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DENSO industrialization process: development of a new production line in accordance with safety, quality and costs targets.

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"Choose a job you love
And you will never have
To work a day in your life"
[Confucio]

SUMMARY

1. INTRODUCTION

The project, main subject of the thesis, was developed during the internship carried out at the Denso Thermal System S.pA. in the headquarter located in Poirino (TO) where are present activities both of production and R&D/administration.

Denso Thermal System S.p.A. is composed by other two production facilities in Italy located in Avellino and Cassino. Furthermore, are present a lot of plants around the world i.e. Spain, Portugal, India, Brazil, Poland and Brazil. Anyway, this company is just a fraction of the multinational Japanese company DENSO, part of the Toyota group, which counts 212 branches around the world.

The internship was carried out in the process development department who is in charge of the designing and implementation of the assembly lines or production lines necessary to process or produce products following client's requests. My figure in the department was the "assembly specialist". By this commitment I have worked strictly with my colleagues working on different projects. The main project I worked on, subject of the thesis, is related to the construction of a brand new assembly line dedicated to the assembly of an automotive cockpit, named *DTPO-project*. Then I had the opportunity to give my contribution also to other projects as the implementation of a station assembly line for a refrigerator engine for a supermarket refrigerator
and I participated in a supplier trial for an assembly line for the production of an engine cooling module.

Speaking about the *DTPO-project*, I was in charge of the writing of the technical specifications, but I didn't get a chance to see the supplier's response to them since there have been delays from customer side indeed the supplier nomination has been postponed.

The thesis is divided into three parts: the first is a description of the company and its values, then there is a brief characterisation of the automotive business and finally, the core of the thesis, the description of the industrialization process followed at DENSO to develop a new assembly line. In this chapter I gave an overview of the development process, up to the point I had the chance to participate, and a detailed description of the technical specifications since that was my job.

2. COMPANY

2.1. History

The origins of DENSO THERMAL SYSTEM are related to FIAT group, in particular, in the 80's FIAT forecast a grow in the climate system business, indeed decided to unbling from the STARS society the activity related to stamping and assembly of the heaters and radiant masses and move them to new born RISCALDATORI s.r.l. located in Poirino (TO). Then in the middle of the 80's FIAT group together with Magneti Marelli decided to create a product division in the Poirino plant called Borletti Climatizzazione, under which were related all the activities and resources involved in the design and manufacturing of climate controls.

In 1992 NIPPONDENSO (future DENSO Corporation) purchased 25% of Borletti climatizzazione. The joint venture had as a goal to improve and speed up the development of the product and process thanks to the know-how of company already leader in the climate control field. With this new company structure there were a rapid expansion in the Europe market and not only. The company got concession for Turkey, South Africa and Morocco. The expansion went on with set up of production facilities in Argentina, India, South America and Brazil.

In 2001 the company became at all part of DENSO Group with the name of DENSO THERMAL SYSTEM S.p.A.

With the total acquisition made by the Japanese group the company started to diversify the investments looking at the aftermarket and vehicle not related to consumer business. In few years two business unit born: O.R.S.A (off road and special vehicle division) and one related to the aftermarket business.

The company continues to expand and develop up to the present where the Denso thermal System S.p.A. design, develop, produce and sell HVAC, engine cooling system, compressors, radiators and heat exchangers for the greatest part of the OEM's as: Alfa Romeo, Audi, Citroën, Ferrari, Fiat, General Motors, Iveco, Lancia, Maserati, Mercedes, Opel, Peugeot, Renault, Scania, Seat, Toyota, Volkswagen, Caterpillar, CNH, New Holland, Lamborghini, Massey Ferguson, Piaggio and Same.

In addition to this products the company is also specialized in the assembly of complete cockpit modules and front end modules.

The company continue (as today) to grow and to expand thanks to the investments and attention on both R&D and quality.

This evolution has allowed the Denso Thermal System S.p.A. to become a multinational and more in general the Japanese group to become one of the more powerful, stable and profitable society worldwide with a turnover of about 45 B $ and about 170.000 employees.

2.2. Vision

The Denso Corp. put as core value for the company the philosophy of "Contributing to a better world by creating value together with a vision for the future". Under this statement the company establish itself with a clear vision toward the future. For this reason the company is recognized as one of the best with respect to environment and in general in creating a better world while improving it's business. With respect to this point it is important to underline the Long-term Policy 2030 "Bringing hope for the future for our planet, society and all people". This is not just a slogan but can be clearly related to real improvement with respect to "green", "safety-peace of mind" and "inspiring".

Green means "contribute to sustainability by increasing efficiency and reducing environmental impact". Looking at the future this point can be really a turnkey for the development. The policy is projected in 2030 when the automotive mobility will be totally different with respect to the one we can appreciate today, especially referring to the products core of the company business as HVAC and engine cooling system. The demand for this components will have a negative trend following the change in propulsion system that will require this systems in a reduced volumes. But there will be for sure a request related to cooling/heating systems also in the future cars, regardless the propulsion system. The heating pump can be a good example of this transition starting from HVAC modules. Furthermore, speaking of electric cars this system can have a real huge impact on the energy saving with a reduction up to 10% of consumption utilising an heating pump instead of a HVAC module.

Safety-peace of mind "contribute to future mobility that is safer, more comfortable and convenient for everyone. Whether at night or during the day no matter where in the world they are or where they're going, we want to enable people to get around safely. That’s our job.” This statement is pursued in reality i.e. developing and producing sensors for ADAS which helps to improve safety for all: drivers and pedestrians.

Inspiring “contribute to happiness for everyone through inspiring value-added offering”. Provide value beyond a vehicle-centric focus to embrace society’s broader needs.

This long-term policy and in general any objective are pursued with an approach and an attitude for achieving goals characterized by principles: open, fair, reliable, passion & initiative.

The automotive world is living a “paradigm shift” that affect not only the car maker but also all the suppliers that have to look to new cars characterized by electrification, automated driving, connected vehicles, car sharing and ride sharing. The CEO of the group Koji Arima intention can be well defined by the statement “To deliver a better future to the next generation, we will reconfirm our significance to society and accelerate efforts toward sustainability management, which has acted as our management ideology since our inception.”

2.3. Process Development

The department process development (PD) is in charge of developing the method and the tools necessary for the production of a product following the requests coming from the client.

The input for the department are the products to produce, resources available and volumes of production. The design of the product can be provided by the client or by the R&D department of the DNTS (Denso Thermal System). In the first case the development of the product is made by the client and the Denso receive technical drawing and other technical specifications necessary to set up the production or the assembly of the product. In the same way the design can be made by the Denso R&D department respecting the performances requested by the client. Resources available can be referred to human resources, money, time, know-how and plant space.

The output from the department is the type of process, quality standards and in general the physical production line.

The designed process has to be tested not just at the end of the phase when the PD present its deliverable, but the process and the quality has to be tested as soon as possible in order to integrate changes and to take into account possible problems from the early stage of the phase. The process has to demonstrate to be able to produce requested volumes and to respect the minimum quality requirements from the customer side. The aim of the process development department is the one to develop the future technology for production in coherence with technology trends and their cost/benefits analysis.

My position during the internship was "assembly specialist" in the PD assembly team. Main activities in this position are related to study technical and economic analysis of the products and process object of the project. In my experience that project is *DTPO-project*, related to the assembly of an automotive cockpit.

The Process Development South Europe department has the headquarter located in Poirino (TO), its responsible is the engineer Lorenzo Allione. The department is characterized by an internal division one for each product line and one other as inter-functional teams. Product focus teams are: *assembly*, *heat exchanger* and *stamping*. Inter-functional team is the *total flow management & NPI*.

The *assembly* team, the one of my internship, is managed by the engineer Massimo Cozzani.

The turnkey for a well-organized and result oriented project is the collaboration between all parties. This is even more important in the process development where different activities are developed at the same time i.e. flow chart (assembly sequence), time and method analysis with relative ergonomic studies, enslavement of the line, lay-out, safety, end of line with test, material handling, location in the plant and technology necessary to guarantee correct quality.

3. AUTOMOTIVE

Market

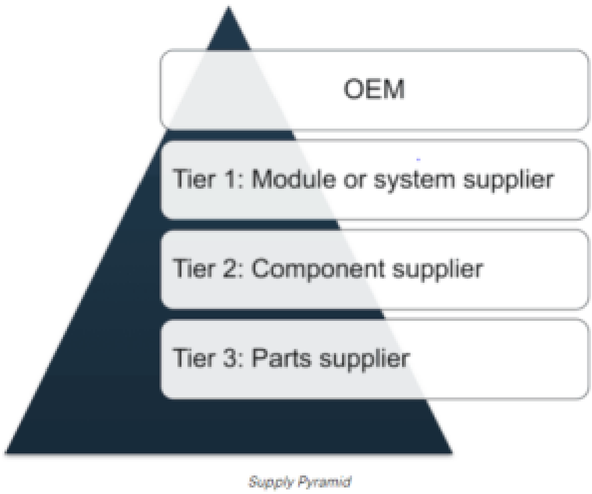


Figura 3-1 OEM'S SUPPLIER

Denso Thermal System S.p.A., as can be seen from his history and product line, has the core business strictly related to automotive and sets itself as Tier-1 and Tier-2 supplier. Tier1 means that the company supply OEM's with modules (cockpit, HVAC, front-end, engine cooling system), instead, Tier-2 refers to the company who sells to car manufacturer components (compressors, heat exchangers, radiators).

The automotive world is a business characterized by huge complexity coming from different side and, at the same time, it is nowadays subjected to deep and rapid changes.

The complexity of the automotive world, as well as every business connected to it, derives from three main aspects.

The first is the complexity of the technical and technological contents of the vehicles, the second is due to the diffusion of the vehicle as a personal good of large consumption with the consequent customizations possible on the customer side and, the last but not the least, is the customer relationship.

Technical and technological contents in a vehicle bring as a consequence that the supply chain, with particular reference to Tier 1 supplier, has to have an high degree of specialization for the components they supply. Furthermore, no component in a car has meaning standing alone, but all the components have to be integrated. This integration of components, to be effective, require also an integration at company level to ensure a smooth constant and rapid information flow. This means to engineering and developing the component aware of its functionality inside the whole vehicle.

The second type of complexity is related to the huge numbers of vehicles available from the customer side for each model produced. Due to the fact that the car, at least now, is considered not just a means for moving from A to B, but it is more an extension and expression of the customer personality, are present for each model numbers of variants as: external colour, internal colour, optional (automatic/manual gearbox, automatic/manual climate control, display inches, sound system, headlights, ADAS…) , propulsion systems and so on, that allow the car to fit different type of customers, even inside the same segment.

The last complexity is the customer relationship. This means that it is absolutely not trivial to understand and, even more complicated, forecast customer's preferences in advance of 3-2 years (TTM). The Time To Market goes from the style freezing of the vehicle to its launch in the market. In this time window the changes that can intervene in the process are quantitatively and qualitatively consistent. What OEM can do is to push on technology before having the answer by the customers, in the meanwhile a huge risk management activity is necessary.

In addition to the "normal" complexity of the automotive business nowadays deep changes, mainly technologically driven, affect the business management and direction for the future. The changes are affecting and will affect more and more not only the OEMs but also the supply chain.

The main changes responsible for the total shift of the automotive are related to i.e.: powertrain system (from ICE to electric-based propulsion), safety (from passive to active), driving mode (from active driver to passive passenger), infrastructure (from passive infrastructure to active infrastructure) and communication (from vehicle stand-alone to vehicle communication).

All this paradigm changes bring with them a lot of demand variations for components characterizing the "old" features and no more able to accomplish request for the "new" features. The changing of components demand will deeply affect the supply chain and this effect is even more consistent for the provider of components who's destiny is to disappear or to be substituted with some other components technologically unrelated.

As pointed out by Deloitte outlook of the future (2025) automotive industry, the demand of every component of a vehicle will change. The prospective make clear the demand variation for every vehicle's component. The forecast considers four scenarios in which two degrees of freedom are considered: technological capabilities of cars and the power of OEM's vs suppliers and outsiders (tech player). With this future-space four possible scenarios are defined:

- Data and mobility manager: e-mobility, autonomous driving and integrated mobility are common reality for the broad public.
- Stagnant car maker: OEMs has prevented hight-tech players entering in the market.
- The fallen giant: the car is just a means of transport wisth low attractiveness.
- Hardware platform provider: IT players disrupt the automotive value chain.

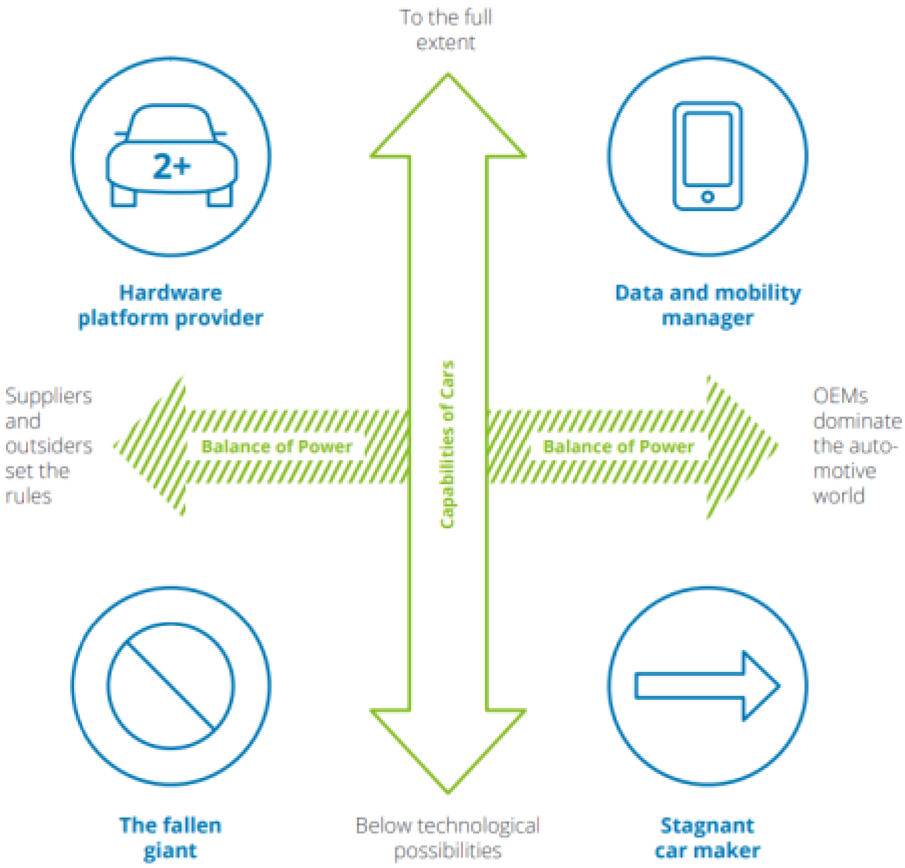


Figure 3-2 SCENARIOS 2025

In the forecast, all scenarios have a similar pattern but with a different gravity in term of percentage change. Electric and electronic components are projected to be likely winners (stunning demand increase up to 1300%), aesthetic components are classified as uncertain demand change and all the components related to ICE and hot-mechanics are projected to have a decrease in market share (falling up to -35%).

