowns of household machinery, safer and cleaner transport systems, better public services;
- for business development, for example a new generation of products and services in areas where Europe is particularly strong (machinery, transport, cybersecurity, farming, the green and circular economy, healthcare and high-value added sectors like fashion and tourism);
- for services of public interest, for example by reducing the costs of providing services (transport, education, energy and waste management), by improving the sustainability of products and by equipping law enforcement authorities with appropriate tools to ensure the security of citizens, with proper safeguards to respect their rights and freedoms.

The document highlights how the strength of EU is in its members. Therefore, the plans desgined by the EC proposes some 70 joint actions for closer and more efficient cooperation between Member States, and the Commission in key areas, such as research, investment, market uptake, skills and talent, data and international cooperation. The plan is scheduled to run until 2027, with regular monitoring and review. One of the main focuses of these actions is to give access to AI to Small-Medium Enterprises (SMEs) and to start-ups (action 4). To this aim, the EC is defining a pilot investment fund of €100 million in AI and blockchain. Another key aspect is to promote the partnership with the private sector while also supporting the adoption of AI by the public sector (actions 5 and 6).

The document also focuses on the crucial aspect of a possible adjustment to the existing EU legislative framework relating to AI, by identifying the risks and situations that should be addressed to improve it. The EC also defines the scope of a future EU regulatory framework. In particular, the Commission is of the opinion that a given AI application should generally be considered high-risk in light of what is at stake, considering whether both the sector and the intended use involve significant risks, in particular from the viewpoint of protection of safety, consumer rights and fundamental rights. More specifically, an AI application should be considered high-risk where it meets the following two cumulative criteria:

- First, the AI application is employed in a sector where, given the characteristics of the activities typically undertaken, significant risks can be expected to occur. This first criterion ensures that the regulatory intervention is targeted on the areas where, generally speaking, risks are deemed most likely to occur. The sectors covered should be specifically and exhaustively listed in the new regulatory framework. For instance, healthcare; transport; energy and parts of the public sector. The list should be periodically reviewed and amended where necessary in function of relevant developments in practice;
- Second, the AI application in the sector in question is, in addition, used in such a manner that significant risks are likely to arise. This second criterion reflects the acknowledgment that not every use of AI in the selected sectors necessarily involves significant risks. For example, whilst healthcare generally may well be a relevant sector, a flaw in the appointment scheduling system in a hospital will normally not pose risks of such significance as to justify legislative intervention. The assessment of the

level of risk of a given use could be based on the impact on the affected parties. For instance, uses of AI applications that produce legal or similarly significant effects for the rights of an individual or a company; that pose risk of injury, death or significant material or immaterial damage; that produce effects that cannot reasonably be avoided by individuals or legal entities (figure 5.5).

> In autonomous driving for example, the algorithm uses, in real time, the data from the car (speed, engine consumption, shock-absorbers, etc..) and from the sensors scanning the whole environment of the car (road, signs, other vehicles, pedestrians etc..) to derive which direction, acceleration and speed the car should take to reach a certain destination. Based on the data observed, the algorithm adapts to the situation of the road and to the outside conditions, including other drivers' behaviour, to derive the most comfortable and safest drive.

Fig. 5.5. Example of a critical AI application.

Finally, the document defines the key aspects that must be taken into account when designing the future regulatory framework for AI. It will be necessary to decide on the types of mandatory legal requirements to be imposed on the relevant actors:

- training data;
- data and record-keeping;
- information to be provided;
- robustness and accuracy;
- human oversight;
- specific requirements for certain particular AI applications, such as those used for purposes of remote biometric identification.

5.6. Safety and liability implications of AI

Released on mid February 2020, the “Report on the safety and liability implications of Artificial Intelligence, the Internet of Things and robotics” [115] declares the EC will make Europe a world-leader in AI, IoT and robotics. In particular, the commission stresses the fact that this must be done within the already existing robust and reliable safety and product liability regulatory framework and within a robust body of safety standards, complemented by national, non-harmonised liability legislation.

To some extents, the documents can be seen as an overview of the topics faced by the commission in the AI files, providing a set of pointers to other document, recommendations, resolutions, etc., while reporting the important challenges to face. In particular, the document recalls

- the EC notion of safety in AI, stressing the fact that AI systems should integrate safety and security-by-design mechanisms to ensure that they are verifiably safe at every step, taking at heart the physical and mental safety of all concerned;
- the autonomy in decision making, that should always be by-passable by an human operator;
- the need for the development of new and future-proof policies to avoid opacity in AI systems.

These aspects are gathered under the umbrella of AI liability, with the aim of supporting the development of an harmonised liability framework as companion to the Union and to the National rules. This aspect is particulalry stressed since while in principle the existing Union and national liability laws are able to cope with emerging technologies, the dimension and combined effect of the challenges of AI could make it more difficult to offer victims compensation in all cases where this would be justified. Thus, the allocation of the cost when damage occurs may be unfair or inefficient under the current rules. To rectify this and address potential uncertainties in the existing framework, certain adjustments to the Product Liability Directive and national liability regimes through appropriate EU initiatives could be considered on a targeted, risk-based approach, i.e. taking into account that different AI applications pose different risks.

