Digitalisation in the textile and clothing industry*

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Keywords: Digitization, Digitalization, Textile industry, Clothing industry, Industry 4.0

Digitalisation is now a keyword, at the heart of the fourth industrial revolution (commonly known as Industry 4.0). Education was digitalised during the Covid epidemic, workshops between teleworkers are digitalised, e-commerce is digitalised, our tax returns are digitalised, we send documents, letters and pictures to each other, automated equipment works with digitalised data – and so on.

The European Commission initiative

But the digitalisation process is much more than that. In 2016, the European Commission launched an initiative to digitise European industry, the Digital Europe Programme, which aims to strengthen the EU's competitiveness in digital technologies and ensure that all European businesses can fully benefit from digital innovation. Under this programme, the Commission has published a working paper on the creation of European Digital Innovation Hubs (EDIH), which will develop the digital development of Member States' economies and societies through a new funding programme with a budget of €26.8 million for the period 2021–2027.[1]

Fig. 1. The Eurpean Commission initiative

According to a report for the European Commission, in the post-Covid era, the proliferation of digital, environmental and recycling technologies will be critical to the survival and renewal of the industry. In particular, the use of artificial intelligence (AI) technologies offers the potential to revolutionise inventory analysis and better organise the supply chain. Three-dimensional (3D) design and visual reality/augmented reality (VR/AR) applications will provide new ways for companies to facilitate their operations and connect with customers in a world with limited freedom of movement.[2]

According to the Hungarian National Research, Development and Innovation Office, digitalisation is essential to maintain competitiveness, and its integration into business processes, products and solutions contributes greatly to the efficiency of companies and public sector players. The initiative aims to strengthen Europe's capacity in high-performance computing, artificial intelligence, cybersecurity and advanced digital skills, and to support their uptake in the economy and society. To ensure that these capabilities can be effectively used by companies and public administrations, EDIHs work closely with the relevant specialised centres and ensure that companies and public administrations experiment with and apply these technologies according to their specific needs.[3] Accordingly, the National Research, Development and Innovation Office has initiated the establishment of such an EDIH centre in Hungary in 2020, and there are already several examples of such centres in cooperation with universities and professional organisations.[4][5][6]

Some basic concepts

Digitalisation

Digitalisation is the process of converting analogue processes and physical objects into digital format. In other words, digitalisation is the process by which certain processes can be manipulated through digital media, such as computers or smartphones, usually via an internet connection.

The origin of the word **digitalization** is the Latin word *digitus*, meaning finger. The English word *digit* derived from this, means a digit in computer science, a written character representing an integer, presumably because the Romans used their fingers to show numbers (hence the Roman numerals).

In computer science, the word *analogue* means a physical quantity that is constantly changing/changeable. If, for example, the increase of the elongation on a yarn breaking machine is visualised by the rotation of a pointer (analogue process), we are talking about an analogue instrument. If, however, the progress of the elongation on the instrument is indicated by the flash of an ever-changing digit, then the change in elongation is represented by a digital instrument. This analogue-to-digital conversion operation is called **digitisation**.

Digitalisation is the process of making a physical quantity processable by computer in some way. It is the set of operations that are performed using a combination of digitised data and technological tools. An example is the digitisation of a typed text into the memory of a computer and its transmission to another computer in a coded form from which it can be read out again.

However, the concept of digitalisation is no longer just about transferring a text, image or sound into a computer-readable, coded form, but also about creating a new, more complex and higher level of automated unity of machines, data, processes and people.

Digital transformation is putting business and work processes in a whole new perspective. It harnesses technological tools and automation to increase efficiency, create new business/revenue opportunities, manage and

* *This publication is translation of an article published in the Hungarian textile periodical* Magyar Textiltechnika, *see here: http://www.lazarky.hu/08pub/44_Digitalizacio.pdf*

minimise risk. It addresses all aspects of the business. It differs from digitisation and digitalisation in that it is more people-centric. It's about change that is customer-centric, supports employees and managers, makes their work more seamless and faster.

Digitalisation is based on **data**, which is expressed by a numerical value (digit). It can be the code of letters in a text, the instantaneous coordinates of points in a diagram or the spatial position of an object, the frequency of a sound, the wavelength of a colour, the instantaneous value of a quantity measured by an instrument – all data that can be stored, modified, processed, transmitted, re-displayed. The data operations in digitalisation are performed by computers controlled by software. The computer converts the quantities that we can see, hear and perceive into physical quantities (electrical or magnetic signals), which the machine itself then uses to perform the required operations – digitalisation – with the help of a pre-loaded program (software).