This outlook gives a clear indication of the shifts that are deeply affecting the automotive businesses, every company related with this field has to be proactive in follow changes without be stacked in the old automotive characterization.

4. INDUSTRIALIZATION

This chapter, core of the thesis, will address the process that allow to put on market a product with the right features, right performances, at the right time; in particular, after a description of the ESC, the processes of responsibility of the process department will be treated. The process analysed is the one followed by DENSO T.S. and described by the internal procedure ESC (Early Stage Control).

Industrialization is characterized by sequent steps, each one is defined by the

input necessary for the start and the output which are generated through the development of the step.

The identified steps are:

- RFQ
- Preventive
- PFMEA
- Technical specification
- Future development

Personally, I was deeply involved in wrighting the technical specifications and I also participated to the PFMEA. The analysis of the RFQ and the creation of the preventive is mainly done by managers using experience as main asset.

Products belonging to all product families produced in big series have to follow the ESC procedure in the step development.

4.1. ESC

Keeping track of the development of a project is crucial for the well run thereof even more when there are a lot of actors working together, as in the case of a product development process for a mass market production. For this reason, DENSO has defined a procedure that allows to keep track of the project development from the RFQ up to the verification of targets related to quality, costs and productivity of the project. The coordination task of the product development activity of the team is in charge of the project leader. This means that this figure has to facilitate the interaction between different parts of the company to reach all the objectives of the project.

The procedure is called ESC (Early Stage Control). It is structured following the "stage and gate" logic. The project development is divided in temporal sequent phases, each one cannot be overcome if the previous didn't. The end of a phase is identified by a "milestone" during which there is a meeting of the team working in that phase. During those meetings a checklist is analysed to ensure all the activities necessary for the overcome of the milestone are done. The milestones are not the gates but are the intermediate events between gates.

The gates in the ESC are the QAM (Quality assurance meeting), they are milestones too but with a greater importance. The team participating to those meetings is composed by all the responsible of involved functions, whom decide to go on with the project or to give-up.

Now there is a description of the activities to do for the preparation of each milestone and is also presented the graphical situation representing the achievement of targets.

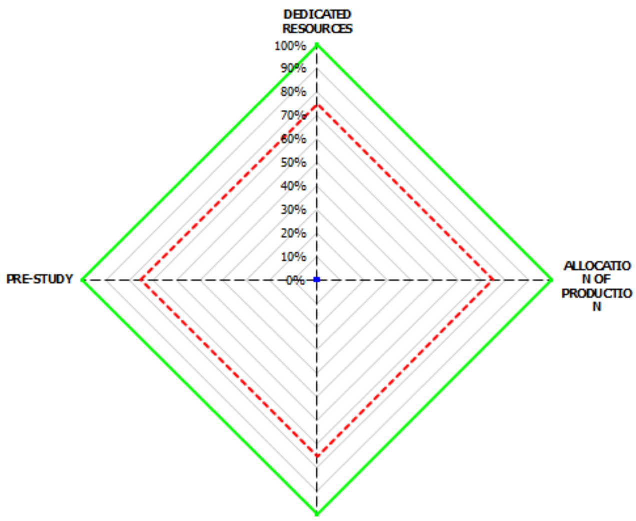


Figura 4-1 KPI MILESTON 1

Milestone 1 - Offer dossier preparation

The ESC start is given by the RFQ coming from the potential client. After this there is the analysis of the request in terms of: evaluation of the business, strategical production allocation and the analysis of *make* components, study of the product specification, creation of the team working on the project and definition of timing for product development according to macro-timing given by the client.

Milestone 2 - Approval of the offer dossier

During this phase there is a quite general overview of the project in order to be sure under all project aspects to be prepared, to face client's requests. All team functions start to move: R&D in the first draft drawing definition, purchasing office looking for possible suppliers, the process department analyses the production capacity, the processability of the product and the strategy of verticalization. Then, with the contribution of all team parts, the preventive is created keeping attention to environmental impact and profitability.

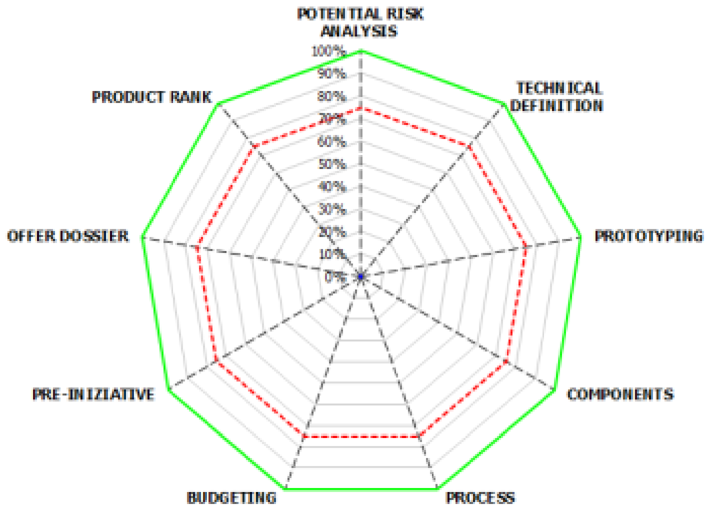


Figura 4-2 KPI MILESTON 2

Milestone 3 - QAM0

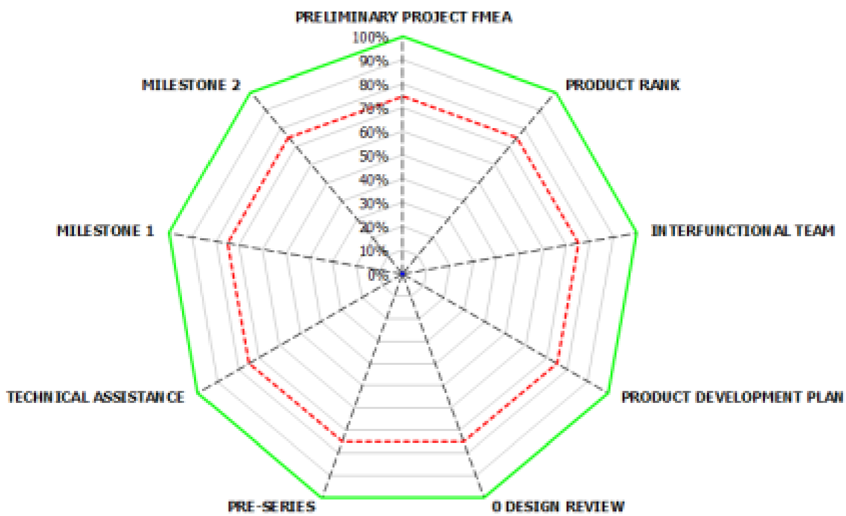


Figure 4-3 KPI MILESTON 3

The offer prepared and approved with Milestone 2 is presented to the client and, in case the client accept the offer, there is the formalization of the order capturing, this define the QAM 0. During this meeting there is a review of what done in the previous milestones and also the first design review. The project leader and the teamwork are defined and confirmed.

Milestone 4 - Final approval of prototypes

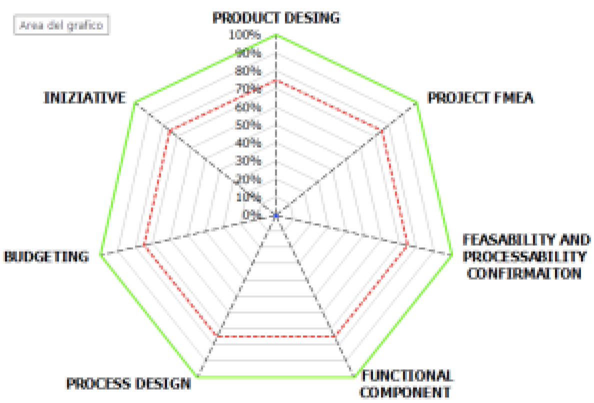


Figura 4-4 KPI MILESTON 4

After the order capturing, the development of product and the process start. They start to be developed quite at the same time during project development with the aim to reduce the overall development time. Product design take place in terms of geometry definition, material definition and the execution of the project FMEA; prototypes are defined. At the same time the process moves on: make/buy strategy, considering plants saturation, is defined; analysis of the timing from client/DENSO/supplier point of view is done to ensure match between them; definition of lay-out of both the line stand alone and the one integrated into the plant is done and finally also a first cycle time is found after the analysis of the assembly cycle and the request of the client in terms of volumes.

Figura 4-5 KPI MILESTON 5

Milestone 5 - QAM 1 Equipment approval

In this phase, in preparation for QAM 1, also the concurrent development product-process take place. During the previous phase the prototypes are defined so that in this phase they can be built-up and analysed regarding safety and quality. After that the verifications of the coupling congruence between the vehicle and the sub-system take place. The built prototypes are used for design validation and are delivered to the client for internal verifications. The final 3D and 2D for the product series production are emitted.

As of process, the assembly cycle or the production is defined as well as his cycle time; the statement of the assembly flow allows to develop the FMEA in order to draw up a plan to face critical points coming out and to define the plan for specifications.

Milestone 6 – Agreement on specification and equipment

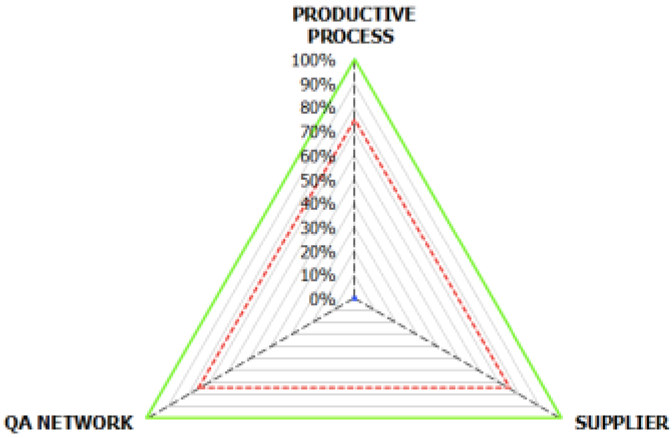


Figura 4-6 KPI MILESTON 6

Moving from M5 to M6 there is the definition of specifications for all the necessary equipment and for the packaging. QA Network development is defined.

Milestone 7 – Agreement on pre-series product delivery

In this phase there is a huge development of the process. The equipment are installed and the QA network is done. Once the equipment are available the operators are trained. Approval and control plan for make component are done, while for the buy components there is the verification of supplier capacity. Internal plant flow for the material handling is defined ensuring good fit between already existing production and the brand new one. Qualification of the product take place. This process takes into account not only the specification requested by the client but considers also internal critical aspects. Qualification tests consider also the durability tests up to the product end life and the worst case study, ensuring the product functionalities also in case of component at the max of tolerances.

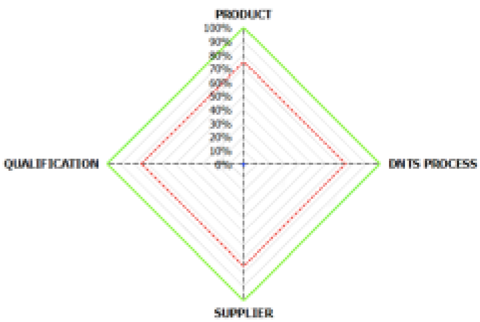


Figura 4-7 KPI MILESTON 7

Milestone 8 – QAM 2 Product approval

The pre-series product delivered at the end of M7 are not only used from the client for product qualification but also used eventually by DENSO to verify products after they have been used on vehicles. This activity is also used to define the assistance plan and to set up the design review 2 based on criticalities coming out during pre-series production. After that there is an analysis of the series process looking for defects, cadence and plant efficiency. In the end the equipment are qualified and final product is delivered to client aiming for the ok to start the production.

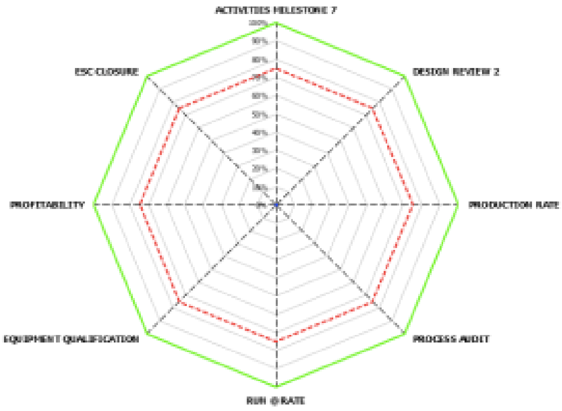


Figura 4-8 KPI MILESTON 8

Milestone 9 – QAM 3

Milestone 9 is not mandatory; it can be used to verify series products collecting data coming from sold vehicles in terms of numbers of defect per km. It is done also the analysis on the profitability to see if targets have been achieved.

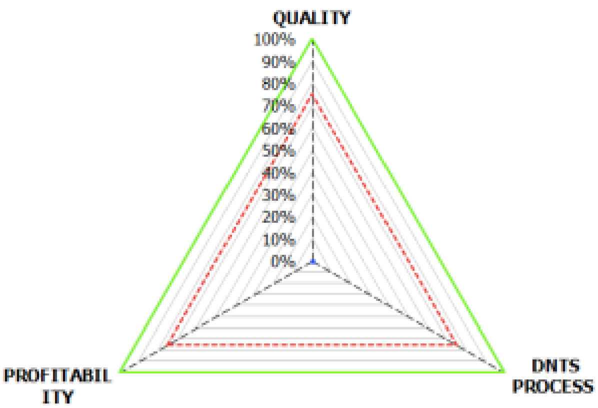


Figura 4-9 KPI MILESTON 9

The timing definition of the ESC milestones is settled following the client milestones to be coherent with the objective of SOP date. In practical terms the project development can differ from the theoretical definition of the procedure. For a matter of time reducing some activities can be anticipated with respect to the theoretical definition. Studies and analysis of the product and of the equipment can be anticipated with respect to the nomination by the client. This happens because, as said in chapter 3, Time To Market is a very critical strategical factor for car makers which, as a consequence, require development time even more stricter and challenging for suppliers

4.2. RFQ

The RFQ (request for quotation) is a business process in which a company request a quote from a supplier for the purchasing of a specific product or service. In the RFQ are given the specifications of the product not only in terms of "what I physically need", that can be described by the request of volumes, product and minimum quality requirements, but are also considered boundary conditions, as services, that are necessary for the well run of the business; this requests can be payment conditions, delivery time, plant location and contract duration.

The company which requests for a quote want to have a set of offers which respond to the same exact product/service in order to be able to compare them looking at the price given as $/product. The request shall be submitted to a number of suppliers sufficient to have different proposal. In this way the offers evaluation is based on the final price per product declared by suppliers since the respect of the conditions presented in the request it's taken for granted.

In the specific case in which I work on, the RFQ comes from an important car manufacturer that send a request for a quote for the production of a cockpit module.

The level and type of requests depend heavily on the type of product the request is send for. In the automotive business, as seen in the chapter 3, there are different type of suppliers which supply different type of products. As said DENSO can be classified as tier 1 or tier 2 supplier, depending on which product of the product family proposed by DENSO we are referring to. Speaking about cockpit DENSO is a tier 1 supplier. The main difference between supplier's tiers is the level of integration between companies that can be translated in a more detailed request for quotation.

