**H I S T O R Y**

**SCIENTIFIC MANAGEMENT**

***Taylor, Gantt and Ford***

**TAYLORISM**

Frederick Taylor formulated the **production management theory**, a scientific approach to manufacturing and

production. It was based on **three pillars**:

* **Management**: it must **take part** in production by constantly **collecting** and **analyzing** data in order to **improve** the process (which was to be regulated by a guideline called **process cycle**);
* **Owner**;
* **Employees**: worker’s operation must be as **elementary** as possible, in order to avoid the need of **skilled people**.

This laid the foundation for the birth of several **professional figures**:

* **Manufacturing engineer**: he defines the **process cycle**, as well as all the **tools** and the **equipment** needed to reach the **production target**;
* **Layout engineer**: he studied the **optimal** equipment, material and workplacement according to the **goals** of the company;
* **Plant staff**: it’s made up of all the figures **below** the engineers, that is to say workers, managers and so on, that **execute** the operations to reach the company goals.

**GANTT DIAGRAM**

Gantt diagram is a **bar chart** that shows the evolution of a project schedule, split in its **elementary** **phases**:

* On the **horizontal** axis it shows **time** **intervals**;
* On the **vertical** axis it shows the **tasks** to be performed;
* It shows the **current schedule status** through a vertical line.

**FORDISM**

During the same years, Henry Ford founded his company and put into practice Talor’s principle, giving birth to the era of **mass production**: goods are now produced in **high volumes** and **standardized versions** with a **low price**, so as to allow even **workers** to buy them despite their low wages.

***The synchronous transfer line***

With Ford, manufacturing system switched from **job shops** – where every operation is executed by a **specialized worker**, so parts follow a **different path** through the same machines – to **flow layouts**: manufacturing operations are executed by **specialized machines** (the transfer line), and workers are only responsible for **assembling**.

The transfer line is made up of a **multi-spindle head** (designed to do a **unique task** for each operation), a **walking beam**, a **lift** and a **translate rail** and the handling is divided into 4 phases:

* **Carrying**: the piece is **carried** to the station;
* **Lift-up**: the piece is **freed** from its fixture;
* **Translation**: the piece is **carried** to the next station;
* **Engaging**: the piece is moved on to **engage** the pins of the next workstation.

More specifically, in a **synchronous transfer line**, workers do their job at the **same time**, with material passing over or under their position: (being the distance between to workstations and the line speed).

**THE 60s AND THE ASYNCHRONOUS LINE**

***The social impact of mass production***

The **impact** of mass production on workers was very **discussed**: despite being highly **productive** and **reliable**, it required high **investments** to handle any kind of **diversification** of the product; on top of this, it caused **stress** and **alienation** to workers, who were reduced to mere **executers** and didn’t develop any **relation** with the final product. This led to a period of **strikes** and **conflict** between workers and employees, and the problem was approached in two different ways:

* Switching from series work to **parallel**, in order to **put** **together** workers and avoid alienation;
* Introduce **robots** to complete the heavy and **repetitive** work, and leave workers to **coordinate** and **maintain** the machines.

**IN ITALY**

In Italy, **Adriano Olivetti**’s vision was based on two pillars: the **integration** between factory and city life and in the future of **information technology**. To fulfill his idea, he:

* Created a center of **psychological research** as well as the **Manufacturing Integrated Unit UMI**, a group of workers responsible for **quality** of the final product;
* Created the first advanced **computer technology company** in Europe by putting together **free minded** **people** from any kind of field and encourage them to work in a **de-structured** **way**.

**IN JAPAN**

In Japan, Fanuc engineer **Seiuemon Inaba** followed the same ideas as Olivetti, but focused his attention on how **computers** could support manufacturing: it was the birth of **CNC and robotics**. For this reason, he started building factories where workers could **live in** and started producing **robots** with idea of **using** them inside Fanuc and **selling** them to companies. He created an assembly model where:

* The product is **conceived to be assembled** by a robot;
* Components are **selected to avoid** jamming and breakdowns;
* Set-up activities are **avoided**.