Machine-to-Machine communication – M2M

Machie-to-Machine (M2M) communication means networked machines being interconnected that communicate with each other without human intervention. It is based on the use of sensors that continuously transmit their data – digitally, of course – to a central system and from there to another machine. In this way, two or more machines exchange information directly with each other, either wirelessly or by wire. The M2M system can be used to control machines and equipment, collect data, signal faults, report maintenance needs, check the amount of material being processed (before it is completely used up), etc. Such machines are called *smart machines*. Many IT companies are developing such systems, also in cooperation with machine manufacturers, and they could certainly be used in the textile and clothing industry.[7]

Internet of Things – IoT, IIoT

Internet of Things (IoT) refers to networked “smart” devices that use built-in sensors to collect data and transmit them to other devices over the internet network, and automatically trigger them to take action when necessary. In the textile and clothing industry, this is the industrial version of the *Industrial Internet of Things* (IIoT) which is capable of processing very large amounts of big data, machine learning and “cloud computing”. (Cloud computing is not run on a specific hardware device, but distributed across the service provider's devices, with the operational details hidden from the user. Services are accessed by users over a network, via the Internet.)

IIoT exploits the combination of smart machines and real-time data analytics, and therefore smart machines provide important information faster and more accurately, which can be used to make business decisions faster and more accurately.[8]

Virtual and Augmented Reality – VR/AR

Virtual reality (VR) becomes “visible” when you put on a pair of glasses and, completely blocking out reality, you appear to enter a space where an event is taking place. It is in fact an illusory world created entirely by a computer. Its application is mainly found in computer games, transport simulations (flight simulators, driving simulators), training in complex operations, etc. In plastic surgery, such solutions can be used to agree the expected outcome of the operation with the patient in advance. At the same time, in addition to planning the surgery, doctors can perform the surgery on virtual models of the patients, before the actual surgery, thus reducing the risks of the real surgery. Another option is to allow customers to view and walk through virtual models of designed buildings or real estate for sale using VR goggles and helmets. Virtual reality can play a major role in illustrating educational material (e.g. geometry, science subjects, art history).[9, 10]

Augmented reality (AR) is a kind of virtual (apparent) extension of reality, for example when virtual elements are projected into the real environment using a dedicated device. An example of this is the way clothing is designed by projecting an image of the garment to be designed onto a real-life model to see if it fits the wearer's body (Figure 2). A similar process is to project an image of the machinery, equipment or decorations to be installed in a room onto a real image of the room and design where it will be placed in the real space.

Fig. 2. Dress trying-on in augmented reality [11]

Augmented reality is part of **mixed reality**: it describes the combination of real and virtual environments. For example, the person (mannequin) is real, the clothes designed are virtual, or the factory floor is real and the machines to be placed there are virtual.

These two areas are considered to be of great importance for the future. The use of VR/AR technology can provide more safety and save time. Some reports cite a 46% time saving and a 32% increase in productivity, which of course also means monetary savings.[12, 13]

Role of digitalisation in the textile and clothing industry

The global textile industry is expected to grow by 4% a year between 2022 and 2030.[14] A well-organised, sustainable value chain, including an important role for digitalisation, is essential to ensure a smooth supply chain. In this sense, digitalisation in principle means that the entire process of textile production can be tracked, from the design, through the sourcing of materials and all stages of production, to the delivery of the product to the consumer and possibly beyond, to the destruction of the end-of-life product by whatever means. This can be done by recording all the states of the product as data and processing them again and again as data, for example by recording them so that they can be retrieved or by passing them on to the next stage in the production or marketing chain so that the operation can be carried out under optimum conditions.

Digitalisation in administration is already widespread everywhere, including in the textile and clothing industry. Data on personnel, labour, production, warehousing, purchasing, delivery, finance, etc. are now stored and processed almost entirely in digital form on computers. In our country, too, this goes back several decades, starting in the 1980s when the first personal computers appeared in factories.