Now the requests input for the industrialization are analysed.

Volumes

The volumes requested in the RFQ come from forecasts of the car manufacturer on what they expect to sell in the short, medium and long term. Produce a forecast is not an easy task but is a crucial point. There are different techniques used for this purpose, main categories are: qualitative and quantitative.

Qualitative forecasts are used when there is no or little amount of data available as base or when the relation between past events and present/future is weak.

Qualitative techniques are for example market survey, built-up forecast and life cycle analogy method. The main characteristic of this methods is that they are based on the experience of the personnel in charge of making them.

Quantitative method is used when there is a data base for the forecast and there is evidence of a relation between the variable of interest and some others. Under this macro-category it is possible to identify two different approaches: time series, when the future level of demand is seen as function of time, and causal model, when the future level of demand is seen as function of something different with respect to time.

The volumes presented in the RFQ are a key factor for the industrialization process even more important while speaking about fixed paced assembly line. One of the main cons of this type of lay-out is the very weak flexibility offered, but at the same time is the only lay-out that allows to produce a huge number of products in a relative small cycle time.

	2022	2023	2024	2025	2026	2027	2028	2029	2030	TOTAL
A	38.512	144.114	154.014	154.014	154.014	154.015	154.015	147.414	29.715	1.129.827
B		154.016	184.816	187.016	187.016	187.016	181.514	173.816	107.816	1.363.026
C		38.505	99.002	99.002	99.002	99.002	91.305	84.156	76.457	686.431
TOT	38.512	336.635	437.832	**440.032**	440.032	440.033	426.834	405.386	213.988	**3.179.284**
	34.661	302.972	394.049	396.029	396.029	396.030	384.151	364.847	192.589	2.861.356
		376.301								

	GSX	GDX
A	94%	6%
B	90%	10%
C	95%	5%

Figure 4-10 PRODUCTION VOLUMES

Figure 4-11 VOLUMES VS TIME

In the graph is represented the request made in terms of volumes. It is possible to clearly see different phases the product faces during the life cycle.

Area labelled with 1 defines the introduction stage characterized by a rapid growth of sales, this is due to the fact that once a product enters in the market requires a time frame to be recognized by the possible customers as an alternative of the current products present in the market.

Stage 2 is called "growth" and is the link between the introduction and the maturity, is the time frame during which the product is already present in the market in a consistent way and has to stabilize to its demand pick.

Stage 3 is the maturity stage. This is the longest time frame of the product life cycle curve. It represents the steady state demand that correspond to the pick of demand. The duration of this stage depends also on the intervention that are done in time in order to keep the product update and coherent with the customer request.

The last stage, 4, is the decline. This represents the final stage of the product life cycle during which the demand for the product decreases since become obsolete respect the new request from market side.

The variation of volumes affects the suppliers that have to be able to adapt their production capacity, when this is possible, or to be prepared for the pick demand if it is not possible to change production capacity. Peak production was considered as a reference in the project in question. This is due to the fact that an assembly line, as said, cannot be flexible in production capacity as other type of line as job shop or cellular manufacturing layout.

Takt time

The other key information we need at this point is the Takt Time. The T.T. define the rate at which you need to work and finish the production process in order to meet customer demand. The value of Takt Time depends on two factors: net production time and customer demand.

$$T.T. = \frac{net\ production\ time}{customer\ demand} \quad \left[\frac{min}{piece}\right]$$

The customer demand has already been addressed. Net production time is quite self-explanatory, it represents the clean time the production has at its disposal to produce a product. To get this number is necessary to subtract the time spent on downtime, i.e. breaks, lunch, maintenance, from the total time at disposal at work.

The net production time of the client is not always a parameter influencing the supplier's operations, but in the case, of tier 1 supplier, the time organization is a major factor influencing decisions in terms of lay-out dimension and work organization. Tier 1 means a high level of integration because the supplied product are modules characterized by relevant dimensions, costs and are customized by customers during the purchasing. For this reason it is not possible to produce them with a logic of make to stock, where the client-supplier production can be asynchronous and independent, but it is necessary to use a make to order logic more specifically following JIT and JIS philosophy.

JIT (Juts in Time) is the method where materials arrive just in time when are needed. This is valid for both purchased or delivered materials and materials produced on site. In theory the part needed arrives in the exact time when that part is needed. This way of working allows to reduce the inventory level, meaning not only to reduce the obsolescence risk, but also to save a huge amount of space. Cockpit module is classified as "A" product, meaning high economical value and great space required for a small amount of items. For the car manufacturer would be impossible to store near the assembly line or anyway in the warehouse the cockpit necessary for just one day production. We have seen from the volumes that the daily production is about 1000car/day that means to store 1000 cockpit modules with the dimension of about 2 m x 1m, 2000 mm^2 and in addition it is an aesthetic part of the car that need to be handled with care and not be moved multiple times, because that could increase the risk of damage.

JIS (Just in Sequence) can be seen as an upgrade of the JIT. Implementing a just in sequence process means the part are delivered in the specific order they are required searching for perfect efficiency. Using sequences allows the production line to handle delivery and use of components in a matter of minutes since they arrive at the right time and in the right sequence near to the final assembly line. There is no need of additional handling and space to store components and pick the right one from them. From product delivery and assembly takes at maximum a couple of hours, ideally zero. This product organization is used especially when the possible customizations are very high and for the cockpit this is totally true. They can be produced in different colours, equipped with different optionals and are present two base-models right and left driving. Three common types of JIS can be used: pick to sequence, buffers are present and the components are picked according to the assembly sequence, ship/receive to sequence, the operation orders and receives components in accordance with the sequence, and make/assemble/built to sequence, the supplier creates the components as they are needed for the customer's sequence. In DTPO case the request made by the car manufacturer is to work with a JIS make to sequence method.

For the aforementioned reasons the production organization of the DENSO must be synchronized with the client one, meaning to have the same shifts and working day organization.

Product

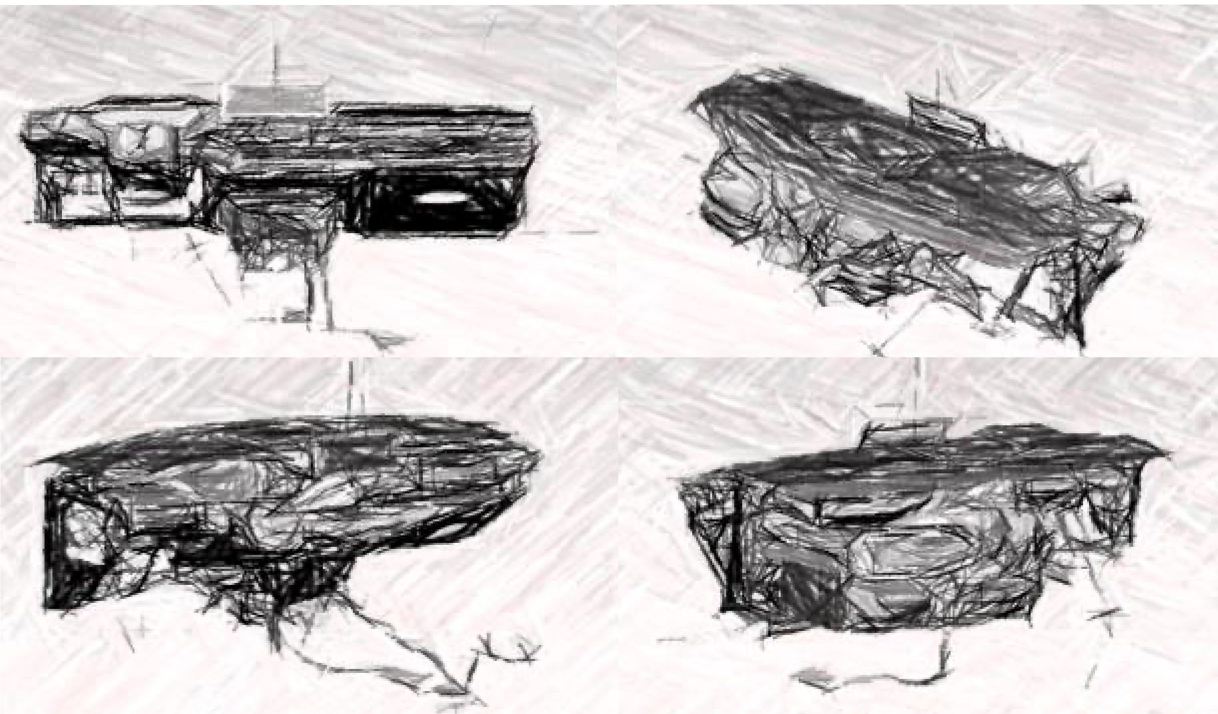


Figure 4-12 COMPLETE COCKPIT

The product at the moment of the RFQ was not already in the state of design freeze, but it evolved going on with the project. Managing changes is a key ability while developing a project. Due to everyday stricter developing time, companies must be able to face changes and that was the case. In every business while taking decision it is possible to find three different situations: decision under conditions of certainty, ideal situation, decision under conditions of risk, the future state of the decision outcome known in terms of probability based on the available informations, decision under conditions of uncertainty, the future outcome is not absolutely known. Presenting the preventive without the design freeze is a typical situation of risk, in fact assumptions are made based on a non-fixed base. The experience make difference at this point.

A cockpit module is highly complex and normally consists of an array of complex electronics, navigation systems, airbags, heating and ventilation systems, structural shaping, digital displays and the steering column. Furthermore, when a customer buys a car from a dealer he is allowed to customise elements of the cockpit to reflect his own personal preferences; this means that each cockpit module can only be fitted in one car. Developing and manufacturing modules, delivering them just in time and just in sequence is a significant challenge to all the parties involved in their provision and present an array of challenges.

B-Pilot refers to N°2 models of cockpit intended for two different vehicles. Each model is produced with two part number, right driving and left driving . With the modularity strategy, it is possible to produce different products starting from the same "core". The dashboards we are referring to, in fact, have in common the same dimensions, same point of attachment in vehicle, same electrical connections and same (in quantity) number of components.

The starting point in developing and implementing the assembly line for the cockpit is to analyse the product in its composition and functionalities. The cockpit is a module composed by a great number of sub-moduls. We can count:

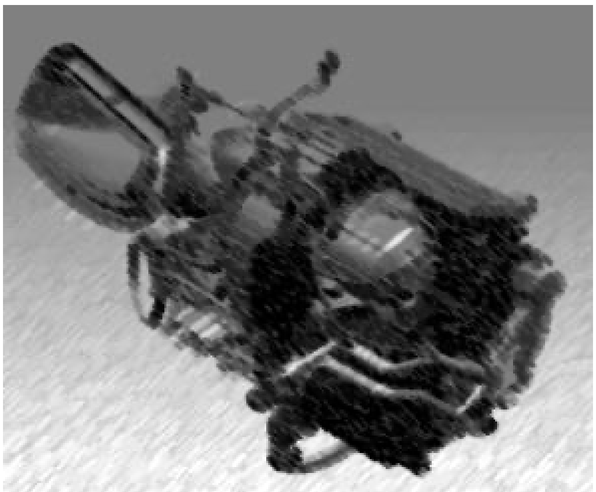


Figure 4-13 HVAC

- HVAC (photo)
- Steering column
- Infotainment system
- Airbag (photo)
- Wiring (photo)
- Speakers
- Drawer

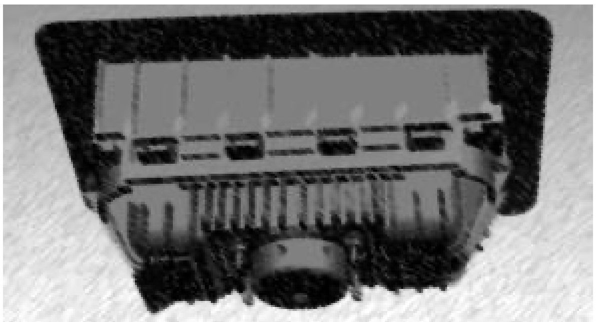


Figure 4-14 AIR-BAG

In addition to sub-modules the dashboard is composed by great number of components like dashboard plastic cover, screws, support frames, displays, devioguide, crossbar, air ventilation ducts and others.

The structural part of the dashboard is made by the crossbar, that is the bone of the cockpit and goes for all the width. In general, components/sub-modules can be attached to the crossbar or to the dashboard (that is attached to the crossbar). The connections are made with screws, for bigger components, and snap connection, for the smaller one. In addition to mechanical connections also electrical connections are done, those are between the wiring and all the electric users as displays, PCC, HVAC, airbag, climate control keys, steering column, ambient light. Wiring-user connections are done with connectors.

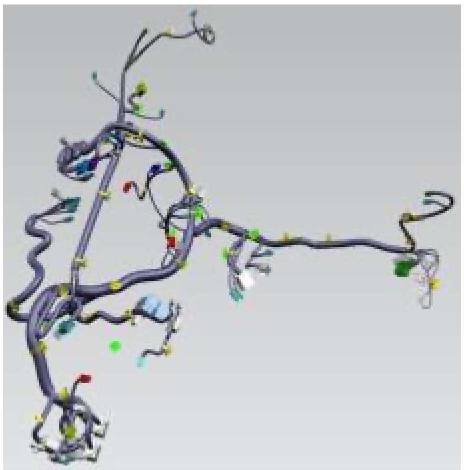


Figure 4-15 WIRING

Assembly cycle

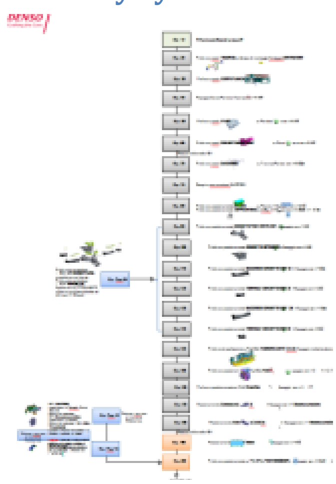


Figure 4-16 FLOW CHART

Another output from the RFQ is the assembly flow chart. The assembly flow chart is the assembly sequence of the product obtained starting from the BOM and searching for the right sequence of putting together components. The logic followed to identify it, is to look what component cannot be assembled after another so to identify the sequence priority. The flow chart, in its creation, takes into account only the assembly sequence without looking at the time necessary for each operation.

In the pictures 4-16 it is possible to see the flow chart with the sequence of operations and in the other picture a focus that shows the first two operations as example.

Figura 4-17 FLOW CHART FOCUS

In Op 20 the crossbar is mounted on the pallet and in Op 30 the dashboard is mounted over the crossbar. Clearly no timing of the operation is present in this chart. While developing this activity, as mentioned, it is possible to propose changes if problems of assembly come out. Modification are proposed to both OEM and tier 2 supplier in charge of developing aforementioned component.

Then, once the flow chart is created, also time is considered. Taking into account time at this stage means assign for each assembly operation the relative base time duration. For "base time" we mean the time that a given task would take, when performed by a qualified worker working at a defined level of performance. To set timing and make the ergonomic evaluation operation ERGO-UAS method is used. The ERGO-UAS method is composed by two parts: MTM-UAS for the evaluation of the time duration and the EAWS method for the ergonomic evaluation.