Products to be assembled are located on **pallets** and have a **magnetic tag** (RFID) that allows workers to **write** all the necessary **features** and **upload** the information on a **central computer**.

***Asynchronous groups***

They were defined by elaborating Olivetti’s UMIs in the **automotive field**. An asynchronous group is a **parallel** **line** were:

* The only **restriction** workers have is to guarantee an **average cycle time**;
* Workers develop more **relation** with the final products (they’re half way between craftsmen and unskilled workers).

Since a single group was not enough, asynchronous groups were organized in **series** (divided by **buffers**) with **6 to 18 workers** for each group.

**THE 80s AND FLEXIBILITY**

***The concept of flexibility***

At the beginning of the 80s, customers started to demand **different versions** for the same products; this is why the concept of **flexibility** was formulated as “the ability to work in an assigned field with medium costs of production and conversion in case of new needs from the market”. Flexibility is based on **four pillars**:

* **Adaptability**: the ability to produce **different products** with the **same machinery**;
* **Convertibility**: the ability to **modify** plant and machines for **new purposes**;
* **Versatility**: the ability to **control** burden costs by modifying the **product mix**;
* **Elasticity**: the ability to **absorb** demand variations without and unbearable increase of costs.

***The Flexible Manufacturing System FMS***

With the birth of the concept of flexibility, companies acknowledged the fact that the transfer line was not compatible with the new needs of the market anymore: the **CNC Machining Center** was introduced. It’s a CNC machining tool that can perform **several operations**. It’s made up of:

* **Spindle**: it moves and executes operations;
* **Automatic tool-changing mechanism**;
* **Table**: it has pallets and a fixture.

Several CNCs form a **Flexible Manufacturing System FMS**. It’s equipped with:

* **Work piece and tool-changing handling device**;
* **Work piece store**;
* **Automatic control and supervision**.

**LEAN MANUFACTURING**

***The birth of lean production***

After WWII, Toyota was facing a hard crisis, so Management focused on solving **two main problems**: dealing with the **stamping process** – which took a long die change and a long set-up – and reducing the **initial** **investment**; the problem was formulated as “to find a way to produce small batches in one single press minimizing the changeover”. The actually manage to reduce the stamping process, so the system was named **Single Minute Exchange Die SMED**.

***Elements of lean manufacturing***

**ECONOMIC ORDER QUANTITY VS BATCH = 1**

Western companies used the **Economic Order Quantity EOQ methodology**, which represented the ideal size of production that **minimized costs** while **satisfying demand**; , with:

* **cost of setup** per unit;
* **annual demand**;
* **holding cost** per unit.

Since it follows the pull system and there’s no annual prediction, Batch = 1 methodology is based on **three** **assumptions**:

* The **tools** required by machines are **always available**;
* All the **equipment** necessary to assembling are **available** in the **line side**;
* For **complex machines** and **stamping** .

This approach focuses on producing according to the **final mix** target while minimizing the **inter-operational stock**.

**JUST IN TIME**

Per Little’s law, : in order to have a **low lead time**, a **low WIP level** is required. For this reason, Toyota invented the **Kanban system**:

* For each line or department, materials are joint with a **card** (Kanban, which are **limited** in number) and is **freed** only when it’s been **delivered** to a customer, enabling a new **supply**;
* Every line or department creates a **link** with suppliers to have new material batches in a **predefined** **time** (relationship with suppliers plays, in fact, an important role in lean production).

**TOTAL QUALITY CONTROL**

Perfection is achievable only through **continuous improvement**, which is not to be performed by specialized workers, but by **line workers**, who knew the product better than anyone else. if an issue was spotted, workers **stopped** the line immediately (**poka-yoke technique**) and **repaired** it themselves (**self-repairing technique**) to avoid proliferation; for this reason, the concept of **quality ease-to-see** was introduced.