5.7. Explainable AI

While the first AI systems were easily interpretable, with the advancement of technology this becomes more complicated. Problem lies in the interpretability, justifiability and explainability of the result produced by these systems. Just think of the abyssal difference between Decision Tree-based models and Convolutional Neural Networks. The former produce a series of tests and, however deep the tree may be, it can always translate into legible rules; the latter involves hundred of layers and millions of parameters, and are often considered as complex black-box models. Explanations supporting the output of a model are crucial, e.g., in medicine, experts require far more information from the model than a simple binary prediction for supporting their diagnosis [116]. The figure 5.6 summarizes the problem: actually most of the outputs of ML-based systems are not directly comprehensible.

Theoretically, Explainable AI (XAI) [116] deals with three particular concepts which should not be confused as they highlight different aspects of a given system:

- The Interpretability (also called Transparency) refers to a passive characteristic of a model referring to the level at which a given model makes sense for a human observer. It helps ensure impartially decision-making (detecting and correcting biases in the dataset) and provides robustness (highlighting potential adversarial perturbations);
- Explainability can be viewed as an active characteristic of a model, denoting any action or procedure taken by a model with the intent of clarifying its behavior;

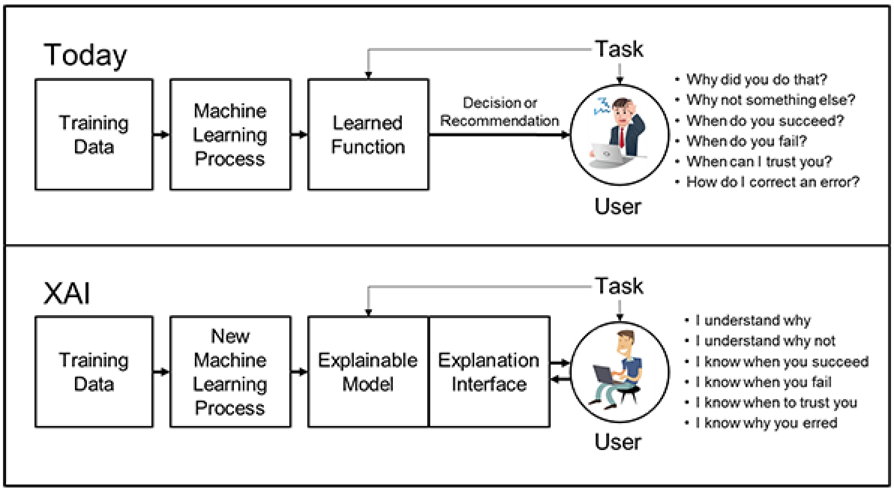

Fig. 5.6. Explainable AI process compared against the tradional Machine Learning training schema (image taken from the DARPA website[1]).

- Comprehensibility refers to the ability of a learning algorithm to represent its learned knowledge in a human understandable fashion.

It is clear that the more a system met these concepts, the more it can be understood and, maybe, trusted.

The same concern was expressed by DARPA (Defense Advanced Research Project Agency) that looks at the future considering Explainable AI, Explainable ML in particular, as the main foundation on which AI systems are built in order to properly understand, manage and also trust them. According to DARPA, ML techniques, both new and actual, will have to be capable to explain their rationale maintaining a high level of learning performaces and this will be possible allowing them to produce more explainable models assisted by an 'Explaination Interface' to communicate with users [117] (as figure 5.6 shows).

[1] https://www.darpa.mil/program/explainable-artificial-intelligence

6. Mapping of Artificial Intelligence on Railway Subdomains

In this Section a mapping of AI on railway subdomains is provided in order to recognize already existing as well as potential applications of AI to the railway sector. In particular, the focus is on the following sub-domains in railway transport:

1. Maintenance and inspection;
2. Safety and security;
3. Autonomous driving and control;
4. Traffic planning and management;
5. Revenue management;
6. Transport policy;
7. Passenger mobility.

The assessment of intersection areas between AI and railway was conducted in the following way. The main database used were the online search engine of the library website of University of Leeds https://library.leeds.ac.uk/. In addition, Google Scholar (https://scholar.google.com/) and Scopus (https://www.scopus.com/home.uri) were used as complementary resources. General Google (https://www.google.com/) was used for searching media news and reports. The keywords used were designed as follows. Primarily, the two terms from a column (e.g. AI techniques) and a row (i.e. subdomains) in Tables were taken and used for the search, with possible contextual words added if needed. For instance, 'passenger mobility' & 'expert systems' were used as the keywords for the search engines. Sometimes, for a single column or row, the key words may be separated in the search, e.g. 'railway safety' and 'railway security' were used separately. Note that this section gives a high-level overview of current usages and opportunities of AI in railways and a comprehensive state-of-the-art will be considered in the following project deliverables.