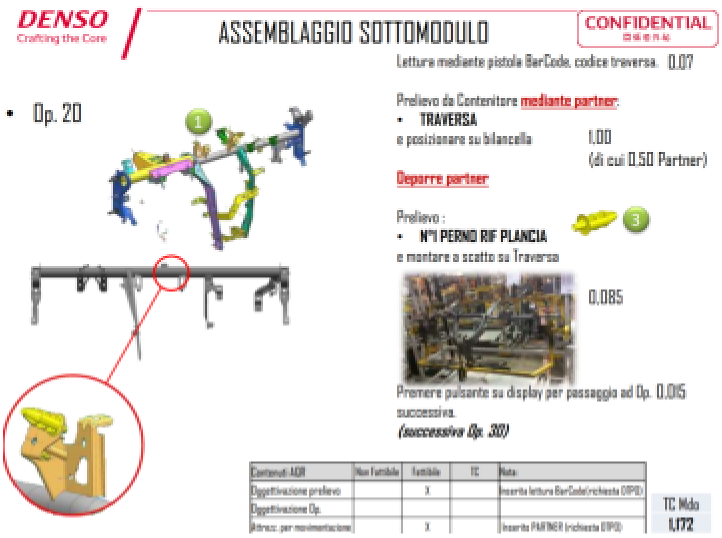


Figura 4-18 ASSEMBLY CYCLE

MTM-UAS method is part of a wider category of work measurement techniques: predetermined motion time system (PMTS). This work measurement technique is prospective meaning that, standard time for operations are based on database and it is possible to jobs' timing before they start. There are three methods belonging to PMTS: motion-based analysis (MTM), action-based analysis (UAS), activity-based analysis (MEK). The difference between them is the level of aggregation of the operations.

Motion-based analysis refers timing to most elementary actions and for this reason it is used for a high-volume production environment. Due to the elementary actions considered the analysis offer the highest level of accuracy, but, on the other side, is also the most time-consuming activity. MTM has as elementary movement for the upper limbs: reach, grasp, move, turn, position, apply pressure, release, disengage. Then in each category the time duration can depend on the distances, dimension of the object to take, the weight, the shape of the object and so on.

Action-based analysis is based on statistical analysis of MTM motion pattern. UAS is characterized by aggregation of predetermined elementary motions to describe sequences of elementary operations. This type of analysis is intended for batch production activity or, anyway, for operations lasting from 1 to 5 min. The basic operations in this case are: get and place, place, handling tools, operate, motion cycles, body motion, visual control. To give an idea of the aggregation the "get and place" operation include elementary movements of MTM as: reach, grasp, move, position and release.

The last type of analysis, MEK, is an activity-based analysis. In this case as fundamental element, activities are considered, one activity made by several actions. This method is used in job shop production where the operation last for several tens of minutes.

Figure 4-19 EAWS SECTIONS

The EAWS evaluate the ergonomics of work with an assessment worksheet composed by the sections in the image above. For each section there is a rating depending not only on the physical characterization of the workstation as: posture, asymmetry of the movement, type of grasp, flexion of arms, height of the arms, weight for handling and so on, but also the frequency of the operation that is a key factor for the ergonomic evaluation.

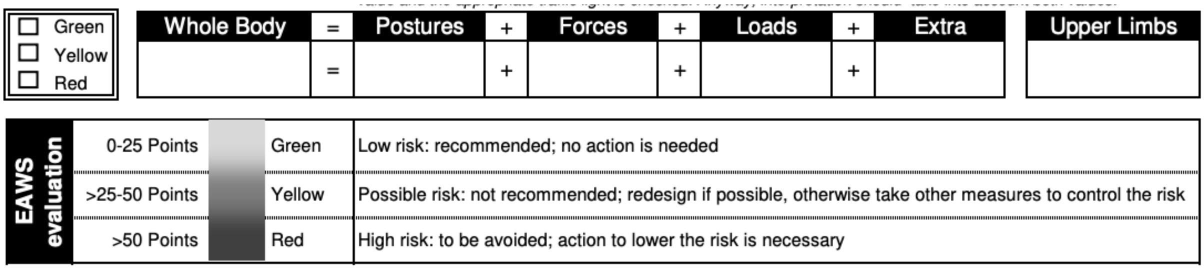


Figure 4-20 EAWS EVALUATION

Two scores are calculated: one for the whole body and the other for the upper limbs, in case of repetitive tasks. Then is taken the higher between the two for the EAWS evaluation that is composed of three outcomes: low risk, possible risk and high risk. In case of high risk is necessary to act in the short term to lower the risk, instead, in the case of possible risk a redesign is recommended or anyway taking measures to reduce the risk. The score obtained is not only used as an evaluation of working condition, but it is also used to provide an increase in the time necessary for a movement, coming from the MTM-UAS analysis, in case of non-favourable working condition.

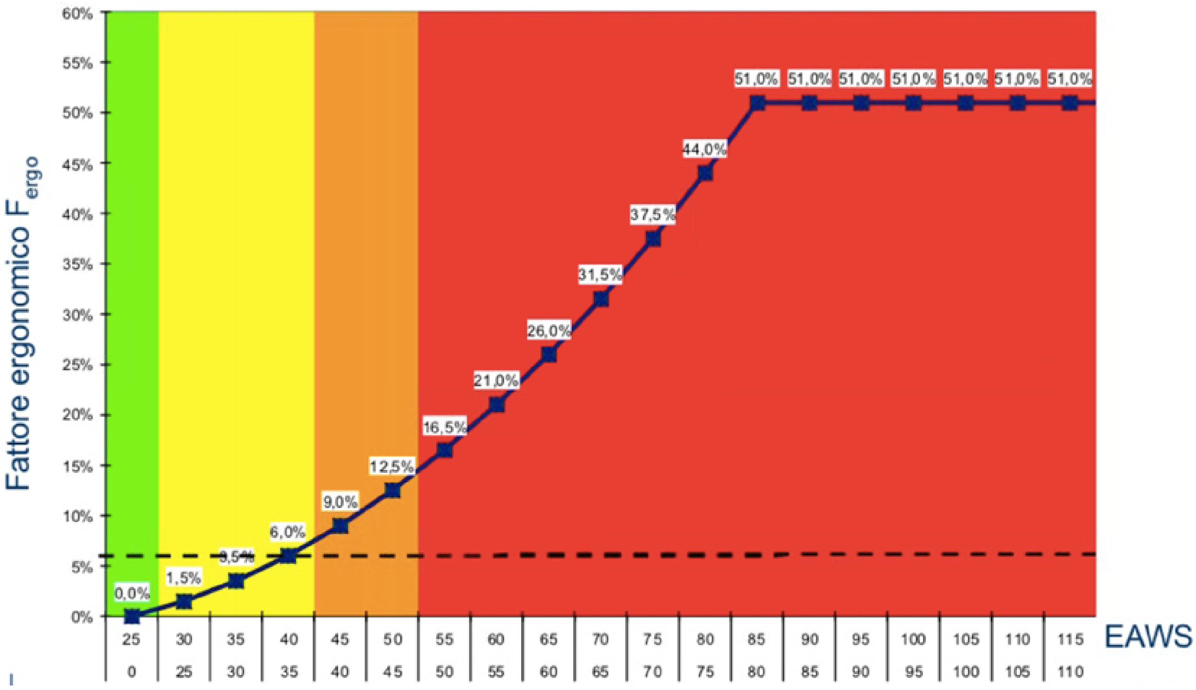


Figure 4-21 RECOVERY FACTOR EAWS

Therefore, with the MTM-UAS, the normal time (T_N) for the operations is defined, then this time is increased by a percentage, which is directly related to the

EAWS score obtained from the ergonomic evaluation, to normalize the time with respect to an ergonomic condition of working.

$$T_{std} = T_n * (1 + A)$$

At the end the standard time (T_{std}) is defined.

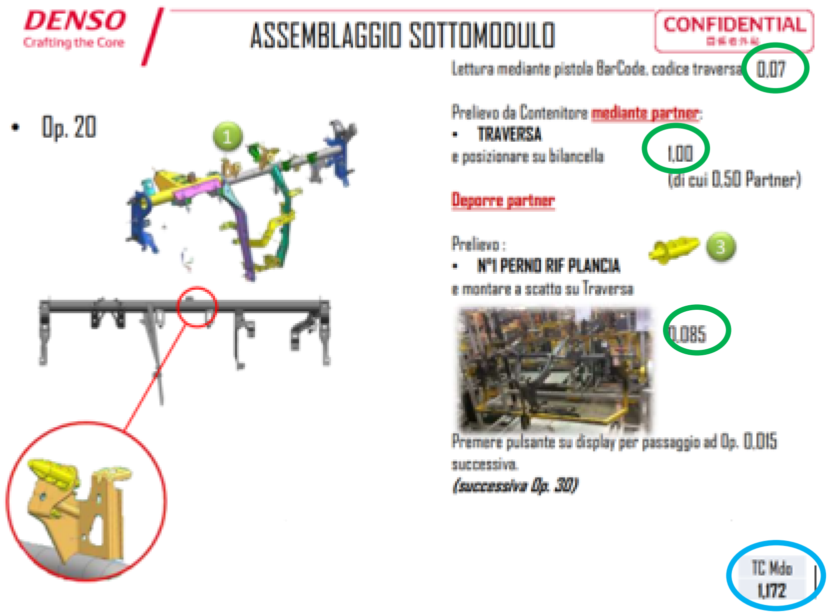


Figure 4-22 TIME IN ASSEMBLY CYCLE

In the above picture it is possible to see the assigned time for each operation (green circles). The blue circle highlights the total duration of the operation. The creation of this first draft of an assembly cycle is used for preventive purpose. The T.T. is taken as reference trying to sum-up a number of actions able to create operations lasting for a time quite similar to the T.T. Problems can come out if there are non-divisible operations with a duration grater then the T.T. In those cases, a solution can be doubling the station characterized by a time greater than the reference one or maybe to support the operation with some robots or automating the whole operation, but in any case the T.T. has to be respected.

4.3. PREVENTIVE

Once the conditions for the supply are defined in terms of volumes to produce through years, product, takt time, working shift/day and the assembly cycle it is possible to prepare the preventive. The preparation of the preventive starts with the RFQ and goes for milestone 1, for the first analysis, and milestone 2, for the deeper study and the completion of the product cost. Process department has to define localization of production, automation level of the assembly line and equipment, equipment necessary and the head count. Those factors together give the industrial cost of the product.

Experience is the main used asset in preparing the preventive, references to past experiences and projects are used to forecast needs and relative costs involved in the industrialization. This is a crucial part of the project development, as it is the first faced turnkey considering the competition that characterize the automotive business. The RFQ principal looks at the responses mainly regarding the price the company has to pay, since the boundary conditions are basically the same. Presenting a preventive with a too high cost, maybe using not necessary and expensive equipment or producing in a non-competitive place or considering a process characterized by an high level of non-value added activities that require extra operators, means, probably, to lose the customer job. On the contrary, preventive prepared without considering equipment or operators necessary to respect the customer requests, can deeply affect the whole profitability of the project.

Now are analysed in detail the responsibility of process department: production localization, automation level, necessary equipment and head count. At the end are presented some considerations about the final cost of the product.

Production localization

The first step is related to the decision of where to produce. The main drivers in the production location are: cost of man power, existing plant and specific customer requests.

Manpower cost can present huge differences between countries. Speaking about the existing production plant managed by DENSO THERMAL SYSTEM South Europe, are available for production four plants located in: Italy, Morocco, Poland and

Spain. Taking as 1 the cost (€/min) in the Italian plant, in Spain the cost is about 0.75, in Poland is about 0.4 and in Morocco is 0.06. As it is possible to quickly understand there is a huge difference in terms of variable cost between plants. As a consequence, depending on the automation degree of a process, a plant will be preferred instead of another. If a process is mainly manual, a plant with lower cost of manpower will be probably selected, instead, if a process requires high investments for automatic stations, the cost of manpower will not be the main driver. In addition to the cost of the manpower, also the effective working hours present differences. The overall duration of one working shift is 480 min, then, from this time, the time used for brake rest and lunch have to be subtracted and, depending on the union agreements, the effective working hours can vary from 420 min to 450 min.

In deciding where to produce a new product it is possible to choose between two main strategies related to the facility construction: brown-field or green-field.

In the first case, brown-field, is expected to modify and renovate an existing facility. The changes of the already existing plant can be consistent, minor or can be considered also a plant relocation to other existing facility. Using an existing plant means that the facility is already present with all the necessary support functions, but has to be considered that, introducing a new process in the plant, means to change part of the facility or to improve some support functions, as receiving area, shipping area and warehouse. This strategy not only can result in cost savings for the investing business, but it can also avoid certain steps that are required to build new facilities on empty lots such as building permits and connecting utilities.

Instead, the brown-field strategy considers the construction of a new facility in an empty field slot. Greater time and costs are involved in the project, but on the other hand there are less constraints in terms of space, lay-out and accommodating due to already established internal flows.

Finally, the last driver to take into account in choosing the production location is related to specific request from the customer side. *DTPO* project is the case in which in the RFQ is requested to produce in a specific location. Wanting to be totally precise in the RFQ is not requested to produce in the Poland plant, but it is requested to work in JIS/JIT and so to deliver the requested product in about 160 min after the request is received. This request puts clear limitation on the production location and it is not possible to select any other location different from the one located in Tychy.

Automation level and layout

The automation level and type of plant layout is another important factor influencing the outcome of the preventive, the product cost.

Automation level means to choose between automatic / semi-automatic / manual process. In the first case the product transformation is totally in charge of a machine, it performs both adding value activities and non-adding value activities, as handling. In semi-automated process activities are performed by humans and machines together and it is normally necessary to orchestrate their interaction with a computer that allows the operator to be aware of the machine pace. Finally in manual process all the activities are in charge to operators whom add value in the product transformation.

The difference between these three categories is deep regarding both flexibility and investments cost. Manual process allows a very high level of flexibility with the possibility to change the process without requiring high investments and long time, in addition the start-up investment cost is low but the variable cost is considerable even if, as seen above, it largely depends on the location of the production.

Considering the *DTPO*-project, the choice was to choose a totally manual process. This decision was based on the type of the process involved in the assembly of a cockpit. As said before the product is composed by a huge number of components, some of them characterized by considerable dimension and the type of coupling between them can be by snap connection or using screws. Automate this process require huge investments with the risk to don't add any value regarding the quality (the operations are technically simple). Benefits that an automation can bring are relative to the time saving in material handling but, considering the manpower cost and volumes through years , was considered not sufficient.

The choice made between manual/automatic/semi-automatic has deep implications also in the lay-out definition. Following the choice of a manual process the lay-out is defined accordingly. The overhead conveyor lay-out, space necessary for the operators, location of the enslavement for material and the partner position are defined. Since this is the preventive phase should not be considered as the final lay-out, but it is considered for the overall dimensions which cannot be overcome, otherwise can occur interferences with current process in the plant.