At the same time, production machines, controlled by electronic equipment and programmable by computer, gradually appeared and spread in all stages of textile and clothing production, from the design of the product (fabrics, models) to textile cleaning, and automatic machines, equipment and production lines based on this technology appeared.

Product design

In the past, the design of various textile patterns (whether they were modifications of the fabric structure or surface patterns created using textile printing techniques) was a paperwork: the pattern had to be drawn, coloured, the technical documentation for creation of the desired structure (knitted, woven, lace fabric pattern) had to be written down, the shape of the garment had to be drawn on a drawing board, the patterns for its production had to be edited on a drawing board, etc. Today, various software tools are available for the aesthetic and technological design of textiles.

Clothing design – and more generally the design of made-to-measure products like furniture covers etc. – can be done on screen, using the drawing and colouring tools provided by the hardware and software, the necessary modifications can be made on the screen, too, and the finished design ca be displayed spatially, and finally, the complete work can be simply printed from the computer (Figure 3). There are software tools that can be used to carry out the preparation work for cutting: grading, designing of the lay-up scheme (Figure 4), and recording it in digitised form so that it can be transferred to the automatic cutting machine using some kind of data carrier; automatic calculation of the amount of thread needed for the seams can be carried out which saves a lot of computing and writing work and avoids

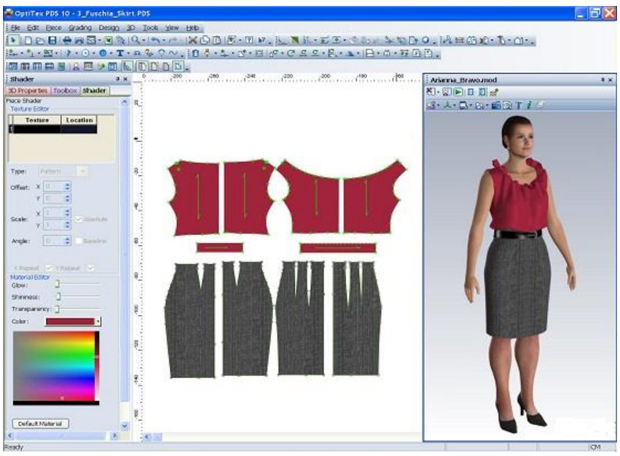

Fig. 3. Clothing design on screen [15]

errors and mistakes. For this whole process, there are different, but mostly compatible, software tools that can use each other's data. Thus, the garment factory has the possibility to carry out all the design, registration and data processing operations necessary for production,

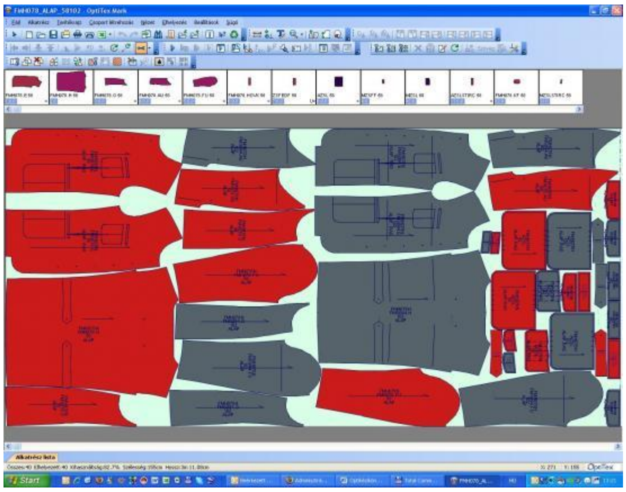

Fig. 4. Lay-up scheme on screen [16]

from the design of the garment to the production of the pattern, on a computer. This allows high precision and thus improved quality, shorter lead times and reduced labour costs.

For modern fabric production machines – weaving, knitting, braiding or lace-making – the design of the **structural pattern** to be produced can be done on a computer screen (Figure 5). Depending on the technology, the yarns or the structural elements that move them must be moved in different ways: on a weaving machine, the individual warp yarns or the healds, on knitting machines the needles and yarn carriers/guides, on braiding machines the bobbins, etc. must be moved in different ways. The modern machines and their patterning devices are nowadays largely electronically controlled, so that the digitised data of the pattern designed on the computer screen can be transferred directly or by means of a data carrier to the machine's control unit, so that the machine produces the pattern accordingly. In this way, the sample can be designed faster, with fewer errors, and the changeover to the new sample can be faster, which means higher productivity. The most recent developments are to store the samples designed in the corporate centre in the "cloud" and to route them on-the-fly directly to the appropriate production machine in case of pattern changes.