Section 6.1 briefly describes railway subdomains and Section 6.2 defines matrices to depict intesections, i.e. crossings, between railways and AI research fields, AI techniques and AI applications.

6.1. Railway subdomains

Maintenance and inspection Railways are made up of complex mechanical and electrical systems and there are hundreds of thousands of moving parts. If a railway service is to be reliable and safe, the equipment must be kept in good working order and regular maintenance is the essential ingredient to achieve this [118]. According to the objects, railway maintenance can be further classified into maintenance on rolling stock, track, infrastructure (station, platform), signalling equipment, and so on. A railway will not survive for long as a viable operation if it is allowed to deteriorate and become unsafe because of lack of maintenance. Although maintenance is expensive, it will become more expensive to replace the failing equipment early in its life because maintenance has been neglected [118].

Safety and security Safety and security are of primary concern for any transport system. Travellers expect transportation to be safe.Transport safety is defined as the absence of accidents that may cause injury to persons and/or physical damages. Therefore, creating an environment for safe transport is essential for European citizens [119]. While the level of safety achieved can vary, railways are typically amongst the safest form of transport. Inevitably, this level of safety comes with a cost and a balance amongst safety, performance and cost, which is one of the key global challenges for the railway industry [120].

Security is an essential part of railway operations, and covers from the physical protection of infrastructure to the technology and management that safeguard people, staff and information [121]. Yet, it is also important that security is not so intrusive as to make travel an unpleasant experience. Transport security can cover everything from terrorist attacks to prevention of vandalism and graffiti.

Autonomous train driving and train control Autonomous trains, also known as driverless trains, are operated automatically without any human intervention, and are monitored from the control station. In case of any obstacle incurred in the route, a message is sent to operational control center and to the attendant on the train, to stop the train [122]. Automatic train operation (ATO) is an operational safety enhancement device used to help automate the operation of trains. The European Train Control System (ETCS) is the signalling and control component of the European Rail Traffic Management System (ERTMS). It is a replacement for legacy train protection systems and designed to replace the many incompatible safety systems currently used by European railways [123].

Traffic planning and management Rail traffic planning and management is the research and application about the effectiveness and efficiency of capacity management, timetabling, management and safety of railway operations. It also covered the analysis of passenger and freight railway transport, estimation of traffic demand and capacity, design of timetables, scheduling of trains and crews, optimal use of rolling stock and energy in order to increase the efficiency and competitiveness of passenger and freight transport [124].

Revenue management Revenue management is the application of disciplined analytics that predict consumer behaviour at the micro-market levels and optimize product availability and price to maximize revenue growth. The primary aim of revenue management is selling the right product to the right customer at the right time for the right price and with the right pack. The essence of this discipline is in understanding customers' perception of product value and accurately aligning product prices, placement and availability with each customer segment [125].

Transport policy Transport policy deals with the development of a set of constructs and propositions that are established to achieve specific objectives relating to social, economic and environmental conditions, and the functioning and performance of the transport system. Public policy prepresents the means by which governments attempt to reconcile social, political, economic and environmental goals and aspirations with reality. These goals and aspirations change as the society evolves, and thus a feature of policy is its changing form and character. More details on policy can be found in [126].

Passenger mobility Mobility is the ability to move all people safely and affordably between where they live, work, and spend their leisure time. It includes walking, cycling, vehicle sharing, public transportation, and much more. Mobility is the ability to move or be moved freely. Three characteristics can be determined[1]:

- Time. If it takes forever to reach the destination, you don't have access to it. You might not always go to the nearest grocery store if the bus that runs past it is always stuck in traffic – you might just run to the convenience store across the street, even though they don't sell fresh food.
- Affordability. Transportation options need to be affordable. If your only option is to drive but you can't afford a car, you don't have mobility.
- Safety. If it isn't safe to walk, bike, or drive, you don't have mobility. You won't use modes that are dangerous.

Emerging concepts such as Mobility-as-a-Service support developments for and around seamless mobility of the future across diverse transport modes. The term Mobility as a Service (MaaS) stands for buying mobility services based on consumer needs instead of buying the means of mobility. Research on the passengers mobility in railway systems includes passenger flow prediction, passenger information retrieval, travel behaviour analysis, passengers' mode choice, and so on.

6.2. Mapping results

We build three matrices showing the intersections between AI and railway, and for each cell, if it is certain (Y), potential (P), or uncertain (U) that the corresponding match will be feasible in theoretical research and/or in practice. Where appropriate, the relevant literature is given to support the conclusion of a cell. The first matrix focuses on AI research fields, the second matrix on AI techniques, and the third on AI applications.