**PUSH SYSTEM VS PULL SYSTEM**

Western companies based their production on the **Material Requirements Planning MRP** algorithm, which:

* Defined **net requirements** of existing stock;
* Defined the **lead time** launch production;
* Defined the **components** and **raw parts** needed according to BOMs.

This system pushed material along the line according to a predefined plan, so it was called **push system**.

However, in case of **lower demand**, stock could **increase** drastically, which was what Toyota engineers wanted to **avoid**. For this reason, the developed the **pull system**: instead, of basing their production on a plan, the based it on **customer demand**, in order to reduce stock.

**NEW TRENDS IN 2000**

***The World Is Flat***

It’s a book that explains the radical changes the world was undergoing in 2000. The author indicated **ten** **factors** that contributed to change the world:

* The fall of the **Berlin wall** and the launch of **Windows**;
* **Internet navigation**;
* **Workflow**: processes are **standardized** and computer allow workers to work from **remote**;
* **Informing**: information was **easier** for anyone to access thanks to the Internet;
* **Uploading**: anyone could **upload** something on the Internet;
* **Outsourcing**;
* **Offshoring**.: companies can **transfer** their businesses among **regions** to improve costs and enlarge markets;
* **Insourcing**: big companies can **support** small companies creating **large networks**;
* **Supply** **chaining**: the supply chain can be **optimized** through **information technology**;
* **Smartphone**.

***No Logo***

It’s a book that describes the new **behavior of customers** at the end of the 1990s. The author explains how customers started buying products not so much for their **quality** but for their **logo** and the **status** it represents; since quality was **less important** than logo, companies started **outsourcing** and delegating manufacturing to **third parties** in order to reduce costs, with no respect for **safety**.

***Automotive in 2000***

Automotive underwent this radical change, too: car manufacturers started to understand the importance of working in **synergy** (through joint ventures), in order to have **shared costs** and **larger markets**:

* They introduced **global cars**, car models thought to be sold in **as many countries** as possible;
* They started looking for the so-called **Best Cost Countries BCC** to acquire components at lower costs;
* They started looking for **new markets**.

**THE JOINT VENTURE**

A joint venture is an **entity** created by two parent companies but **legally separated** from them. The two companies put together a **portion** of their businesses (either equal or unequal) and create a **board** with their respective members, a **CEO** and **Executive Vice President**.

To start up a JV, it is necessary to have a **favorite business case**: the **merged** business plan needs to be better than the **two NPVs** of both of the parent companies; once a JV is started up, the parents companies **shut** **down** a portion of their production and create a plan for the JV that is as **complementary** as possible.

**WORLD CLASS MANUFACTURING**

***WCM principles***

WCM is based on the same principles as lean manufacturing: **workplace organization**, **quality**, **maintenance** and **logistics**; each of these pillars is concentrated in four goals:

* **Zero wastes**: achieved through **total industrial engineering**;
* **Zero defects**: achieved through **total quality control**;
* **Zero breakdowns**: achieved through **total productive maintenance**;
* **Zero inventory**: achieved through **just in time** methodology.

***WCM pillars***

WCM is based on ten technical pillars and ten managerial pillars. For each technical pillars, WCM follows a **7-step approach**, with each step going from **reactive** to **preventive** to **proactive** to allow improvement.

**HEALTH AND SAFETY**

Safety properties are treated with a **pyramidal scheme**: from bottom to top we have **unsafe acts and condition**s, **near misses** and **accidents**.

**COST DEPLOYMENT**

It’s a methodology used to establish a **cost reduction program**. It’s based on three concepts:

* **Cost**: it’s a **useful outcome** (like maintenance);
* **Loss**: it’s a **useless outcome** or a **missed income** due to the ineffective use of an input;
* **Waste**: it’s the **excess of amount** of something.