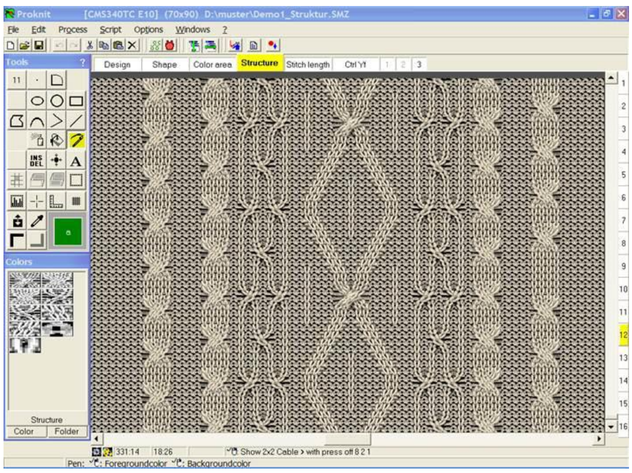

Fig. 5. Knitted pattern design on screen [17]

Colour-printed patterns used to be applied to fabrics on roller printing machines, but nowadays they are applied mainly by screen printing. In a process that has recently also become very popular in the textile

Fig. 6. Digital printing [18]

industry, called *digital printing* (Figure 5). Here the design is created also on a computer and the program is transferred to the textile printing machine, which injects the different coloured inks in tiny droplets onto the chemically pre-treated fabric in the programmed patterned areas, using inkjet technology. The fabric continuously passes under the row of ink injecting heads, which are positioned across the full width of the fabric - or, in other solutions, moving back and forth across the width of the fabric, to produce the multicolour pattern. This process also allows the pattern to be printed directly onto the fabric in a shape corresponding to the pattern of the parts, from which the parts can then be cut out by the usual tailoring processes, after the post-treatment procedures associated with the dye-fixing process.

Machine control

In the early days, Jacquard-type pattern guides used on various fabric making machines and embroidery machines were mostly punched cards and punched tapes. In today's modern, increasingly automated machines, this role is performed digitally by computer: the operation of the machine elements (needles, jacks, yarn guides, etc.) involved in the patterning process is controlled electronically. The same applies to operations that require a particular structural element to be switched on or off or to change its speed or direction of movement: this also requires digital programming. On such machines, various manual interventions can be initiated via touchscreen control panels (Figure 7).

Fig. 7. Touchscreen control panel on a weaving machine [19]

Stock records

Stock record systems record the origin, type, quantity and date of input to as well as issue from the warehouse. With traditional means, this was done by manual recording (writing down the data) on paper or spreadsheets and changes (for example, the stock at any given time) were recorded by calculating the difference between the incoming and outgoing data. (It is not surprising if inadvertent typing or calculation errors resulted in incorrect data being recorded.) Today, with dedicated software, data recording and calculation of changes can be done by computer and the current status can be available and viewed at any time, even printed on paper. Data from the different registers can be automatically transferred to each other, which speeds up operations and reduces the risk of errors. The IoT system can help to continuously process large amounts of data.

A prerequisite for digitised stock records is that the incoming product has a signal on it that can be read by a device, transmitted to a computer and stored there. If the location of the product in the warehouse is deter-mined by a device placed there and the coordinates of the location are trans-mitted to the computer, this location can be read at any time and the product can be easily located. If the product is removed, this circumstance and the new location (e.g. the place of use) can be detected again by reading a signal on it – i.e. the movement of the product can always be traced.

All this requires that the product has some kind of signal that the sensor can detect. This could be, for example, an optically readable tag (bar code or QR code) or an RFID tag (short for Radio Frequency IDentification) (Figure 8) attached to the product or its packaging, whose passage through certain points is detected by a sensor and transmitted as data to a computer. In this way, the location and movement of the product, together with all the other data originally entered into the computer, can be determined, recorded and processed as data.