We determine whether an entry in the three tables belongs to Y, P or U by the following rules:

1. Y: Applications of the exact match are found in academic journal/conference papers and/or successful real-word applications are found in magazines/news or other media.
2. P: Similar applications of the match are found in academic journal/conference papers and/or successful real-word applications are found in magazines/news or other media. For instance, an application of AI in another sector other than rail but the principles are possibly transferable.
3. U: No explicit literature/media report/applications can be found by the databases, even from other sectors. In addition, we use our own judgement based on expertise and experience of the consortium.

Table 6.1 gives intersections with AI research fields, Table 6.2 gives intersections with AI techniques and Table 6.3 gives intersections with AI applications.

[1] https://mobilitylab.org/2018/07/26/what-is-mobility/

Table 6.1: Intersection between AI research fields and railway subdomains

	Expert systems	Data mining	Pattern recognition	Adversarial search
Maintenance and inspection	P [127–131]	P [132, 133]	Y[134, 135]	P [136]
Safety and security	Y [137–139]	Y [140, 141]	Y [142]	P [143]
Autonomous train driving and vehicle control	P [144–147]	P [148, 149]	U	P [150]
Signalling	U	U	U	U
Traffic planning and management	Y [151–155]	Y [156–161]	Y [162, 163]	Y [164–168]
Revenue management	U	P [169, 170]	U	P [171–173]
Transport policy	P [174–176]	P [177, 178]	U	P [179, 180]
Passenger mobility	P [181]	Y [182, 183]	U	Y [184, 185]

Y: Certain with existing examples (in theory or practice)
P: Potential (based on existing literature in other areas or our judgement)
U: Uncertain

6.2.1. Existing intersections (Y)

Maintenance and inspection In [239], optimization techniques are used for rolling stock assignment and maintenance scheduling with predictive maintenance. It proposes an optimization process for assigning rolling stock to utilization paths and maintenance tasks in accordance with the predictive maintenance strategy (PdM) with trainset-specific reliability models. In [240], preventive maintenance (PM) scheduling problem for a rolling stock system is considered. The goal is to determine the interval of PM for components in rolling stock system. The total expected cost for system life cycle and system availability are used as optimization criteria. Two types of PM (short-term and long-term PM) are considered. For given PM intervals, the authors estimate availability and life cycle cost by simulation (a commercial simulation program, AvSim). Numerical examples show the effect of model parameters on the optimal solution. In [134] ProRail uses pattern recognition and image processing technology to predict where and when a malfunction will occur on switches, such reducing the number of delays on tracks. The switches are equipped with sensors that transmit information about the power consumption, vibrations and heat of the switches. By analyzing the data produced by them, the prediction can be realised before a disruption would happen.

Safety and security All the AI research fields focused by us have been applied in the sub-domain of safety and security. [137] gives a review on the application of various AI and expert systems for fault diagnosis of high-speed railways. Reference [253] reports the pinieering work in autonomous systems for condition monitoring Of railway infrastructure. Reference [140] explores the employment of the decision tree (DT) method in safety classi-

Table 6.2: Intersection between AI techniques and railway subdomains

	Evolutionary computing	Machine learning	Logic programming
Maintenance and inspection	P [186–192]	P [193–200]	U
Safety and security	P [201–203]	Y [141, 204]	U
Autonomous train driving and vehicle control	Y [205, 206]	P [207–211]	U
Signalling	Y [203, 212]	U	U
Traffic planning and management	Y[213–215]	Y [216–222]	U
Revenue management	P [223]	P [224–226]	U
Transport policy	P [227]	P [228, 229]	U
Passenger mobility	P [230]	Y [231–238]	U

Y: Certain with existing examples (in theory or practice)
P: Potential (based on existing literature in other areas or our judgement)
U: Uncertain

fication and the analysis of accidents at railway stations to predict the traits of passengers affected by accidents. In [148], Wayside Train Monitoring Systems (WTMS) are introduced, which use pattern recognition for defect detection in uncontrolled environment railway applications. Authors in [204] developed a prediction model for the railway disruption length using Bayesian Networks.

Among the AI applications, in [242], big data and natural language processing are used for analysing railway safety. The focus is on accident causation for the railway industry by exploiting text analysis approaches mainly NLP. Investigation reports of railway accidents in the UK were reviewed and analyzed, to reveal the presence of entities which are informative of causes and failures. The proposed method is able to assist risk and incident analysis experts to study causal relationship between causes and failures towards the overall safety in rail industry.

Reference [139] gives a survey on applications of visual inspection technology based on image processing in the railway industry, where it introduces the research and contribution of various academics in the field of visual inspection, summarizes the application and development of this technology in the railway industry, and finally predicts the future research direction of visual inspection technology. In [252], computer vision techniques are used for various types of applications, including train stations. According to the authors, the challenge does not lie on acquiring surveillance data from video cameras, but for identifying what is valuable, what can be ignored, and what demands immediate attention.