Cost deployment is divided into **two phases**:

* Identification of the **main losses** and their **causes and amounts**;
* Planning of **resolution strategies**, followed by a **projects list** and a **cost/benefit analysis**.

**AUTONOMOUS AND PROFESSIONAL MAINTENANCE**

It consists in the delegation of **machine maintenance to workers,** resulting in improving reliability and reducing costs.

**BUILT-IN QUALITY**

This approach focuses on the preventive implementation of **error-proof solutions**.

**INTRODUCTION TO ELECTRIFICATION**

***Background***

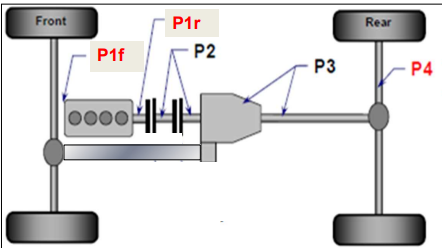
For the last 25 years, governments have been introducing **more restrictive regulations** on emissions, so companies have acknowledged the fact that new engines are not enough: vehicles need to be **electrified**.

Since 2020, Europe has fixed the CO2 target emissions at **95 gCO2/km**; this value is based on the **average mass** of cars. Unfortunately, this creates a **paradox**: light cars have to be **necessarily** **electrical**, while heavy cars can just be **hybrid** (or even not electrical at all); in this way, emissions are **shifted** from consumers to **manufacturers**.

***Electric vehicle glossary***

These are the main **criteria of classification**:

* **Voltage**: the range of **autonomy is proportional to voltage level**: being and , **low** **tension** values allow the car to have **more** **current** but also **more** **losses**;
* **External charging**: plug in systems allow a clean recharge;
* **Structure of electrical motor and traditional engine**: parallel or series.

**HYBRID TYPES**

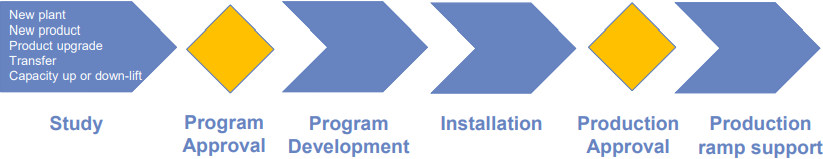
There are **four types** of hybrid cars, according to the **position** of the **electric machine**:

* **P1f**: the e-machine is mounted on the **front** end **before the clutch**;
* **P1r**: the e-machine is mounted on the **front** end **behind the clutch**;
* **P2**: the e-machine is mounted on the **transmission input**;
* **P3**: the e-machine is mounted on the **transmission output**;
* **P4**: the e-machine is mounted on the **non-drive axle**.

**MAIN COMPONENTS**

The main components of an electrical car are: **battery pack**, which is inside the vehicle perimeter, the **electric** **drive motor**, the **battery** **module** and the **electric motor**, which are inside the powertrain perimeter.

**P R O D U C T I O N**

**MANUFACTURING ENGINEERING PROGRAM**

***Study phase***

A manufacturing engineering program is divided into **four phases**, separated by two **program approvals**.

The **study phase** is divided into **four steps** and follows the **I/O methodology**: each step uses as an input its predecessor’s output:

* **Process cycle study**: its inputs are the **BOM**, a **mechanical drawing** and a **volume** to be produced for each component analyzed. Its output is the required **machines and tools** for each operation (in case of **manual assembly**, it defines the **manpower time** needed, too);
* **Concept layer**: it synthesizes the process cycle with **material flows** and **manpower distribution**;
* **Plant engineering design**: it uses concept layer’s output to define the required **buildings and utilities**;
* **Economic evaluation**: it defines the **investment** needed to cover everything that’s necessary for production and the **transformation** **cost** of the plant.

After this phase, the first **program approval** compares **different scenarios** and chooses the best one.