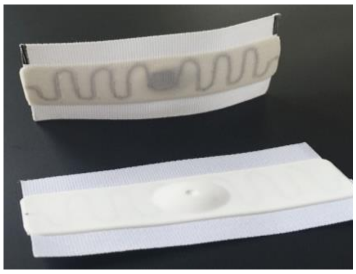

Fig. 8. Washable RFID tag used in textile cleaning

Production control

Ther are sets of programs that, via the computer, is connected to the transponders of each production machine which, together with the basic machine data (make, type, etc.), provide instantaneous data (speed, rpm, temperature, etc.) on the machine's performance and process parameters. Thus, using IIoT technology, it is possible to display at any moment the status of all the machines in the plant, their possible malfunctions and to collect aggregated data per unit of time. Such software helps the plant manager to constantly monitor the operation of a given fleet of machines and to take action if intervention is required (e.g. due to abnormal operation or a machine stop). The machine can even communicate the cause of the fault, for example in the event of a yarn break or a fabric fault, if the stop signal from the yarn detector or fault sensor is transmitted not only to the machine control unit (the circuit breaker of the operating circuit) but also to the computer and displayed there. In such a case, statistical processing of the frequency of faults is also possible. Production control software can also be linked to stock records to ensure that a continuous supply of material is guaranteed and to detect possible shortages.

In modern plants, the production management software is accessible online (via the internet), so the plant manager can check the production rate even when he is not present.

Clothing retail trade

E-commerce, i.e. commercial activity conducted over the internet, is a typical case of digitalisation and the use of IoT systems. The retailer uploads the image and main properties of the products in its stock in a digitised form on its website and the sale itself – the selection, ordering and payment of the price by the buyer – is carried out with the help of the Internet. This of course requires that the buyer has access to all the information he needs, in addition to the image and price of the product (possibly shown from several directions), such as size, colour, quality and various usability data.

Digital shelf labels (electronic shelf labels, ESL – electronic ink based digital displays) are also being used in retail, logistics and even industry (Figure 9). Digital shelf labels display prices based on the store's cash

Fig. 9. Digital shelf label on garment [20]

register database, ensuring that customers always see the same price on the shelf as in the cash register. The cash register IT system communicates with the shelf labels using radio frequency signals. The so-called fashion TAG labels introduced in the German clothing retailer in Germany display the current stock and price in electronic form. In the fashion retail sector, this digital price tag has an attractive design and finish that even encourages consumers to buy.

According to US experience, technologies that can “move” goods (virtually) through the supply chain with minimal human intervention are also becoming increasingly popular among retailers. Automation of the supply chain and minimisation of labour can bring significant efficiency gains. This area is becoming increasingly important as retail sales increasingly bypass

Fig. 10. Scanning with body scanner [22]

stores and wholesalers and go directly to consumers. Smart shelves, cameras and RFID chips on products in stores or warehouses can be used to instantly update inventory records of retail goods. They also enable faster coordination between retailers during restocking. [21]

A related area of clothing retail and sizing is **digital sizing**. The garment to be made for the customer requires the determination of the main body measurements, which can be done by taking three-dimensional photographs, using so-called body scanners (Figure 10) and evaluating the photographs using appropriate computer software, or simply by computer evaluation of front and side views of the body, also using computer software.[23]

Digital Product Passport

The Commission of the European Union published a plan for the production and marketing of more environmentally sustainable, circular products in March 2022 as part of the European Green Deal. Its proposals aim to make sustainable products the norm in the European Union, to promote circular business models and to enable consumers to actively and consciously support the green transition. This would be facilitated by the *Digital Product Passport* (DPP), which would be available on all products placed on the market, including textiles and clothing (Figure 11). It would contain all the key information on the material composition of the product that could help it to be repaired, reused or recycled, or to be properly treated in waste treatment facilities, and would help to trace substances of concern through the supply chain. The idea is to implement the objectives of the EU Strategy for a Sustainable and Circular Textile Industry by 2030, including the uptake of the use of digital product passports.[24]

Fig. 11. Digital Product Passport [25]

Smart clothing

Smart garments are also typical examples of digitalisation and IoT solutions in the textile and clothing industry. Smart garments are products that, with the help of built-in sensors, continuously transmit information wirelessly via Wi-Fi or Bluetooth to an external monitoring device about the wearer's physical condition, the functioning of certain organs (e.g. heart, lungs, muscles), temperature, muscle tone, etc. (Figure 12).[26] They may also

Fig. 12. Smart clothing for built-in body health monitoring sensors [26]

include entertainment electronic devices, telephones, light sources. Smart clothing often also has a built-in solar panel.