Table 6.3: Intersection between AI applications and railway subdomains

	Operations research and scheduling	NLP & speech recognition	Computer vision & image processing	Autonomous systems & robotics
Maintenance and inspection	Y [239, 240]	P [241, 242]	Y [134, 135, 243–249]	P [250]
Safety and security	U	Y [251]	Y [139, 252]	Y [253, 254]
Autonomous train driving and vehicle control	Y [255–258]	P [259]	P [260]	U
Signalling	Y [261–264]	U	U	P [265]
Traffic planning and management	Y [266–269]	P [270]	U	U
Revenue management	P [271, 272]	U	U	U
Transport policy	Y [273]	P [274]	P [138]	U
Passenger mobility	Y [275]	U	U	U

Y: Certain with existing examples (in theory or practice)
P: Potential (based on existing literature in other areas or our judgement)
U: Uncertain

Autonomous train driving and vehicle control Reference [205] proposes a method for energy optimization of the train movement through their control using genetic algorithms, which was tested based on a real subway line in Milan through the implementation of a dedicated Matlab code. The algorithm provides the optimization of the trains movement through a coast control table created by the use of a genetic algorithm that minimizes the energy consumption and the train scheduled time. Reference [255] proposes novel approaches for solving the complex optimal train control problems that cannot be perfectly tackled by existing methods, including the optimal control of a fleet of interacting trains, and the optimal train control involving scheduling. The proposed methods are utilised to formulate more complex optimal train control problems, including scheduling a subway line considering train control, and concurrently optimising the control of a leader-follower train pair under fixed- and moving-block signalling systems. In [258], a real-time optimization method for autonomous vehicle motion planning is presented. the authors use differential dynamic programming (DDP) to optimize the trajectory, where DDP not only smoothes the trajectory but also considers the non-holonomic constrain of the vehicle. The optimized trajectory is proved to be able to executed by the vehicle. Computational experiments were conducted with an autonomous vehicle model in Gazebo simulation environment.

Signalling In [212], a genetic algorithm and particle swarm optimization algorithm are presented for speed error reduction in railway signaling systems. The focus of this paper is about common concepts of modern methods of train speed determination with minimal errors. Balise locations depend on different parameters. With genetic algorithm and particle swarm optimization, plus Kalman filtering, the best locations are determined to reduce tachometer errors. The PhD thesis by Zhao [203] deals with railway traffic flow optimisation with differing control systems, where a large number of railway signalling systems are considered.

Reference [261] uses optimization to design railway section signalling layout. The proposed model uses traction calculation and signalling layout principle, and considers railway objects such as orbit code sequence, OCS mast position, and electrical sectioning position. A heuristic simulation algorithm is designed for getting a satisfactory solution. With the goal of the minimum signalling layout under the condition of quasi-moving block, the proposed algorithm can automatically realize the signaling layout. In [262], A mixed integer linear programming model based on alternative graph is used to handle disruption in high-speed railway with a quasi-moving signaling system, by integrating traffic management and speed management. The model is suitable for disruptions causing speed restriction with a unfixed time and geographic extension, and the concurrent presence of smaller primary delays perturbing further the traffic.

Traffic planning and management Traffic planning and management is another sub-domain where many AI research fields have been extensively used.

Even in the 70s, an expert system for real-time train dispatching was developed [151]. In [152], expert systems are used for intelligent train operations. In [156], an data analytics approach is designed for train timetable performance measures, where automatic train supervision data is used. [158] applies data clustering techniques to analyze train delay patterns. Finally, [159] gives a comprehensive survey on the use of data-driven approaches for train dispatching management.

Reference [276] uses machine learning approaches to incorporate weather conditions and travel history in estimating the alighting bus stops from smart card data, where the proposed gradient boosting decision tree (GBDT) algorithm outperforms traditional ML algorithms on estimation precision. In [216], a scalable reinforcement learning algorithm is presented to scheduling railway lines. The goal is to define track allocations and arrival/departure times for all trains of a line, provided with their initial positions, priority, halt times, and traversal times, while minimizing the total priority-weighted delay. The method is suitable for bidirectional railway lines (both single- and multi-track).

Reference [163] solves the problem of optimizing dispatching and rerouting decisions in the Swiss railway network by deep learning and pattern recognition, where the recorded data is variable over time and only contains a few valuable events. To overcome this deficiency of the lack of valuable data, they use the high computational power of modern GPUs to simulate millions of physically plausible scenarios. Artificial data are used to train their deep reinforcement learning algorithms to find and evaluate novel and optimal dispatching and rerouting strategies.

Reference [164] presnets a multi-agent based timetable scheduling algorithm for railway system. the algorithm handles the in-between time delay of the newly introduced train. The delay management optimizes the total journey time, hence increases the total utility of the whole railway system. The process is accomplished by DCOP (Distributed Constraint Optimization Problem), where some metric are specifically defined to analyze the system to achieve our goals. JADE (Java Agent DEvelopment Framework) platforms are used to simulate our work and test it using a small network.