***Program Development and Installation***

Once the program has been approved, all the aspects need to be defined **with major precision**:

* The **building** needs to be **prepared**;
* **Machines** have to be **designed and installed**;
* **Workers** need to be **trained**;
* The **logistic process** has to be **certified**.

These two phases are followed by another **program approval**, after which there is **production ramp support**.

**PRODUCTION CAPACITY AND EFFICIENCY**

***Production capacity***

Production capacity is calculated on the basis of **annual demand prediction**, but it has some **ground rules**:

* The **variability** of demand;
* The possibility to **adapt** capacity;
* The product and process **flexibility**;
* The **efficiency** and the effect of **variability** on it.

Target production capacity is then used to calculate **machine rate**, which is the **number of products per time** **unit**, and **cycle** **time**, which is the **time needed to produce one unit**.

***Efficiency***

There are two main **definitions** of efficiency:

* **Availability**: , it’s the ratio between the time to **failure** of a machine and the sum of time to **repair** and to **failure**;
* **Overall Line Efficiency OLE or Operational Efficiency OPE**: , with:
* **Actual Production Time APT**: (being the **actual production**);
* **Available Time AT**: (being the **scheduled downtime** and the **losses**).

In order to compensate the **lack of efficiency**, machine rate must be **higher** and cycle time must be **shorter**: and ; this has to be done for **every operation**: to maintain the target cycle time, all operations must have a cycle time that’s **lower or equal** to .

If all operations were **independent**, the overall efficiency would that of the **bottleneck** workstation, but in a real line all operations are **depending** from one another, so the actual efficiency is **lower**: every time a new line design is proposed, it is tested through an **iterative process** until a **satisfactory result** in terms of efficiency forecast is reached.

***Series vs parallel efficiency***

The CNCs that made up an FMS can be organized in **two ways**:

* **Series line**: in order for the FMS to have production, **all the machines** have to run, so the efficiency is ( being the efficiency of a single machine). It’s **cheaper** and **easy** to manage;
* **Parallel line**: there’s no need for all the machines to run to have production, so . It’s more difficult to manage but it’s more **efficient** and more **flexible**.

**POWERTRAIN TECHNOLOGIES**

***Powertrain assembly***

It’s the most common operation in powertrain; it’s **reversible** and **sequential**, and it can be **automatic** or **manual**. The two main technologies for assembly are **inserting with pression** and **tightening**; on top of this, a series of **tests** is taken, like **leak** test, **hot/cold** test, **electric** tests or **mechanical** tests.

***Powertrain machining***

**MACHINING TYPES**

Machining is a process in which **metallic** parts are **cut** in order to obtain a certain **shape**. There are two main types of machining:

* **Prismatic**: the **part is fixed** and the **tool is rotating** on a spindle;
* **Rotating**: the **part is rotating** and the **tool** is mounted on a tower and **slowly moving**.

**MACHINING TERMINOLOGY**

Here’s the terminology used in machining:

* **Cutting tool**: it’s the part of the machine **in contact** with the part;
* **Reek angle**: it’s the angle between the **cutting tool** and the **original surface**;
* **Cutting chip**: it’s the **excess of material** that has to be removed. It is usually **thicker** and **tougher** than the original metal, and must be correctly managed to guarantee **quality** and **cleanness**;
* **Coolant**: it’s a fluid used to **reduce the heat** and maintain the **temperature** of the part inside an acceptable range.

**MACHINING OPERATIONS**

The main machining operations are:

* **Turning**: it’s a **rotating** operation used to get a **cylindrical shape**;
* **Drilling**: it’s a **prismatic** operation used to **create a hole** in the workpiece;
* **Boring**: it’s a **refining** **prismatic** operation used to **enlarge** and **refine a hole** inside the workpiece;
* **Milling**: it’s a **prismatic** operation used to get a plain or straight **surface**.