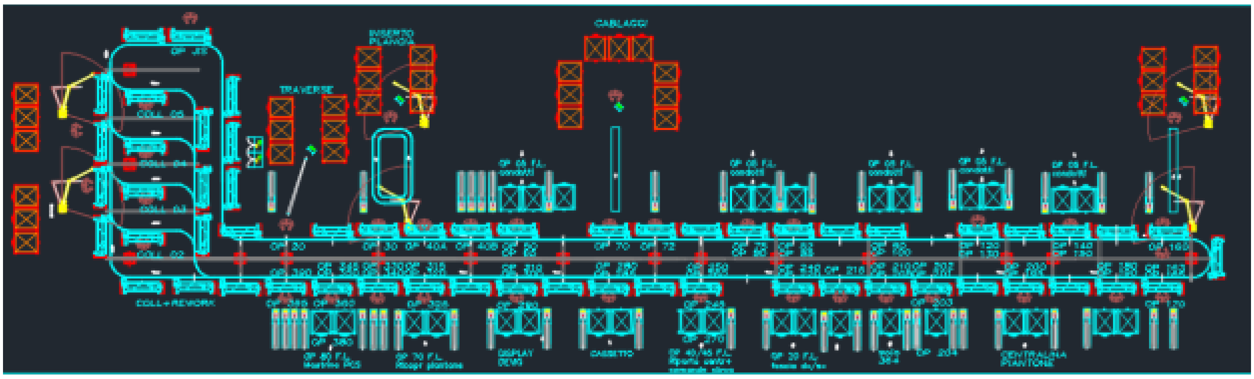


Figure 4-23 LAY-OUT

Equipment

Another important consideration in preparing preventive is related to the necessary equipment for the assembly line. The list of necessary equipment is made by different categories: test benches, offline benches, line equipment, pallet, pilot area, screwdriver/ecu/reader, partner, software/installation/transport/certification. Divide the investment cost in categories allow to deeply understand the cost structure of the preventive and also to assign the part of the client's share as specific investment. Looking at the investments for the equipment it is possible to divide them in common and specific. The common investments are not associated at one object observed, instead the specific ones refer specifically and exclusively to the object observed. Considering the product as object observed we can define specific investments as dedicated to its production, common costs instead refers to machines or equipment used to process the product.

The part share identified as specific is asked to be paid directly by the client. This part can be 100% of a voice or can also be a fraction of the investment. Following the definition the 100% investment related to the pallet, about 70% of the investment for the offline benches and about 50% of the test benches are identified as specific.

BANCHI F.L.		
Banco preparazione insonorizzanti completo di saldatrice US, telcamere,MFS ,stampante JIS, Stampante PF, lettore bar-code (OP 05)	*2*	
Banco preparazione piantone sterzo con blocchetto commutatore completo di avvitatore Wi-Fi, centrlina contaviti Wi-Fi, telcamere,MFS ,stampante JIS, Stampante PF, lettore bar-code	*0*	
Banco preparazione bocchette / Fascia Katana completo di avvitatore Wi-Fi, centrlina contaviti Wi-Fi, telcamere,MFS ,stampante JIS, Stampante PF, lettore bar-code (OP 20)	*3*	
Banco preparazione ambient light infe+sup su fascia completo di avvitatore Wi-Fi, centrlina contaviti Wi-Fi, telcamere,MFS ,stampante JIS, Stampante PF, lettore bar-code	*2*	
Banco preparazione Riporto centrale completo di avvitatore Wi-Fi, centrlina contaviti Wi-Fi, telcamere,MFS ,stampante JIS, Stampante PF, lettore bar-code	*1*	
Banco preparazione Start, Riparo inf, Cassetto, completo di avvitatore Wi-Fi, centrlina contaviti Wi-Fi, telcamere,MFS ,stampante JIS, Stampante PF, lettore bar-code	*0*	
Banco preparazione dispay, completo di avvitatore Wi-Fi, centrlina contaviti Wi-Fi, telcamere,MFS ,stampante JIS, Stampante PF, lettore bar-code	*0*	
Banco preparazione Staffa dispay, completo di avvitatore Wi-Fi, centrlina contaviti Wi-Fi, telcamere,MFS ,stampante JIS, Stampante PF, lettore bar-code	*0*	
Banco preparazione Ricoprimento Piantone + anttena + tappo + mostrina PCS + tasti , completo di avvitatore Wi-Fi, centrlina contaviti Wi-Fi, telcamere,MFS ,stampante JIS, Stampante PF, lettore bar-code	*2*	

Figure 4-24 OUT OF LINE EQUIPMENT

For each test bench is specified the equipment necessary for the station in terms of screwdrivers, screwdrivers ecu, cameras, printers and bar code reader. The greater part of test bench is designed and specifically made for the product to process, that is the reason why there isn't the total number of offline benches but each type is considered as different from the others.

AREA PILOTA	
Progettazione e costruzione 1° carrello campione VdP	*1*
Carrello di montaggio VdP	*2*
Avvitatori a batteria per VdP wifi	*4*
Centralina contaviti Wifi per VdP	*2*
PC MFS gestione postazione pilota per VdP	*2*
lettori bar code per VdP	*2*
stazione di ricarica batterie per VdP	*1*
batterie per avvitatori	*4*
Avvitatori coppia/angolo CLECO per VdP	*2*
Stampanti report per avvitatori coppia/angolo per VdP	*2*
Banco EOL pilota	*1*
Kit componenti per set-up banchi collaudo e attrezzature montaggio	*1 kit*
Stampante Prodotto Finito per VdP	*1*

Figure 4-25 PILOT AREA EQUIPMENT

The pilot area is totally in charge of DENSO since these are equipment necessary to verify the fairness of the process during the development of the same. The pilot area has to represent all the final line but with smaller dimension. That area is constructed in the final plant.

AVVITATORI/CENTRALINE/BATTERIE/LETTORI	
Avvitatori a batteria (q.tà 26) WiFi con centralina e gestione contaviti	26
Lettori bar code wi-fi (q.tà 34)	34
n° 4 stazioni caricabatterie avvitatori	4
n° 30 batterie ricambio avvitatori	30
n°4 avvitatori coppia angolo CLECO con centralina	4
PARTNER	
Partner scarico carrello montaggio / carico tradotta	2
Partner linea alimentazione traversa/plancia/piantone/hvac	4
partenr FL alimentazione componenti a nastro alimentazione traversa/palncia/piantone/Havc	4
SOFTW / INSTALLAZIONE / TRASPORTI / ASSERVIMENTI / CERTIFICAZIONI	
Opere di carpenteria generale (spostamento / rifacimento magazzini e lay-out aree)	
Software e hardware per nuovo sistema supervisione da sviluppare	1
Postazione gestione Jis Cliente compreso stamp0anti, lettore bar-code, …	1
Asservimento nuovi prodotti (rastrelliere componenti area kit, banchi fuori linea,)	1 kit
Carrellame per trasporto componenti area preparazioni e area finizione	50
Impiantistica elettrica / pneumatica per allacciamenti banchi 17 FL/ 1 inea principale / collaudi	1
Documentazioni, certificazioni CE	1
Installazioni, trasporto, avvio…. (4 mecc. + 2 elettr + 2 softw. X 15 giorni lav)	1

Figure 4-26 LINE EQUIPMENT

ATTREZZATURE LINEA	
Struttura linea 170m con asservimenti elettrici pneumatici	34
Postazione di montaggio standard (PC MFS, lettori RFI pallet/postazione, overhead,	34
Software supervisione gestione linea e banchi F.L.	1
carrelli trasporto moduli nuovo prodotto per tradotte PROTOTIPO per fase VdP (progetto interfaccia partner)	1

Figure 4-27 LINE STRUCTURE

These last type of equipment are defined as common and are in charge of DENSO. They are considered as common since they are used independently from the specific product processed. In this category are present software, PC's, screwdrivers, means of enslavement and so on.

As it is possible to see from the images there is a quantification of equipment in terms of number besides costs (cut from the image). The quantity is just an indication, it is not a constrain in preparing the technical specification. What is a constrain is the total investment considered in the preventive.

Head Count

Having already defined takt time, production volumes, assembly cycle, production location, automation level and the equipment, it is possible to calculate the manpower necessary for assembly line, out of the line and handling operations.

For the assembly line are taken into account the workers directly working on the product, the operator in charge of receiving JIS order to be assigned to the pallet, the operators dedicated to the test benches and also operators responsible for unloading the product from the line and loading on the transport means directed to the client plant.

Then, are also considered operators in charge of material handling activities, the ones who transport materials to the line, and operators responsible for sequencing activity where is needed.

Linea di montaggio	operai/turno	**38,0**	+	**1,0**	distributore del jis
Test	operai/turno	**4,0**			
Partner	operai/turno	**2,0**			
HC per area di montaggi	**operai/tur**	**45,0**			
Tempo ciclo sfr calcolato	min/pz	45,00			
Operazioni aggiuntivi:					
Handling	operai/turno	7,0			
Sequenziamento - Traversa	operai/turno	0,0	partner		
Sequenziamento - Cockpit	operai/turno	1,0	**partner**		
Sequenziamento - HVAC	operai/turno	1,0	**partner**		
Sequenziamento - Cablaggio	operai/turno	1,0			
Totale operazioni aggiuntivi					
TOTALE HC (w/o TL)	**operai/tur**	**10,0**			
Tempo ciclo sfr calcolato	min/pz	10,00			

Figure 4-28 LINE HEAD COUNT

Preparazione insonorizzanti su condotti	operai/turno	2,0	**2 banchi**
Preparazione bocchette su katana sx e dx	operai/turno	2,0	**2 banchi**
Preparazione amb.ligth per katana sx e dx	operai/turno	2,0	**2 banchi**
Preparazione riporto centrale	operai/turno	1,0	**1 banco**
Preparazione start su riporto + (preparaz.cassetto)	operai/turno		
Preparazione ricoprimento piantone inf+ mostrina pcs	operai/turno	1,0	**2 banchi**
HC per area di PREPARAZIONE	**operai/turn**	**8,0**	
Tempo ciclo sfr calcolato da TT	min/pz	8,00	

Figure 4-29 OUT OF LINE HEAD COUNT

Cost of the product

The process development department is in charge to provide the industrialization cost of the product. This cost is composed by the manpower costs and the investment costs. The final goal is to relate every cost to the piece produced [€/piece].

Manpower cost is calculated starting from the cost [€/min] for the manpower and it is multiplied by the cycle time [min/piece].

$$Man\ power\ cost\left[\frac{€}{\text{piece}}\right] = \text{man power hourly cost}\left[\frac{€}{\text{min}}\right] * \text{cycle time}\left[\frac{\text{min}}{\text{piece}}\right]$$

Investments are amortized on the product considering the total investment costs [€] multiplied for the duration of the investment [years] and for the production volumes per year, we get [€/piece].

$$investment\ cost\left[\frac{€}{\text{piece}}\right] = \text{total investment}\ [€] * \text{investment duration}[\text{years}] * \text{production volumes}\left[\frac{\text{pieces}}{\text{year}}\right]$$

The sum of these two terms gives the cost of the product. This represent the outcome from the process development department regarding cost, but it is not what is presented to the client. The price for the client starts from the cost and then the commercial department add profit and other mark-ups to define it.

As seen in this chapter, there are different variables which contribute to the cost definition: localization, automation level, necessary equipment and number of necessary workers. To get with the lowest possible cost, taking for granted the respect of the client requests, multiple scenarios are created. A scenario is characterized by specific solution for each possible variable presented. In this way all possible solutions which can satisfy customer's requests are considered and the most convenient, from the cost point of view and from the DENSO internal strategic development, is chosen to be presented to the client.

4.4. PFMEA

Once the preventive is ended, it is sent to our client for a response. In case the client responds in a positive way to our quotation the company must prepare for the sequent phases of industrialization process. Specifically, it needs to have a deep understanding of the process at issue. With this aim the PFMEA is performed. As written in the FMEA 4th edition manual "*FMEA is an analytical methodology used to ensure that potential problems have been considered and addressed throughout the product and process development process. Its most visible result is the documentation of the collective knowledge of cross-functional teams.*

Part of the evaluation and analysis is the assessment of risk. The important point is that a discussion is conducted regarding the design (product or process), review of the functions and any changes in application, and the resulting risk of potential failure... To achieve the greatest value, the FMEA must be done before the implementation of a product or process in which the failure mode potential exists… Actions resulting from an FMEA can reduce or eliminate the change of implementing a change that would create an even larger concern…the process FMEA [should be initiated] before tooling or manufacturing equipment is developed and purchased."

The aim and the time location in the project development are clear. The PFMEA analysis is conducted by the project manager and participate to it the cross functional team identified in the first milestone of the ESC procedure.

In the PFMEA every process step is analysed in detail looking for requirement of the product/process and for potential failure mode relative to those requirements. In the images in the following pages is presented an example of PFMEA.

The first column is the description of the process steps, in this case relative to "take the frame, place on the pallet and lock it".

The second column is relative to the requirements for that process step. The requirements are multiple for every step, this is the reason why multiple rows are present for each process step.

In the third column a potential failure mode for every requirement is defined. It can be seen as the contrary of the requirements: integrity – damage, right PN – wrong part number…

Process Step / Function	Requirements	Potential Failure Mode	Potential Effect(s) of Failure: AIAG Criteria	Potential Effect(s) of Failure: Effect Detail	Severity	Classification	Potential Causes(s) Mechanism of Failure	Current Process Controls Prevention	Occurrence	Current Process Controls Detection: AIAG Criteria	Current Process Controls Detection: Control Method see details here	Detection	RPN	Severity Zone	Detection Zone	Priority Level
Take the frame, place on pallet and lock it	Integrity	Damage	7 CUST: Degradation of primary functions (vehicle operable but at reduced level of performance)	Vibration	7		Handling	w ork instruction	3	4 Failure mode detection post-processing by automatic controls that w ill detect discrepant part and automatically lock part in station to prevent further processing	Vibration test on EOL	4	84	2	3	2
	Right PN	Wrong PN	8 MANUF DENSO: 100% of product may have to be scrapped. Line shut dow n or stop ship	Assembly line stoppage	8		Wrong line feeding	Specific gauge and one PN	1	1 Error (cause) prevention as a result of fixture design, machine design or part design	Specific gauge and one PN	1	8	3	3	3
	Presence of component	Missing part	2 MANUF DENSO: Slight inconvenience to process, operation, operator	Assembly line stoppage	2		Missing w ork instruction	Work instruction	3	2 Error (cause) detection in-station by automatic controls that w ill detect error and prevent discrepant part from being made	Poka-yoke 10.1 - presence sensors on part and fixture cylinders	1	6	3	3	3
Poka-yoke check - 10.1	Presence sensor operating	Presence sensor not operating	2 MANUF DENSO: Slight inconvenience to process, operation, operator	Assembly line stoppage	2			Poka-yoka check list	2	5 1.Failure mode or error (cause) detection in-station by operator trough use variable gauging or by automatic controls in station that w ill detect discrepant part and	Poka-yoke check once/shift	5	20	3	3	3

Figure 4-30 PFMEA ex.1

	Right position of pallet	Wrong position of pallet	8 CUST: Loss of primary function (vehicle inoperable but doesn't affect safe vehicle operation)	Serious vibration and noise	8		Wrong execution of work instruction	Specific gauge and one PN	5	2 Error (cause) detection in-station by automatic controls that will detect error and prevent discrepant part from being made	Poka-yoke 10.1 - presence sensors on part and fixture cylinders	2	80	1	3	2
	Right position of part	Wrong position of frame	2 MANUF CUST. PROCESS: Slight inconvenience to process, operation, operator	Difficult assembly	2		Wrong execution of work instruction	Work instruction	5	2 Error (cause) detection in-station by automatic controls that will detect error and prevent discrepant part from being made	Poka-yoke 10.1 - presence sensors on part and fixture cylinders	2	20	3	3	3
	Right position of part	Wrong position of frame (upside-down)	2 MANUF CUST. PROCESS: Slight inconvenience to process, operation, operator	Assembly line stoppage	2		Missing work instruction	Work instruction	3	2 Error (cause) detection in-station by automatic controls that will detect error and prevent discrepant part from being made	Poka-yoke 10.1 - presence sensors on part and fixture cylinders	1	6	3	3	3
	Complete locking of the frame	Incomplete frame locking	8 CUST: Loss of primary function (vehicle inoperable but doesn't affect safe vehicle operation)	Serious vibration and noise	8		Wrong execution of work instruction	Work instruction	3	2 Error (cause) detection in-station by automatic controls that will detect error and prevent discrepant part from being made	Impossible to complete assembly cycle	2	48	2	3	2

Figure 4-31 PFMEA ex.2

Then, for each row, and consequently for each potential failure, three main factors are identified: severity of potential effect of failure, occurrence and detection.