Since most traffic planning and management problems have NP-hard nature, evolutionary algorithms are often used to get near-optimal solutions within reasonable time. In [213] Genetic Algorithm is designed to solve the Train Timetabling Problem on a single line track. This GA includes a guided process to build the initial population and is tested using real-world instances from the Spanish Manager of Railway Infrastructure. The results show that GA is able to produce good solutions in a short amount of time. Reference [214] presents a heuristic model based on the concept of "Fixed Path + Genetic Algorithm". The Fixed Path model assumes that path of the trains is fixed for preparing the train schedule. The GA is used for selecting the path for each train that takes minimum time to arrive at the destination. Combined, they will give a schedule minimizing the travel time of each train while maximizing capacity of the network. This paper also shows that by applying the proposed model, rail traffic can be improved regarding the increase of the timetable stability and maximizing capacity subject to safety constraints. In [215], an alternative mathematical model to tackle the TTP is proposed and Genetic Algorithm is used for solving the model in order to rapidly obtain near-optimal solutions. Computational experiments were conducted based on a German railway network.

For various railway planning and scheduling problems (e.g. timetabling, rolling stock scheduling and crew scheduling), it is well-known that most of them can be modelled as combinatorial optimization problems. Recently, there has been impressive advance in solving combinatorial optimization problems by mathematical programming and machine learning [277]. This implies that as there is great potential in solving railway planning and scheduling problems using AI given the fast-growing research interests in the theoretical optimization community.

Passenger mobility The last sub-domain that has recived researchers' attention in the use of AI research fields and AI techniques is passenger mobility. In [182], spatio-temporal data is used for forcasting railway passenger flows. The method forecasts time sequences of target objects by statistical principles, and figures out the spatial influence of neighbor objects by a neural network. It combines the two forecasting results using linear regression. It is used in forecasting railway passenger flows during the Spring Festival period of 2004. Reference [183] also uses data mining to forcast railway passenger flows. A collection of methods such as data warehousing, data mining and neural networks are used. In particular, the result was applied to the Ticket Selling and Reserving System of Chinese Railway (TRS).

In [231], artificial neural networks are used for forcasting passenger flows on metro lines. Artificial Neural Networks are trained by using simulated data from a dynamic loading procedure of the rail line. The proposed method was tested on Line 1 of the Naples metro system in Italy. Computational experiments show that the proposed approach is able to forecast the flows on metro sections with satisfactory precision. Reference [238] proposes a deep learning based architecture for metro passenger flow prediction. This architecture is highly flexible and extendable, suitable for the integration and modeling of external environmental factors, temporal dependencies, spatial characteristics, and metro operational properties in short-term metro passenger flow prediction. It achieves a high prediction accuracy due to the ease of integrating multi-source data as evidenced by computationa experiments.

Reference [185] combines an improved gray prediction model, modified gravity model, and Logit model to predict the average passenger flow, induced passenger flow, and transfer passenger flow. According to predicted results, the authors establish a game model considering different stages of the HSR development. The method is applied to an empirical study in China, i.e. the competition between Beijing-Shenyang HSR and airline. Results show the HSR contribution is greater than the airline in the assumed scenarios.

6.2.2. Potential intersections (P)

Evolutionary algorithm and maintenance and defect detection In [278], a model of texture segmentation using Gabor filters is used to the analysis of texture and defect regions found on wooden boards. A method to find an optimal set of parameters for a given two-dimensional object detection approach is proposed. Feature selection techniques is used to maximize discrimination: the selection method uses a genetic algorithm to optimize various parameters of the system including Gabor weights, and the parameters of morphological pre-processing. Similar feature selection method is possible to be applied to defect detection in railway maintenance and safety, such as signal fault, track inspection, and so on.

Machine learning and automated driving There has been a great number of research in investigating the application of ML to automated driving. Currently, the major focus is still on car driving, but it is likely to be transferred to railway once the technique in car driving is mature enough. ML may play a key role in this area but this is not as simple as out-of-the-box deployment of strategies and models developed in related fields. Rob Weston argues that a system-centric approach not only allows us to meet the necessary requirements for real world deployment but also affords the machine learning community new opportunities for developing the next generation of intelligent algorithms [211].

Traffic management and machine learning Most typical traffic management problems can be modelled by combinatorial optimization problems, which are traditionally solved by classical approaches such as branch-and-bound or heuristic based methods. Thanks to the newly developed approaches recently in solving combinatorial optimization problems by ML techniques [277], e.g. by sampling, and by designing variable/node selection strategies in branch-and-bound guided by ML. We thus conclude that it is highly likely that in the future, the toolbox for railway traffic management problems will include machine learning.

Revenue management and AI We have seen several literature where revenue management (RM) systems guided by AI are developed. Revenue management systems for railway transport share certain features with other RM systems, while having its own uniqueness. As the application of AI in RM systems in other areas becomes mature, it is likely to be transferred to the railway sector, since the differences between the RM systems in different fields should not be significant enough to challenge such a transferring process.