**QUEUING THEORY**

***Definition and general aspects***

The queuing theory studies the phenomena happening **between** the customer arrival and the service:

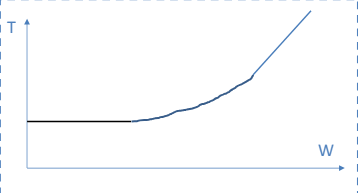
* **Open stationary systems** made up of **infinite customers** with an arrival rate **minor** than the service rate;
* **Closed stationary systems** consisting of a **finite number** of customers (most of manufacturing systems);
* **Dynamic systems**.

***Little’s law and main functions***

A very important pillar of the queuing theory is Little’s law, :

* is the average number of **customers** or ;
* is the average **arrival** **rate** or ;
* is the average **time** that a customer spends in the system.

The importance of this law is due to the fact that this relationship is **very little affected** by any kind of factor.

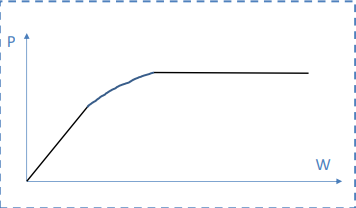
**AVERAGE TIME**

There are two main areas that can be evaluated:

* **Low** : time is constant and is the **sum** of technical time and cycle time;
* **High** : time **grows linearly** with the customers.

With , we **always have** : there is **no queue**.

**AVERAGE ARRIVAL RATE**

Its behavior follows the relationship :

* **Low** : the throughput **grows linearly**;
* **High** : the throughput stops growing and is equal to the **bottleneck**.

With there’s queue, so ; being , we have .

***Open system/single server***

It is indicated with the notation , so this system is characterized by:

* Infinite customers with arrival rate (Poisson’s law);
* Single service with service rate (Poisson’s law).

Being , we have:

* **Probability that there is no queue**: ;
* **Average time a customer spends in the system**: ;
* **Average time a customer waits in the queue**: ;
* **Average length of the queue**: .

***Conclusions***

Besides the several formulas, it’s important to know that:

* system can be used for services with **high number of customers**;
* is usually **not used** because it is shorter;
* has a large range of application in **building** and **utilities design**;
* **None** of the open systems can work for a **closed system**;
* There are some **iterative algorithms** that can reach a good level of approximation, but the best way is to use **simulation** with a better definition of the statistics.

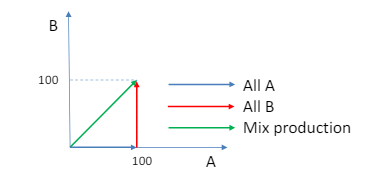
**PLANNING AND SCHEDULING**

***Planning***

It is realized through **linear programming**, an algorithm that can be described as the **minimization** of an **objective linear function** submitted to one or more **linear constrains**. Capacity planning has **two goals**:

* Obtain the selection of the **maximum production feasible** in the line horizon;
* Obtain the **optimal tool configuration**.

***Scheduling***

Its goal is to obtain the optimal order of production. The most used tool is the **mix production algorithm**, which is based on a general law: “a cumulated production aligned to the final mix minimizes the inter-operational stock”. As a matter of fact: if a product is made up of components **A and** **B**, producing **one component at a time** will result in having **100% stock** of each of them before delivering; by producing them at the **same time**, stock is **always 0** instead.

**LOGISTICS AND FLEXIBILITY**

***ABC approach***

Giving more importance of flexibility meant for the companies to pass:

* From one manufacturing volumes to **many volumes**;
* From one list of components for product to **many lists**, called Bills of Materials BOMs;
* From one destination for component to **different destination**.