Severity of potential effect of failure is evaluated with a rating scale from 1 to 10, where 10 is the most critical effect and 1 is the least. Every rating level can be associated to an effect under three points of view: customer, client manufacturing and DENSO manufacturing. As in the first row in example, in case of assembly of a damaged part, who perceive the effect of that failure is not the manufacturing at DENSO (the product can go on with the assembly process without problems), neither the customer manufacturing (the product can be assembled on the car without problems) but it is the customer that will perceive the effect of the failure in terms of "7 CUST: degradation of primary functions (vehicle operable, but at a reduced level of performance)". The next to column explains the effect in detail: in this case the customer can perceive vibrations while driving the vehicle. The evaluation of the rating and the sequent allocation of the effect on customer / client / DENSO is made by the team using experience and previous project references.

The second factor taken into account in this evaluation is the **occurrence**. This evaluation is based on the statistics of occurrence. Even in this case the rating goes from 1 to 10, but for each value is associated a percentage of occurrence of that potential failure. The score 10 is associated to an occurrence of 10% or 100000 PPM, the score 2 is related to an occurrence of 0,0001% or 1 PPM. The score 1 is for a failure that is not possible, in fact is practically never used. In order to choose the score there is a huge contribution of the team, especially of the figures which work strictly with the production that have a real experience on the probability of failure.

Finally, the last factor, is relative to **detection** of the possible failure. As in the previous cases also for detection the rating goes from 1 to 10. To value 10 is associated with the impossibility to detect the failure. Value 1 is associated with the error prevention as a result of fixture design, machine design or part design; an example can be: the wrong assembly of a component can be avoided using poka-yoke, that means the impossibility to assembly the component in a different way from the correct one. Generally, increase the score of detection, means to postpone the moment of operation's verification; low value are used if the detection is done in the same station of the operation done, while high value if the detection is done in an end of line station.

Those three factors are combined together to come out with an indication of the priority between actions to reduce the level of possible risks. The manual we refer to is the 4th edition. In the previous edition the priority was assigned looking at the RPN (risk priority number).

$$RPN = Severity\ (S) * Occurance(O) * Detection(D)$$

As can be seen from the formula, the priority comes out giving the same weight to three factors. Then an acceptable threshold for RPN is fixed; normally is asked by customers to find countermeasures on possible failures with RPN greater then 100. Weight the three factors in the same way can bring to a situation as:

Item	Severity	Occurrence	Detection	RPN
A	9	2	5	90
B	7	4	4	112

Figure 4-32 RPN example

In this situation item B will be considered as priority with respect to item A even though item A has a severity score of 9 versus a score of 7 of the item B.

The last edition of the FMEA manual from AIAG recommends looking at the "priority level" instead of RPN. The main difference with respect to RPN is that in this case the severity acquires more weight in the definition of the priority.

Severity Zone

Occurrence \ Severity	1	2	3	4	5	6	7	8	9	10
10	3	1	1	1	1	1	1	1	1	1
9	3	1	1	1	1	1	1	1	1	1
8	3	2	1	1	1	1	1	1	1	1
7	3	2	2	2	1	1	1	1	1	1
6	3	2	2	2	1	1	1	1	1	1
5	3	3	2	2	2	2	1	1	1	1
4	3	3	3	3	2	2	1	1	1	1
3	3	3	3	3	3	3	2	2	1	1
2	3	3	3	3	3	3	2	2	1	1
1	3	3	3	3	3	3	3	3	3	3

Figure 4-33 SEVERITY ZONE MATRIX

Detection Zone

Detection \ Severity	1	2	3	4	5	6	7	8	9	10
10	3	2	1	1	1	1	1	1	1	1
9	3	2	1	1	1	1	1	1	1	1
8	3	2	2	2	2	2	1	1	1	1
7	3	3	3	3	3	3	2	2	1	1
6	3	3	3	3	3	3	2	2	1	1
5	3	3	3	3	3	3	3	3	2	2
4	3	3	3	3	3	3	3	3	2	2
3	3	3	3	3	3	3	3	3	3	3
2	3	3	3	3	3	3	3	3	3	3
1	3	3	3	3	3	3	3	3	3	3

Figure 4-34 DETECTION ZONE MATRIX

Priority Level

Detection Zone \ Severity Zone	1	2	3
3	2	2	3
2	1	2	3
1	1	1	2

Figure 4-35 PRIORITY LEVEL

As can be seen from the matrixes the priority level can assume value 1, 2 or 3 and this value depends on the "detection zone" and "severity zone", that are function of severity. In this way the severity has a higher weight with respect to RPN.

Taking as reference the number presented in the previous example:

Item A → Severity zone = 1; Detection zone =2; Priority level = 1

Item B→ Severity zone = 1; Detection zone = 3; Priority level = 2

With this evaluation method item A is priority with respect to item B.

PFMEA can now be used as base reference for the technical specification writing. It gives attention to critical points coming out from the work and putting in place countermeasures where high values of occurrence or detection are found, since it is not possible to act on the severity, that is an intrinsic characteristic of the product.

4.5. TECHNICAL SPECIFICATION

The technical specification is the document that describes in detail the technical characteristics the line has to have to accomplish customer and DENSO requests. The file used for the description of the necessary process and tools, has been standardized by the company to simplify the work and ensure a level of quality and functionality constant for every project. Many aspects are common to almost all projects, so it is more efficient to modify only the parts that differs, and at the same time ensure that these common aspects are respected in any new project. Instead, the other part of the technical specification is related to the product characteristics. The inputs for the definition of this document are all discussed in the preventive chapter and in the PFMEA one, but now every possible solution and every countermeasure is analysed in detail and a technical solution has to be found.

The writing of the document was my primary responsibility. I was guided and helped in the understanding of the objectives by the engineer Francesco Passannante.

Sommario

Figure 4-36 TECHNICAL SPECIFICATION INDEX

Figure 4-37 TECHNICAL SPECIFICATION INDEX

Standard

The standard part of the technical specification is the one related to DENSO general specifications, DENSO general safety specification and characteristics directly defined by the legislation.

Chapter 2 ask to the supplier to be coherent with the certifications asked by the legislation or by the DENSO general specifications

In chapter 3 is requested to present with the order or with the letter of intent a detailed development plan with a GANTT chart in order to keep track of the evolution of the job. In the GANTT have to be present the four supplier milestones, specifically: final design review, pre-testing at the supplier, final testing at the plant and reliability testing and approval to produce.

The final design review phase arises from the fact that, after receiving the final order from the DENSO, the chosen supplier must draw the line according to the specifications. In this phase, the PD assembly team remains in constant contact with suppliers, both to dispel any doubts and to make new requests in case the process, or the product, requires a change not foreseen in the first revision of the specifications. Different aspects are analysed to ensure that the line meets all standards and requests. Only if the final design is approved they can move on to the next phase.

Pre-testing at supplier is used to verify on the final line the correct functioning and the reliability of the equipment as well as efficiency and performances. A certain number of products are produced to verify the fairness of the process and of all systems involved. This test is the last one before the transfer of the line in the final plant. Once the line is moved to the plant other tests are done to verify again all the systems present in the line and the relative reliability level: this is the final testing at the plant.

Finally, the last milestone is the reliability test and approval to produce. This verification is done evaluating the performance of the line in a pre-production series. Reliability of the equipment and performances are evaluated and there is the final OK to start with the production. The final verification is done in the destination plant to involve plant's responsibles and technicians in the project to demonstrate the line functionalities as how it works. After the positive result of the testing in final plant the line is officially under responsibility of the plant.

Chapter 4 refers to safety specification, which depends on both DENSO technical specification and on legislation.

Chapter 6 and chapter 13 are related to the additional documents, with respect to the technical specification, given to the supplier to be able to develop the requested line. Those documents are composed by product's mathematical and drawings, lay-out of the plant and the general specifications as well as safety specification.

In chapter 10 are specified all documents, as i.e.: use and maintenance manual, electrical and pneumatic schemes, assemblies and detail drawings and so on, that the supplier has to give concurrently with the product to be supplied.

Chapter 11 points out the attention on safety and ergonomic topics; the requests are based on national or international regulations also taking in consideration the general safety specification of the DENSO.

Chapter 12 define the way in which the offer has to be presented, generally is asked a specific quotation for each component of the product to supply considering both materials used, design of the concept and the transportation and installation cost.

Chapters 15 and 16 specify modalities and timing for the installation and the start-up of the line. The start-up assistance is a crucial moment in which the supplier has to convey the experience and know-how acquired during the design and construction of the assembly line to operators, team leaders, UTE head and the technologist of the destination plant.

The last but not the least chapter 17 and 18 are related to the warranty, which is a standard defined in the general specification document, and the spare parts list necessary for the correct and smooth run of the line. The recommended spare parts are used as the starting point for the definition of the preventive maintenance program.

Specific

Now the specific part is analysed. For every chapter is highlighted the correlation between RFQ, preventive and PFMEA with the technical specification. The requests of the technical specifications can be seen as the translation of our customer's requests, and to some extent DENSO request, into technical and technological needs for the development of the assembly line. Technical specification text is reported in the boxes.

Chapter 1 is an abstract in which there is a general description of the specific that describe the aim of the supply.

> The object of the contract is the design, manufacturing and installation of an assembly line in the Poland plant located in Tychy. This assembly line is designed for the assembly of an automotive cockpit.
>
> The cockpit is an automotive module which is composed by several sub-systems and components. For example, it is possible to identify sub-systems like HVAC, infotainment system, steering column. Components instead can be plastic cover, buttons, air ducts ecc. The cockpit is basically what the driver sees in the car while driving plus all the under-components. For this reason, it is important to keep in mind while developing the line that the component is an aesthetic component and cannot be damaged during handling or soiled with oil, dust since those occurrences would affect deeply the customer perception of the product value in a negative way.
>
> The assembly line must be designed with a "greenfield" method since there is no previous line to modify.
>
> The conveyor must be an overhead conveyor with the running rail suspended from the ceiling or from dedicated pillars so to leave the floor area under the track free

for work and assembly purpose; on the floor can be installed just a guide, small in dimension, in order to do not interfere with the operators work.

On the running rail are suspended the pallet. The pallet has in principle an "H" shape on which the product is placed in the horizontal segment characterized by some specific stuff that allow to fix all the degree of freedom of the product with respect to the support. This support must have a hinge that allow a complete (360°) rotation along the horizontal axis in order to be able to work ergonomically on the product regardless the location of the working area. The number of pallets is 45, but the possibility to add or remove some of them has to be taken into account.

We are speaking about a manual assembly line where the operators work directly or with the help of partner on the product.

The line has to be designed so that the operators are placed parallel to the line. The speed of the line has to be designed in order to allow operators working on the products while the line moves according to assembly line tack time.

The type of conveyor can be electrified conveyor system, power and free conveyor system or friction drive conveyor but, in any case, the possibility to stop the single pallet without stopping all the line as to be guarantee. All the operations of the assembly are made in series up to the control step (last operation) for which five parallel stations are set and the conveyor system has to be able to direct the pallet in the free station.

Regarding the project development, since the dimensions of the line are huge, the pilot area will be set-up in the final plant where process verification and process validation activities will be held.

For the pre-testing activities a test-line has to be set-up at supplier. This test-line has to fully represent the functionalities and characteristics of the final line but the dimensions can be smaller. This test-line must have at least three stations for the assembly and one station for the testing. The aim is to validate the correct design and implementation of technical specification considering all possible variables of the line.

As it is possible to read, in this chapter are present the elements that make the supplier aware of the aim, giving general information about our needs.

In chapter 5 "*General Description*" are present two sub-chapters. The *process* one used to describe the logic of the process, underlying the material and information flow to accomplish the customer request of working in JIS/JIT and the internal request to objectify the operator's operations for traceability purposes. In the *product* sub-chapter there is a description of the physical product to produce, as already done in the thesis in chapter "4.3 – product", for this reason is now presented only the first.

The assembly process starts in OP10. In this station we have N°2 printers who stamp the JIS/JIT order. The JIS (Just In Sequence) is the order coming from the client that indicate the exact sequence of the products that we have to assemble. As mentioned in the introduction the cockpit is a module with huge number of components and some of them are available in different form (think at the optionals available in a car regarding the cockpit, i.e. : automatic/manual conditioning, dimensions of the infotainment display, keyless starts, different speaker power ecc.).

Figure 4-38 JIT

For this reason no cockpit is produced by chance, but every cockpit has his own order which describe in detail the product with the list of all components we have to assemble. In the picture at the side it is possible to see how the JIT is characterized. There is the code of the cockpit to produce with the list of all variable components to use. There is one JIT for each product. After the printer stamp the JIT the operator through the bar-code reader read the code of the JIS and the code of the pallet. In this way up to the end of the cycle the pallet is univocally associated to the product to produce and thanks to the "intelligence" of the pallet it is able to communicate while arriving in a station to the MFS (Multi-function system) which parts has to be mounted on the product. With this method it is possible to assess the right match between the part needed and the assembled part.

The JIS arrive not only in the OP10, but the order sequence is sent also to all off-line stations. The sharing of information along the line and the off-line station is used so that all parts of the production works synchronized with respect to the client order. Being the off-line station aware of the sequence allow to bring the products to the line in the right order, so that no additional sequencing is requested.

The MFS is the tool that helps the operator in the work that have to do avoiding possible errors. It display on the monitor the assembly sequence with the right component (information coming from the smart pallet) and allow the objectification, meaning that the MFS wait an electrical input to go on with the assembly sequence, of the operations (ok by the operator by means of a biometric sensor, power on/off of the screwdriver, pick by light, counter of the screw, ensure the match picked component-component to be take thanks to bar-code reader…)

The MFS is relative to a single workstation.