NLP and transport policy Reference [274] discussed the potential in applying big data and text mining technologies from social media to help policy makers in transport analysis and policy making. NLP, as a powerful tool for text mining and analysis, has been mentioned. The article is about generic transport policy making, and railway, as an important sector of transport, has no reason to be excluded from this potential direction. For instance, by analysing the information extracted from train operators' official websites and tweets, and the tweets from customers, policy makers can respond accordingly.

6.2.3. Uncertain insersections (U)

For a large number of the entries in the three tables, we conclude that the applications of the corresponding AI to the railway sub-domains are uncertain. As explained earlier, this is because no explicit literature/media/applications can be found, either from the railway sector or other sectors. Some of the Us are more self-explanatory, e.g. revenue management & pattern recognition, but some are less obvioous, such as signalling & machine learning. In particular, logic programming has received Us for all the railway sub-domains. Our conclusions are mainly based on the result of the data base searching, such that they are not necessarily indicating the possibility of an entry labelled by U is absolutely zero or tiny. This is why we use "Uncertain", rather than "No". In addition, those cells with U may even imply research opportunities in the future that are not aware by the research community and railway practitioners a the moment.

7. Artificial Intelligence in related domains

AI has been already in use in various business practices including medicine, law, finance, accounting, tax, audit, architecture, consulting, customer service, manufacturing, and transport [279]. Here we introduce the main applications of AI in other fields that are relevant to railway transport. In particular, we assessed road transport, aviation, public transport, manufacturing and supply chain management and logistics. For the analysis, we used mainly recent scientific review papers on specified domains including [280–284].

7.1. AI in manufacturing

Computational intelligence is an essential part of smart manufacturing to enable accurate insights for better decision making. Machine learning has been widely investigated in different stages of the manufacturing lifecycle covering concept, design [285], evaluation, production, operation, and sustainment [286]. The applications of data mining in manufacturing engineering are reviewed in [287], covering different categories of production processes, operations, fault detection, maintenance, decision support, and product quality improvement. Smart manufacturing also requires prognostics and health management (PHM) capabilities to meet the current and future needs for efficient and reconfigurable production [288].

AI has been used also to monitor machinery conditions, identify the incipient defects, diagnose the root cause of failures, and then incorporate the information into manufacturing production and control [289]. Finally, in order to increase manufacturing productivity while reducing maintenance costs, it is crucial to develop and implement an intelligent maintenance strategy that allows manufacturers to determine the condition of in-service systems in order to predict when maintenance should be performed. To do so, the temporal behaviour in the historical data is important for prediction, and the deep recurrent neural network has demonstrated its capability to model temporal pattern.

7.2. AI in supply chain management and logistics

Supply chain management (SCM) is one of the most challenging fields which emphasizes interactions among different sectors, primarily marketing, logistics, and production. Therefore, success in SCM lies in the overall success of any business. However, with the consistent changes in business practices like lean management and just-in-time philosophy both in production and logistics, globalization, adverse events i.e. natural disasters, political instability, etc. SCM always need to develop an adequate solution to mitigate such challenges. In recent years technologies like Artificial Intelligence (AI) is been proved extremely valuable to SCM.

Applications of AI has helped businesses gain a competitive advantage in a) getting accurate projection and forecast the customer demand, b) optimizing their R&D, i.e. increase in manufacturing with lower cost and higher quality c) supporting them in the promotion (identifying target customers, demography, defining the price, and designing the right message, etc. d) providing their customers with a better experience.

Modern logistics systems are supported by increasingly ubiquitous and powerful computing networks. Within these networks, oceans of data are continuously being generated by sensors, machines, systems, smart devices, and people. Together with rising computational capabilities, this Big Data is being analysed faster, more broadly, and more deeply than ever before. These advances have redefined the value of Artificial Intelligence (AI) technologies and opened a new age known as Industry 4.0 [290].

Advanced AI methods have begun to find application in logistics systems for automated visual inspections, fault detection, and maintenance. There are active efforts to apply reinforcement learning methods to material handling systems and production scheduling. Industries aiming to convert real-time data into actionable decisions seek opportunities to integrate AI methods with traditional Operations Research approaches, the concepts and technologies of the Internet of Things (IoT), and cyber-physical systems.

7.3. AI in aviation

AI has been acknowledged to manage the flight journey more effectively. AI can help in Technology (Machine Learning), software/hardware and Application (Intelligent Maintenance, Flight Route Optimization) [290]. AI has been very fruitful in the domain of predictive maintenance and inspection in all domains. For example, [291] showed that using ANN is important to enhance the monitoring system of the gas turbine during flights. Also, AI has been used for effective scheduling of aircraft maintenance checks [292] and crew rostering [293]. NLP has been applied in aviation, [294] developed a system to extract information from highly dense aviation reports and modify it to AI systems.