The problem of flexibility was divided into three subproblems (**physical transport**, **optimal** **packaging strategy** and **internal logistics**) and was approached scientifically through:

* **Pareto law and diagram**: according to the **Pareto law** “80% of an achievement is determined by 20% of its causes and vice versa”. Pareto **diagram** shows the **cumulating percentage** of a population of tasks from the **most important** to the least;
* **ABC analysis**: products are divided into **three classes**, from A to C, according to their **dimensions** or their **annual consumption value** (class A products are to be reordered frequently, while class C products need to be ordered rarely);
* **Kitting**: it’s a **feeding methodology** for an asynchronous line, which consists in giving each work position a **kit** with the product and its components.

**FOOTPRINT EVOLUTION**

***What is a footprint***

A footprint shows the **geographical distribution** of a company’s facilities, mainly its **production plants** and **engineering centers**; it can also show the allocations of the **main products** and the **production capacity**. The official footprints show only the **current status** of the company, but the **work versions** also show the future **evolution** of the plants.

***Footprint management***

In the past, the golden rule for a footprint was: “two products in a plant, two plants for a product”:

* Having **two products in a plant** allowed the company to **compensate** the losses of one with the production of the other;
* Having **two plants for the same product** allowed the company to face **issues** properly.

This rule is not put in practice anymore because it goes **against** the modern goals of **carbon** **neutrality** and **logistics** **minimization**.

**THE PHASE IN-PHASE OUT PROBLEM**

It’s one of the major issues companies have to face. When **switching** production from one product to another, it’s impossible not to have the two products to **overlap**: there will be a period where company’s producing **both** of the products. As a matter of fact:

* The **dismantling** processes take at least **three months**;
* It also takes at least **three months** to **refurnish** the plant;
* **Installation**, **retooling** and product **validation** take at least **nine months** in total.

The electrical transition is an example of a very **complicated** phase in-phase out problem; however, since it’s highly **disruptive**, it has to be treated with unusual procedures with a **gradual** **transformation** of the plants.

**A U T O M O T I V E**

**PRODUCT DEVELOPMENT PROCESS**

***What, how and why***

It’s a project management tool that defines the **methodology** to execute an automotive system program. It specifies the **work** to do and **how** to do it, as well as **rules** and **governance**. Governance is structured on **two** **levels**:

* **Managerial**: it deals with **technical and financial** review, **risk** management and so on. Its decisions are based on **Key Performance Indicators KPIs**, useful to provide new targets and track progress;
* **Operative**: it **monitors** the day-by-day activities on a **weekly** **basis** and **plans** the following ones.

**ELECTRIC DRIVE MOTOR ASSEMBLY**

***Battery Electric Vehicle BEV***

The main parts of a BEV are:

* **Battery**: it generates energy through **DC current**;
* **Power Inverter Motor PIM**: it transforms DC current generated by the battery into **AC current**;
* **Electric Drive Motor EDM**: it replaces the traditional powertrain and includes an **eMOTOR** and a **reducer**;
* **Alternator**: it transforms AC current generated by braking **into DC current** to **recharge** the battery;
* **On-board charger**: it includes the **plug-in system** to recharge the battery.

These components are divided into two groups: the **battery system**, that includes the battery and the **charger**, and the **electric drive module**.

***Electric Drive Motor***

The EDM follows the **3-in-1 archetype**, meaning that inverter, reducer and eMOTOR are managed as a **single** **component**: every piece is designed, manufactured, tested and assembled in the **same plant** and then **shipped** to the vehicle assembly plant. the main trends for automotive companies are:

* The **X-in-1 archetype**;
* To use the **Rare Earth Elements EER Free EDM** with a lower Global Warming Potential GWP as an alternative the current **Permanent Magnet Synchronous Motors PMSMs**.

**INTRODUCTION TO BATTERIES**

***Definition***

A battery is a device that transforms **chemical energy** into **electric energy** through a **redox reaction**. From inside out, we have:

* **Cell**: it defines the **voltage** and the **capacity** of the battery,
* **Module**: it’s a group of cells connected in **series** or **parallel** and it’s responsible for **signal monitoring**;
* **Pack**: it’s a group of **modules**;
* **Battery systems**: it’s made up of **battery packs** as well as **electronics**, **cooling**/**heating systems** and **external connectors**.