With the association of the JIS to the pallet in OP10 and since the pallet has a RFID/TAG it can communicate with the PLC that manage all the information flow during the assembly process in a passive and active way. In a passive way keeping track of all the events that occur at the product and keeping in memory them up to the test operation when, if some problem occur, it is possible to associate it to the history of the product facilitating the eventual reworking operation. The PLC works also in an active way meaning that it can power-on the MFS of the station when the pallet arrive with the right working instruction on the display. The PLC also control the line and the motion of the pallets and the possibility to stop the single pallet detaching it from the power source (in case of power & free conveyor and friction conveyor) or controlling the complete movement of the pallet in case of electrical overhead conveyor.

At the end of the line there are N° 5 equal test bench where the pallet has to be detached from the power source of the line and stand still up the end of the test cycle. In this station we have to test the right functionality of the product and to ensure that the assembly is done in the correct way. We have to keep particular attention on the electrical connections and on the right colour and optional we have assembled. To verify the electrical connection we have to connect the wiring of the dashboard to a system of the bench which communicate with electrical and electronical components. To verify the correct set-up of the components the test bench has to take a picture of the module and compare it with a reference one.

After the OK from the test bench we have to print a label which contain information about the assembly operations and the result of the final test attaching also the photo of the cockpit.

At this point the cockpit is placed on a carts which accommodate N° 4 cockpits, N°4 carts are attached together and are brought with a tractor to the customer's line.

In this chapter there is an overview of the process. The first crucial point is that the line has to be characterized by two information systems, one managed by a PLC and the other by the MFS (which is a program running on a normal computer). It is crucial that these two systems exchange input/output each other since they are devoted to a different aim, but only working together they can guarantee the fairness of the process.

Both systems receive inputs from sensors and sent outputs to sensors / actuators present in the line but, while the PLC works running every time, in loop, the MFS works in phases that cannot be overcome if all the conditions imposed in that phase are not respected. This working difference allow the PLC to manage the line in general, including safety protections, while the MFS is mainly devoted to the assembly process itself.

The other important technical characteristic requested, coming out from this chapter, is the "intelligence" of the pallet. Having a pallet equipped with a RFID/TAG allows to make the PLC and the MFS aware of the pallet and, consequently, of the product going to be processed. This is key point working in JIS/JIT since, in principle, every product can be different from the sequent and cannot be implemented a process without taking care of this logic.

In chapter 7, the first draft of the lay-out is presented to the supplier. The lay out must not be considered as definitive and binding in all its parts. The only constraint defined in this phase of the development is the one related to the maximum dimensions that are imposed by the destination plant.

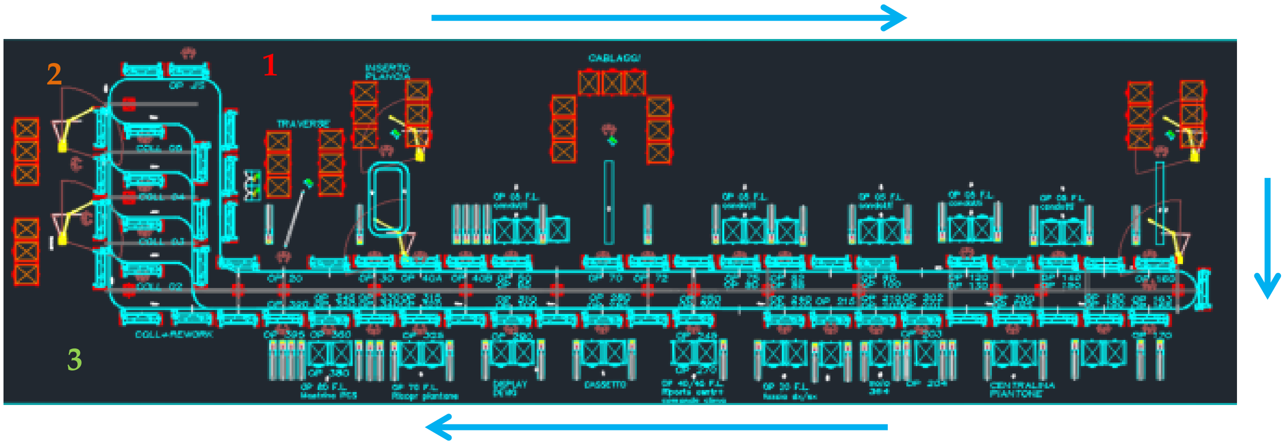


Figure 4-39 LAY-OUT

In the picture it is possible to see the lay-out of the line. The movement of the pallet follow a clockwise cycle (as indicated by light blue arrow). The cycle start in the area labelled 1 where we have the allocation of the JIS to a specific pallet. The end of the cycle is labelled as 2 where the complete dashboard already tested is placed on the transport mean directed to the client line. The area 3, made by two stations, is used as a re-work station and at the same time as testing station so that once the product has been reworked can be immediately tested.

The overall dimensions are 68m X 20m. These dimensions are constrained by the plant lay-out and cannot be overcome.

The number of stations is a consequence of the assembly cycle and of the takt time imposed by the client. The number of testing stations is 4 inasmuch as the time for the testing is fixed and non-divisible. Assuming, based on past projects, the testing time is about 4 times the takt time indeed 4 stations are necessary.

The rework stations are considered to allow to rework KO products. Since the handling system is an overhead conveyor, there isn't the possibility to stop the piece every time a problem occurs disengaging it from main line, otherwise a second parallel line accommodating the KO products must be designed but, is not convenient both in terms of cost and space, that cannot be traded. Therefore, a pallet that carries a product with some assembly phases (managed by the MFS) KO is directed to the rework station instead of the testing station. The rework station has also the possibility to test the product after the rework is done so to be independent avoiding possible interferences with the testing stations.

After providing general process descriptions, product drawings and layout, it is necessary to provide an almost final version of the assembly cycle, based on the one defined in the preventive phase, and a final set-up for the working stations. The chapter 8 is used to define the specific of the line and is characterized by a sub-chapter for every component of the line.

The 8.1 is about the type of overhead to use.

The overhead conveyor is the transport means for the pallet along all the line. The system must have the power transmission located overhead to leave the floor free from any means. It is allowed a guide at the same level as the flor to do not create obstacle for the operator's movement. The power system can be by chain, by friction or electric.

In any case the system must be able to detach single pallet from the power source in case of some special events in the line or in the test operation where the pallets have to be still for the proper carrying out of the test. Before the testing areas the carrying system have to split from one line to 5 lines and then to reconnect in one line.

The power and detachment from power source is controlled by the PLC how know the position of every pallet along the line and it has the ability to control them individually.

If the motion is controlled by a chain the conveyor has to be of the type "power & free" to guarantee stop of single pallet without stopping all the line. The overhead rail is made by two channels, the upper one accommodates the power chain, the lower one accommodates the pallet hinge while detached from the chain. The mechanism to attach and detach can be mechanical with reference on the rail or mechanical electronically actuated. Since the product is an aesthetic product the overhead conveyor has to be designed to prevent possible oil leakages (or any substances that can damage the product).

In case of friction conveyor the split from 1 to 5 lines can be also made by translating ducts taking care to do not modify the cycle time.

In case of EMS (Electrified monorail system) all the motions are controlled by the PLC and every pallet has his own control of motion.

In case of power & free and friction conveyor consider the possibility to electrify pallets with conduction rail.

For the definition of the overhead conveyor type there were no constrains except the alignment with the cost presented in the preventive but, at this stage, it is preferred to ask to suppliers quotation for different type of transport mean leaving cost consideration for a sequent phase.

It has considered the power & free conveyor as the "standard" type and then alternative solutions that could improve the criticalities of the latter have been sought. Critical point of a power & free overhead conveyor are: little flexibility of the system (change in the lay-out are not cheap in terms of time and money), noise produced by the motion of the chain, fixed speed (the pallet can be attached or detached from the motion chain, but the speed cannot be set for the single pallet or at least just two speed can be set in case of a bi-rail conveyor type), presence of oil for lubrication over the product (which is clearly an aesthetical product), no presence of electrical connection (the pallet has no electrical power supply)

The alternatives that have been identified are friction conveyor and electrified monorail system.

Figure 4-40 FRICTION OVEHEAD CONVEYOR

Friction conveyor type, depicted in the figure, is powered by a rotating aluminium tube or by a friction belt, depending on the weight to transport. The pros with respect to the power and free overhead conveyor are: little noise (there is no chain), no presence of oil (no need for lubrication), more flexible system (the power system is made in branches indeed modification of the layout are easily operable). Despite these improvements some cons remain: no presence of electrical connection, no possibility to set pallet speed independent from the other.

The last type of overhead conveyor system considered as possible alternative is the EMS (Electrified Monorail System).

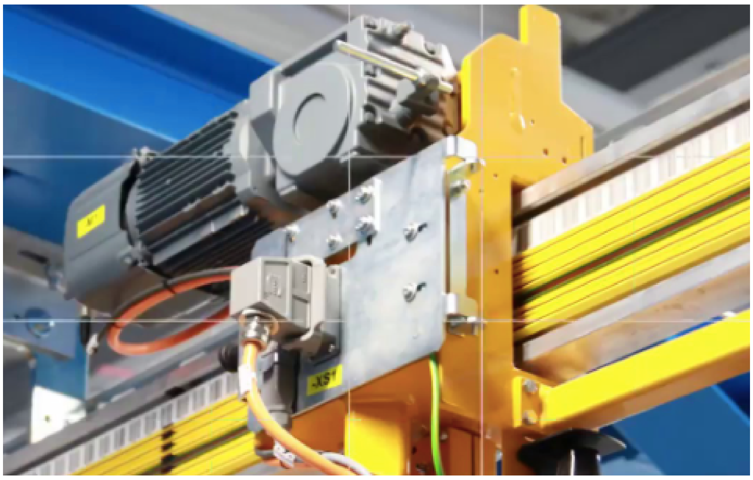


Figure 4-41 EMS

This system is moved along the track by an electric motor jointly liable with the pallet. This mechanism allows the higher level of flexibility since every pallet is totally independent from the others and in addition is electrically powered. The logical cons can be the higher price for this system with respect to the previous but, since this is a request for a quote, the consideration about the cost will be made forward in time.

The final request for the supplier is to consider the possibility to power the pallet regardless the type of overhead conveyor used. Feeding the pallet with power supply can be made with conduction rail placed in parallel to the overhead rail. The electrification of the pallet allows to improve the workplace adding the possibility to locate the MFS pc directly on the pallet, improving the readability for workers, and the possibility to place and leave the screwdrivers on the pallet which can recharge them (this simple solution avoid forced walks to and from the screwdriver station while not used).

Furthermore, installing a conduction rail allows to use it also as a reference for the position. In fact, are present on the market systems that can transmit the position of the pallet with respect to the line with an accuracy in the order of 1mm. This solution has some advantages with respect to the use of the RFID/TAG.

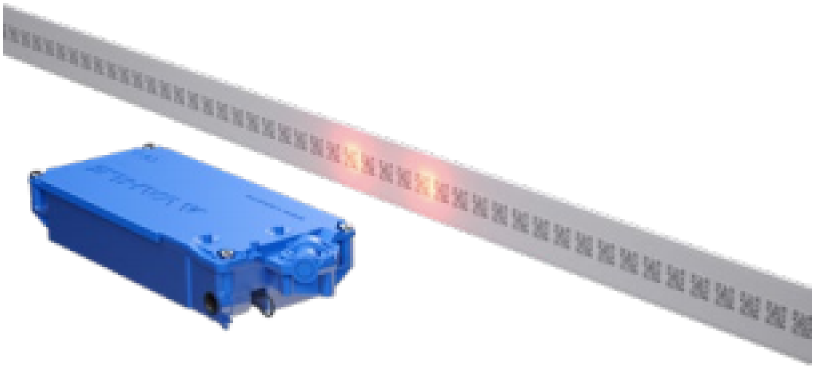


Figure 4-42 OPTICAL READER POSITIONING

The RFID/TAG can give its position once for working station, meaning that the detection is made by a spot and not in continuous, so that the detection occur at the beginning of the workstation to make the MFS aware of the working station the pallet is entering, in case the MFS is united with the pallet, or to make the MFS aware of the pallet entering in the working station, in case the MFS is relative to the working station. Instead, systems for the definition of the position which use an optical reader (in fig.), allow to monitor in continuous the pallet position. This feature can be used to moderate the pallet speed in function of the operation done on the product or to objectify the position of the screwing having an indoor positioning system which control the position of the screwdriver.

In chapter 8.2 there is the description of the requests relative to the pallet design and features.

The pallet of the line is moved by an overhead handling system. On the floor are present N°4 pivoting wheels.

The pallet is made by two main structures with different aim: structural part (green) and the hanger.

The **structural part** besides linking the hanger to the overhead conveyor has also a function of support for some component. Indeed, the pallet is used to transport small part (as screws) and also some bigger components that are placed next to (1) or in a plane over the cockpit (2). With this feature of the pallet it is possible to put on it components in a point in the line convenient from a logistic point of view and use them in a sequent station in the line cycle.

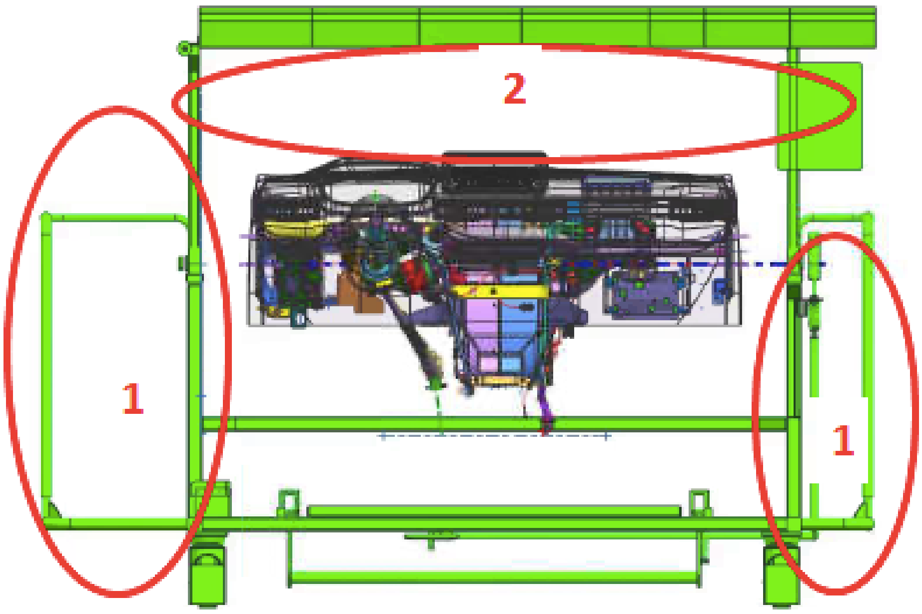


Figure 4-43 PALLET

The **hanger** is the part of the pallet dedicated to the attachment of the crossbar. It is developed by DENSO, but the pallet has to guarantee the possibility to attach the hanger to the pallet and also to guarantee the rotation of it by an automatic system. The rotation of the hanger is actuated by an electric wi-fi screwdriver (3) which allow the rotation of the hanger without any effort by the operator.