The latest developments involve the use of thin, flexible sensors, actuators, electronics, mobile connectivity and even nanogenerators in the fabric of the suit. The combination of all these gives in-smart clothing new functionalities. Experiments are also underway to develop textile-based solar cells for use on smart clothing.

One of the most important challenges in the development of smart clothing is to achieve and combine different properties (elasticity, flexibility, wearing comfort and miniaturisation of components, possibly fashionable look). To achieve this, researchers are using different materials such as nano-materials, polymers, di-electric elastomers and composites. These are adapted to the specific application depending on their different characteristic response to different stimuli.

Intelligent garments play a major role mainly in distinctive sportswear, protective clothing and military uniforms, although some applications also capture the imagination of fashion designers (e.g. producing light and sound effects in response to certain external conditions).

Use of the artificial intelligence

There is a lot of talk these days about artificial intelligence (AI) and its potential applications in a wide range of places, including the textile industry and trade. Professionals have high hopes for it, and it is developing at an enormous rate.

Artificial intelligence, in particular its Artificial Neural Network (ANN) version, is recommended for the textile industry in some fields [27][28]:

- *Identification of fabric defects.* – Any defects in the fabrics are transferred to the final product which may result in rejects. It is therefore very important to check the quality of the fabric before further processing. Inspection of fabrics by visual inspection is slow and often not reliable enough. The use of artificial intelligence for this purpose shows faster and more reliable results, because it uses information about the used yarn and fabric structure.
- *Pattern checking.* – To visually check the textural or colour pattern of the fabric, the fabric image to be analysed is collected in the image collection system and the system “learns” the pattern, colours and any discrepancies that are still present from these images. Any deviation from these is immediately and automatically indicated.
- *Colour matching.* – The colour of the fabric is judged by eye as “acceptable” or “inappropriate”, possibly in more detail as “too light” or “too dark”, or more specifically as “too red” or “too green”. The “learning capability” of AI may enable it to indicate these quality indicators automatically, based on optical observation.
- *Dyehouse application.* – Interactions can occur between the dyes used in a recipe, in their combinations, or in use of a certain substance or a slightly different process, which can cause the resulting colour to be slightly different from the desired one. Based on the colour measurement data, AI will then search the database for similar colours in the same material and suggest recipe modifications.
- *Cutting.* – Artificial intelligence can help reduce the amount of waste generated during the cutting process, by optically observing the movement of the fabric and its possible deformations, and modifying the originally loaded program for optimal placing of the components.
- *Production planning and control.* – Production planning and control coordinates the cooperation between the different departments of production to ensure that delivery times can be met and customer orders can be fulfilled on time. Artificial intelligence can be used for machine scheduling, operation scheduling, balancing the performance of different elements of the production chain, preventing and predicting defects, etc.
- *Quality management.* – Artificial intelligence can support quality management by collecting data by continuously sensing the production process with sensors, and if it detects any deviation from the previously collected data, it will give a signal and at the same time an instruction to make the necessary changes and implement them automatically.
- *Final product quality control.* – In-process quality control of finished and semi-finished textile products is essential to achieve less waste. Final quality control of finished garment products is usually carried out by trained professionals by visual inspection and possibly by measuring. The result may be influenced by the physical and mental state of the inspector. Automated inspection using artificial intelligence improves efficiency and accuracy. A combined application of image processing and artificial intelligence can be used.
- *Supply chain management.* – This activity involves the flow of all materials and semi-finished products in the manufacturing process between the different production points, up to the retail level. It integrates the different business processes, activities, information and resources. Supply chain management, supported by artificial intelligence, can manage cost evolution and competitiveness.
- *Retail sale of clothing.* – In clothing retail, especially in e-commerce, artificial intelligence helps to identify images and recommend products that can be ordered online and are more likely to be purchased by the customer. It is able to exploit the information available about shoppers, as well as their preferences, similarities and differences in the types of applications and products they are looking for. In this way, artificial intelligence can create a truly personalised shopping experience.
- *Market data analytics.* – The intervention of artificial intelligence can help the industry not only to analyse large amounts of data, but also to predict consumer trends, making commercial activity error-free and better adapted to customer needs.

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