**BATTERY CELL STRUCTURE**

It’s made up of two main parts:

* **Cathode**: it contains the **cathodic paste**, a series of **metal oxides** (for cars NMC 811 and NCA+ are the most used), and the cathodic **current collector**, an **aluminum** tape;
* **Anode**: it contains the **anodic paste**, mainly composed of **graphite**, and the anodic **current collector**, a **copper** tape;
* **Porous separator**: it **separates** the two areas both mechanically and electrically.

Both the anode and the cathode are immerged in an **electrolyte**.

**BATTERY CELL TYPES**

Cells are classified according to their shape:

* **Prismatic**: it’s **easy to integrate** and needs **minimum mechanical support**, but it’s very **expensive** in terms of manufacturing;
* **Cylindrical**: it’s **cheap to manufacture** and has a **flexible** design, but it’s **difficult to cool and heat**;
* **Pouch**: it’s **cheap to manufacture** and **flexible**, but it’s sensitive **to mechanical stress**.

***Cells performance evaluation***

**EVALUATION CRITERIA**

Cells are evaluated on the basis of:

* **Specific energy**: it’s the ratio between the **amount of energy** contained and the **weight** of the batter, so it’s measured in ;
* **Safety**: it depends on the **thermal stability** of the battery,
* **C-rate**: it’s the **charge/discharge rate**;
* **Life cycle**: it’s the **number of times** a cell can be charged and discharged;
* **Cost**.

**POWER AND ENERGY**

Batteries can be optimized for power density or for energy density:

* **Power**: they support **fast charges/discharges**, so they have a **higher C-rate**;
* **Energy**: they deliver **less current** but store more energy, so they have a **lower C-rate**.

**ECONOMICS AND EVOLUTION**

The forecast of battery production evolution is:

* **Cell block**: it’s similar to a module, but **bigger** and with **specific dimensions** and number of cells, each of which is **adapted** to the pack;
* **Cell to pack**: cells are directly **integrated** into the **battery pack** by gluing;
* **Cell to body**: pack housing and **body in white** are integrated.

**VECHILE MANUFACTURING**

***Process and manufacturing***

A process is a systematic series of operations performed in order to produce something, while manufacturing is the process of converting raw material, parts or components into finished products. The manufacturing processes for a vehicle are:

* **Stamping**: it includes a variety of sheet metal forming;
* **Welding (Body in White)**: it consists in welding together the sheet metal components of the car body;
* **Paint**: it consists in cleaning and covering the body with layers of chemicals and pigments;
* **Plastic shop**: it includes a variety of polymeric processes, like stamping and extrusion;
* **General assembly**: it’s a process in which parts are added in sequence from one workstation to another until the final product is completed, and it includes testing and final certification.

Between stamping and welding and welding and paint, vehicles are inspected in the so-called quality centers.

***Digital manufacturing validation***

**PLANNING**

It includes different phases:

* **Building modeling**: the building is modeled through laser scanning technology, together with its assets (like machinery and components):
* **Feasibility analysis**: the workplace is simulated with 3D modeling and is tested regarding its safety, ergonomics and quality;
* **3D layout and line configurator**: new production lines are sketched in 3D;
* **Throughput simulation**: it’s a tool that predicts plant performance and helps identifying wastes, losses and bottlenecks.

**DESIGN AND BUILD**

It includes different phases:

* **Virtual Design Reviews VDR and ergonomics**: VDR allows to validate the design of machinery at an early stage, in order to optimize the design;
* **ImMErsive Technology**: different scenarios are evaluated through virtual reality devices;
* **Digital cross sheets**: they integrate all the information required to draft or modify a production line;
* **Offline programming**: it’s a robot programming method;
* **Virtual commissioning**: it’s used to validate the real control systems.