On the pallet are requested reference guides for the partner in both placing crossbar/dashboard and remove the complete module. The guides are used to ensure only the right movements, especially while removing the complete module that cannot be damage for any reason since it has already passed the test of integrity.

The pallet has a **TAG** that transmit from the pallet to the line. This communication system allows an interaction pallet-PLC. In this way the PLC know the position of the pallet with respect to the line and can activate the right MFS in the line as well as the screwdriver for the rotation of the hanger.

The key point for the pallet design is the possibility to accommodate on it small parts as screws and bigger parts as plastic cover common to all models. Another possibility has come out from discussions, the proposal to use instead of the pallet itself, a cart which can be attached/detached to the pallet to support the components. The difference between the two solutions is that in the last an indirect workers can be in charge to load the carts with the components coming from out of the line stations instead, in the first solution is a direct worker which occupy a line station to place components directly on the pallet.

In chapter 8.3 there is the description of the hanger with particular attention to the mechanical system used to fix the crossbar to the hanger. This work is done by the R&D department and for this reason is not presented here.

In chapter 8.4 there is the description of the workstation in its components.

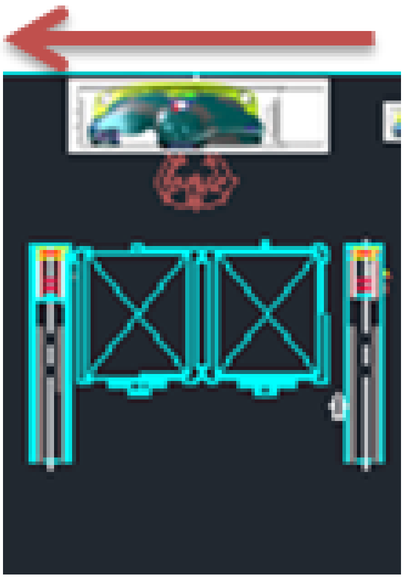


Figure 4-44 WORKSTATION LAY-OUT

As general description each assembly workstation is characterized by the layout depicted in the figure above. The operator is in front of the line which moves from the right to the left.

- The operator has the material located behind him/her. Depending on the type (dimension) of the material and the numbers of part numbers (P.N.) the material is stored inside boxes, carts, odettes or directly on the pallet. Design the lay-out of the material ergonomics from operator trying to locate as much as possible materials in the “golden zone”.

- The screwdriver in the working-station where is needed (specified in chap. 8.3 assembly cycle) is located behind the operator. The screwdrivers are powered by battery and are equipped with WI-FI connectivity that allow the MFS (Multi-Function System) to communicate with screwdrivers in order to: power them only when the right sequence of operations is done and control the reaching of the right torque. The screwdrivers are supported by mean of a pulley that make them weight-free.
- Every station has an All-in-one PC that gives information about the assembly sequence. Monitors are placed in front of the operators so that it is easy and ergonomic for them to look at the monitors.
- Under the operator there is an anti-fatigue floor covering
- Every station is illuminated with led (1000 Lumen)
- Every station has his own electric fan.
- Every station has a support for a water bottle.
- Manual objectification of the operation with a wireless biometric sensor that the operator has with him/her. The support can be watch or a necklace.

The workstations characteristics are quite standard and in general should take care of the safety and ergonomics of the workers. The proposal relative to this topic was related to use a cart attached to the pallet in order to reduce at the minimum the turnaround of the worker during the shift, the use of a pulley supported by a moving crossbar able to follow the operators in the movement making the screwdriver weight free and ,finally, to provide the operator with a watch or necklace to support a wireless biometric sensor, with which, gives the ok while having finished an operation that cannot be objectified otherwise (now are used a button on the screen or pedal in fixed position, but this force the operator to walk to reach them).

Chapter 8.5 describes characteristics necessary for working stations that require a report of the operations done (this request comes directly from our customer). The report is requested to certify with a label the fairness of the operation done by the worker. This request is relative to safety component present in the dashboard, specifically: airbag, PAB bracket and the steering column. The first request is to install a CLECO screwdriver with the control of the torque and the angle to ensure the right torque application. The screwdriver is linked with an ECU and a printer that print a label in case match set torque - effective closing torque. Verification of closing torque is not enough to verify the fairness of the operation since there is the possibility to screw with the right torque into the wrong hole. The proposal for this verification is to install a support arm, for the screwdriver, which is fixed on a runner running into a rail parallel to the overhead conveyor rail. Once the pallet arrives, the support arm matches mechanically with the pallet. Using absolute encoder for each articulated joint of the arm, it is now possible to verify the spatial position of the screwing with respect to the product. The last request is to use an absolute encoder also in the joint that allows the rotation of the hanger to verify the position of the piece with respect to the pallet.

In chapter 8.6 there is a brief explanation of what is a partner and where is needed. A specific technical specification will be prepared and sent to company specialized in this type of products. Specify the presence of the partner also in the technical specification of the line makes the constructor aware of the presence of the manipulator which requires sufficient space to be installed. Specifically, the partners are expected for the handling of dashboards, HVAC and the final product after the testing. The use of the partner it is imposed by the weight and the frequency of handling by the EAWS analysis.

Figure 4-45 PARTNER

The chapter 8.7 is devoted to the testing stations.

The testing phase is the last before the movement of the product to the client. There are N° 4 equal testing stations in which the product is analysed under pre-defined cycle and, if all checks are good, conformity label is emitted. The station has two test to execute: electrical and visual.

In the figure is presented an example of electrical testing station with similar components with respect to the desired one and some differences.

In 1 there are the electrical connection to the cockpit to:

- Silver box
- Speaker E-Call
- Displays
- CSS
- Speaker Hi-fi
- Solar sensor
- Ambient LIGHT
- Recovery
- Steering column stalk
- Electric steering lock
- instrument panel
- PCC
- HVAC

- KIN key
- Climate control
- Air-bag deactivation key
- Immobilizer
- ALM ECU
- wiring harness
- logic box.

Figure 4-1 TESTING STATION

With reference to this connection the testing machine has to verify the electrical continuity.

In area 2 there is the display that gives information about the on-going operations and gives indication to the operator if there is some component to use in order to verify the connection (i.e. push the hazard, turn on the indicator light, wipers pump, acoustic, horn, electro fun…). The indication on the screen about the operations are managed by the MFS.

In area 3 there is the support of the station. In this case the support of the station is on the floor, but the solution we are searching for has the support of the station on the "roof". The support can be stand-alone or can use the overhead support of the line, but in any case it cannot be placed on the floor.

When the cockpit arrives at the testing station, the station has to know automatically which product has arrived (thanks to the RFID of the pallet and thanks to the PLC who manage all the information of the line and store also the data of the test).

There is no BCM (Body Computer Module) on cockpit. The minimum requirement is to verify the electrical continuity of the users. The ideal solution is to verify through a software the part number of each user.

The only electrical user that cannot be verified with electrical impulse is the airbag. It is not possible to test it with electricity otherwise it would activate, but it is a must the connection verification. Indeed, a camera specific for certification of the right connection is needed. This camera has to take a photo of the connector and through a comparison with respect to a master understand and certify the right done connection. The photo is attached to the cockpit with all the other executed test.

In addition to the electrical test, is present also a test by means of a camera. This system compares a master photo, referred to the JIT request, with the photo of the real components to ensure the correctness of colours and optional.

The camera is able to move in order to take picture from different point of view and have a global view of the component.

In the testing station we have to verify electrical connection and the correct dressing. This request comes directly from the customer. For the first verification it is sufficient to assess the electrical continuity for each component connected, instead, for the second request, a photo of the final product is taken, and it is compared with the reference one.

All these tests are specifically requested by the client. These verifications are necessary to avoid the case in which a cockpit is assembled on the vehicle and then is found some electrical component not correctly coupled with the electrical system.

In chapter 8.8 are specified requests for the rework stations. These requests are basically to have the possibility to dismount, reassemble and test the product. What is important to provide is the possibility to understand the KO given during the assembly so that the operator know where to act.

In chapter 8.9 are described the characteristic necessary for the *pilot* line. The aim of the *pilot* line is to verify the well running of the system before the construction of the final assembly line. It has to be as the final line but smaller in dimension. It has pc's, screwdriver, CLECO screwdriver, bar code reader and also the test workbench. With these equipment it is possible to verify every component that will be present in the line

The last chapter belonging to technical specification machine/plant is the 8.10. In this chapter it is described the assembly cycle defined during the preventive phase underlying the poka-yoke and equipment necessary in each station. Now are presented two stations as example.

OP 30

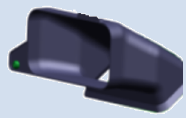
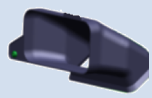
- In this station are present two operators. The "A" operator has the task to prepare the sequence of the dashboard in coherence with the JIS request. "A" operator picks the right dashboard (part number requested by the JIS) with a partner and place it on a rotating-support/conveyor. The "B" operator takes the dashboard from the rotating-support/conveyor with a partner and place it on the crossbar. The hooking has to be done with some mechanical guide partner/crossbar/dashboard/hanger that give reference to the operator for placing the dashboard on the crossbar.

Component	**Equipment**	**Enslavement**	**Objectivation / Poka-yoke**	**Photo**
Dashboard #P.N=3	Hanger Bar/QR code reader	Partner	Bar/QR code reader	

OP 50

- The operator takes the **silver box** and, after the reading of the bar code, place it on the dashboard. The silver box is located inside a box behind the operator or, if the part number are few, directly on the pallet.
- Operator takes the screw counter screwdriver and fix the dashboard on the crossbar with N°2 **self-taping screws**.
- The operator takes the **frontal-DX-ventilation duct and the frontal-SX-ventilation duct** from the box behind him/her and, after reading the bar-code, place it on the dashboard.
- Operator takes the screw counter screwdriver and fix both components with N°1 **screw** each.

Component	**Equipment**	**Enslavement**	**Objectivation/ Poka-yoke**	**Photo**

Silver box # P.N=3	Bar/QR code reader	boxes	Bar/QR code reader	
Self-taping screws 4.8x19 1.5±0.4 Nm (Qty 2)	Screwdriver	Odettes	Battery wi_fi screw counter screwdriver	
Frontal-DX-ventilation duct #P.N=2	Bar/QR code reader	Carts	Bar/QR code reader	
Self-taping screws 4.8x19 1.5 ±0.4 Nm (Qty 1)	Screwdriver	Odettes	Battery wi_fi screw counter screwdriver	
Frontal-SX-ventilation duct #P.N=2	Bar/QR code reader	Carts	Bar/QR code reader	
Self-taping screws 4.8x19 1.5 ±0.4 Nm (Qty 1)	Screwdriver	Odettes	Battery wi_fi screw counter screwdriver	

As it is possible to see from the second and third column, relative to the equipment necessary and the poka-yoke or objectification method, for each station are defined the necessary equipment. This equipment are, in principle, the one defined in the preventive phase, specifically as indicated in chapter 4.4 – equipment.

In Op30, that is the operation in which the dashboard is assembled on the crossbar, we have to distinguish if the dashboard taken is the right one with respect to the JIT/JIS order. To accomplish this aim a bar code reader is used, by this means the MFS compare the code of the piece taken with the code it expects from the order and, if they match, the response is OK, otherwise is a KO.

Regarding OP 50 the operator has to assemble three components: silver box, frontal-DX-ventilation duct and frontal-SX-ventilation duct. Those are all component screwed, for this reason we have two controls or poka-yoke, one that controls the pick-up of the right component and the second that controls the right assembly. The first poka-yoke is again a bar code reader that compares the component taken with the code of the component present in the order. The second objectification tool is the screwdriver endowed with an ECU for the screw count and the closing torque control. With this double control we are sure that the right component is assembled in the right way.

In addition to the ECU of the screwdriver also the MFS enforce a control on the screwing. In particular the software applies a control on the time necessary to reach the closing torque, start the time counting when the MFS receives the input from ECU of "motor run" and stops when receives the input of "reached torque". The gap for the OK is narrow, in the order of 1 hundredth of a second. This control allows to exclude from the OK the screw assembled with the axis misaligned with respect to the hole's one or to avoid the screwing in the wrong hole.

Up to this point all the technical characteristics of the line are defined with a complete description of the systems necessary and of the process involved. Now, in chapter 9 are specified the performances necessary to follow our customer's request. First request is relative to productivity that is defined as number of product produced/shift with a reference to the specific shift duration. This is a crucial characteristic for the line qualification, if not respected it is not possible to respect the customer requests.

Another performance requested is the cycle time. As in the case of productivity, they are strictly related, the request for the cycle time working in JIT comes directly from our customer. It is evaluated with the production of 50 consecutive pieces.

The last performance requested is the technical efficiency grater then 95%.

$$Tecnical\ Efficiency\ [\%] = \frac{produced\ pieces\ (n) * Theoretical\ cycle\ time}{Operational\ Time\ for\ (n) pieces} * 100$$

- Produced pieces is the number of good pieces + waste produced during the operating time.
- Theoretical cycle time is the machine design's theoretical time, illustrate by the cyclogram.
- Operation time: this time doesn't include any stops caused by external factors.

Technical efficiency represents the relationship between the time the equipment has actually worked to produce and the total time available for production. Stopping times not directly attributable to the equipment (lack of material, absence of operator, lack of power, ...) are excluded from the efficiency calculation.

4.6. Future development

After completion of the technical specification, the document is sent to a certain number of suppliers for a quotation. The suppliers are searched by the purchasing department. Once the quotation arrives, the PD has the task to evaluate the offers under technical characteristics offered comparing with internal standards and personal experiences. Once the offers are accepted by the PD department the economic analysis is made, again, by the purchasing department and the supplier is chose.

Once the supplier project starts, the evolution is followed with the GANTT chart defined in the technical specification and following all the verification necessary to face up the Milestone described in the ESC procedure.

During the development there is a strictly relation between the DENSO and the supplier, not only for verification purpose but also to keep the supplier aware of possible changes of the product that can occur due to the parallel development of the process / product to lower the time to complete the project, or for the implementation of possible improvements found in the process development.

5. CONCLUSION

The work done in these months has been fulfilling under different aspects.

This was my first working experience. Starting from multinational company, leading and competing in the automotive business, allowed me to understand the organizational structure of the same and the job division to face huge projects. In the meantime, I take the first taste of the automotive business, core of my studies and of my interests. I really appreciated the collaboration between colleagues to solve problems with simple and effective solutions. I want to thank all the colleagues which have dedicated time to me making me participate to their expertise and expertise, huge tanks to Massimo, Giovanni, Mauro and Roberto. I want to give a special thanks to Francesco which gave me a lot of time and knowledges beside the patient to control and improve the works I did.

With the master thesis I end my university studies which I could not have dealt with without the support of friends and family, their support was essential to face the difficult moments and to celebrate the achievements. Thanks to those how accompanied through the entire journey, to those who were present even for only part of it and to those I found during the same. A heartfelt thanks goes to my father and my mother, which has always supported me in my choices, without which I would not have been able to achieve this goal. Finally, I want to thank my brother, Vittorio, who has always been a source of pride for me and a point of reference for the person I want to become.

6. FIGURE LIST

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