Regarding safety, unsupervised machine learning algorithms showed reliable to increase safety when an airplane is landing [295] and assessing the safety of a plane by checking the engine on-board using the Probabilistic neural network (PNN) [296].

From a security perspective, (efficiency, and the relationships relations between them,) [297] proposed an agent-based methodology to evaluate security regarding an Improvised Explosive Device attack.

AI has been successfully used in the prediction of airport operations, e.g. in runway utilization, predictions and scheduling resources. AI was useful to extract the runway utilization as a function of operational parameters from historical data. Also, AI was applied to develop a real-time prediction model of runway utilization with their associated risk precursors.

Forecasting future passenger demand has always been one of the most challenging tasks for revenue management systems. This is not only because of the technical complexity but also because of the industry's fast-changing requirements. As airlines service more passengers with different profiles, while offering more travel options and more types of services and ways to combine them, AI and ML backed solutions is expected to be a key in helping them make better decisions [298–300].

7.4. AI in road transport

AI has been very fruitful in the domain of Predictive maintenance and inspection in all domains. Also, drones have been used for visual inspection of critical infrastructure and in particular, roads, rails, bridges, and tunnels.

Regarding safety, AI plays an important role to prevent accidents as well as to reduce the impacts of accidents. The reasons for vehicle accidents vary in space and time. Hence, AI can capture the spatial-temporal pattern of accidents in databases and identify patterns for which mitigation strategies can be designed [301, 302]. Moreover, incidents in real-time can be detected from social media [303]. It showed that Twitter is a cost-effective and efficient technique to acknowledge incident occurrence on both, freeway and arterial roads.

Autonomous Vehicles are forecast to have a major change in how transportation systems are operated around the world and their impact on traffic safety and traffic congestions has been predicted in some detail, along with their potential to shift travel behaviour [304]. These AVs are expected to change the travel patterns of people to result in different social structures and urban forms. They will help in car sharing and ride sharing with new business models for solutions to existing barriers, such as limited accessibility and reliability [305].

On the strategic level, the objective of planning in transport domains is to identify the community needs and decide on the best approach to meet this demand while utilizing the impact of social, environmental and economic in transportation. Designing an optimal road method for transport planning is part of the Network Design Problem (NDP) [306]. For solving NDP, [307] applied GA and SA algorithms. In addition, AI has been used for searching, evaluating, and optimizing highway location and alignments of highways [308] as well as for vehicle design [309].

On the tactical level, planning of routes for vehicles is important to avoid congestion and delays in travel times. Authors concluded that optimization and evolutionary algorithms are promising approaches for the vehicle routing problem [310, 311].

On the operational level, AI applications have also seen rapid developments. Traffic management systems aim to alleviate congestion and improve the driving experience using a variety of technologies and communication systems. Machine learning can help capture important data. For example, deep reinforcement learning has been used for real-time optimisation of traffic control policies [312] to control the traffic signal on highways and intersections and predict future traffic congestion.

7.5. AI in public transport

In public transport passengers greatly benefit from AI applications. This future mobility demand estimation is important to make a decision on planning and future techniques that are most needed to manage a more effective transportation system [313].

AI can benefit from data (fare collection data, passenger flows, automated passenger counting, automatic vehicle location) to predict passenger demand effectively to avoid empty vehicles which in return will reduce congestion and energy consumption [314]. Also, real time short term predictions of public transport users waiting at bus stops and also on-board passengers can help operators to control transit trips more effectively [315]. At the same time, it helps travellers to decide on the best route during congested hours. The communication of information requires integration between public transport systems and ITS which in turn will enhance the forecasting tools for advanced traveller information systems and operation controls.

In terms of finding best paths for public transport users, travel apps can learn and update the real time path generation system according to the preferences of travellers [316].

8. Conclusions

In this deliverable we have provided a taxonomy of current terms and concepts used in the field of Artificial Intelligence applied to modern railway transportation systems, including train control, infrastructure maintenance, traffic management and supervision. Among relevant AI concepts we have addressed machine learning, optimization algorithms and artificial vision. All those concepts have been structured in a systematic and semi-formal representation through class diagrams and related classification relationships such as inheritance, composition, etc. We believe that is an effective way to overcome the disadvantages of existing definitions that are often affected by ambiguities and therefore difficult to frame in terms of characterizing attributes and means. Such a report is the first step in the development of the RAILS research project as it is needed to provide basic definitions, interrelationships and a common understanding of reference concepts as well as their detailed explanation. It is important to underline that it was not the scope of this deliverable to provide an extensive state-of-the-art or literature review on those topics, because those activities will be reported in other deliverables within the RAILS research project. Finally, we consider this report as a ”living” document because the reference taxonomy, besides being admittedly non-exhaustive, is subject to possible adjustment and evolution according to most recent developments in AI and railways.

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